229th AAS

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Meeting Abstracts

Session Table of Contents

90 – HAD I: The 2017 Osterbrock Prize: The Biographical Encyclopedia of Astronomers

– Jay M. Pasachoff, presentation of the Osterbrock Prize and memorial to Prof. Donald Osterbrock

90.01 – Osterbrock Prize Lecture: The Coming to Be of the Biographical Encyclopedia of Astronomers

The four-volume Biographical Encyclopedia of Astronomers (and cosmologists), second edition, is one of a kind: There is no discipline-specific counterpart in the physical or biological sciences. The BEA is the work of 430 authors, translators, and editors who produced biographies of approximately 1,800 persons, from the beginning of history to the beginning of the era of Big Science. How did this happen? The Editor-in-chief will give a "behind the pages" view of the construction of this first-look, first-reached-from-the-shelf reference work.

Author(s): Thomas A. Hockey[1]
Institution(s): *1. University of Northern Iowa*

90.02 – Keeping the *Biographical Encyclopedia of Astronomers* Relevant for a Generation

The *Biographical Encyclopedia of Astronomers* is a magnificent accomplishment, but like all such compilations, it faces potentially rapid obsolescence. Relying on my experience as an encyclopedia editor and a contributor to more than 20 other biographical reference works, I will highlight potential pitfalls for the BEA in the future and suggest ways in which the publisher can ensure that the BEA will continue to remain relevant for a generation.

Author(s): Marc Rothenberg[1]
Institution(s): *1. Smithsonian Institution*

90.03 – Reading BEA II in Irvine (And Elsewhere)

It is just possible that the number of BEA authors and editors exceeds the number of its readers, but I doubt this, having done all three. Perhaps unusually, I have gone through each edition page by page: BEA I several years ago, looking for what everybody who was alive at the time did during World War I, and BEA II just recently, in the process of compiling potted history of the development of stellar astronomy and astrophysics in Germany. Neither task would have been possible without BEA, which I therefore celebrate, along with Tom Hockey's enormous foresight, energy, and persistence. If we were starting over, I (and probably he!) would ask authors and editors for at least two things -- closer adherence to a format that puts the most notable work (why this person is here!) first, followed by "life" and "works" - and, where the information is available, what the person did or had happen that must surely have influenced life, beliefs, philosophy, what have you, beyond the scientific achievements. We know what Einstein, Karl Schwarzschild, and Rudolph Minkowski were doing in 1916, while a number of other articles have holes about that time. And it is obvious why Martin Schwarzschild and Hans Bethe ceased to be *German* astronomers; not so obvious for others. And, while we are at it, what turned von Weizsäcker and Albert Wilson so firmly away from the science in which they had already left large footprints?

Author(s): Virginia L. Trimble[1]
Institution(s): *1. UC, Irvine*

– Panel Discussion

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100 – Welcome Address by AAS President Christine Jones (Harvard-Smithsonian, CfA)

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101 – Kavli Foundation Lecture: Early Solar System Bombardment: Exploring the Echos of Planetary Migration and Lost Ice Giants, William Bottke (SwRI)

101.01 – Early Solar System Bombardment: Exploring the Echos of Planetary Migration and Lost Ice Giants

Heavily cratered surfaces on the Moon, Mars, Mercury show the terrestrial planets were battered by an intense bombardment during their first billion years or more, but the timing, sources, and dynamical implications of these impacts are controversial. The Late Heavy Bombardment refers to impact events that occurred after stabilization of planetary lithospheres such that they could be preserved as craters. Lunar melt rocks and meteorite shock ages point toward a discrete episode of elevated impact flux between ~3.5 to ~4.2 Ga and a relative quiescence between ~4.0-4.2 to ~4.4 Ga. Evidence from Precambrian impact spherule layers suggest a long-lived tail of terrestrial impactors lasted to ~2.0-2.5 Ga.

Dynamical models that include populations residual from primary accretion and destabilized by giant planet migration can potentially account for observations, although all have pros and cons. The most parsimonious solution to match constraints is a hybrid model with discrete early, post-accretion and later, planetary instability-driven impactor populations.

For the latter, giant planet instability models can successfully reproduce the orbits of the giant planets, the origin/properties of Jupiter/Neptune Trojans, irregular satellites, the structure of the main asteroid and Kuiper belts, and the presence of comet-like bodies in the main belt, Hilda, and Trojan asteroid populations. The best solutions, however, postulate there were once five giant planets: Jupiter, Saturn, and three ice giants, one that was eventually ejected out of the Solar System by a Jupiter encounter. Intriguing evidence for this "lost" ice giant planet can be found in the orbital properties of bodies captured in the main asteroid belt.

The applicability of giant planet instabilities to exoplanet systems seems likely, with the initial configuration of giant planet orbits a byproduct of their early migration and subsequent capture into mutual mean motion resonances. The question is how long can a stable configuration be maintained; dynamical models suggest the interval may be short, while bombardment evidence possibly favors hundreds of Ma.

Author(s): William Bottke[1]
Institution(s): *1. Southwest Research Inst.*

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102 – Star Formation I

102.01 – Measuring Dark Molecular Gas

It is now well known that a substantial fraction of Galactic molecular gas cannot be traced by CO emission. The thus dubbed CO dark molecular gas (DMG) occupy a large volume of ISM with intermediate extinction, where CO is either not self-shielded and/or subthermally excited. We explore the utilities of simple hydrides, such OH, CH, etc., in tracing DMG. We mapped and modeled the transition zone cross a cloud boundary and derived emperical OH abundance and DMG distribution formulae. We also obtained absorption measurements of various species using Arecibo, VLA, ATCA, and ALMA. The absorption technique has the potential to provide systematic quantification of DMG in the next few years.

Author(s): Di Li[1], Carl E. Heiles[2]
Institution(s): *1. National Astronomical Observatories of China, 2. University of California at Berkeley*

102.02 – Fragmentation of Filamentary Molecular Clouds Threaded by Perpendicular Magnetic Field

Filamentary clouds are ubiquitously seen in the star forming regions and the fragmentation of them are thought to result in star formation. Some of them are threaded by magnetic field parallel to the cloud axis and some others are thread by perpendicular ones. The effects of the parallel magnetic field on fragmentation have

been studied well. However we know little about the effects of the perpendicular magnetic field on fragmentation. A strong perpendicular magnetic field is likely to suspend the fragmentation. In order to assess this effect, we have performed a linear stability analysis of an isothermal filamentary cloud while taking account of a uniform magnetic field perpendicular to the cloud axis. We have used the ideal MHD approximation in the stability analysis for simplicity. Then the analysis is formulated to be an eigenvalue problem in which each eigenmode has either a real frequency (stable) or a pure imaginary one (unstable). The growth rate of the instability as well as the eigenmode is obtained numerically as a function of the wavelength and magnetic field strength.
The magnetic field suppresses gas motion perpendicular to it. Accordingly, the growth rate of an unstable eigenmode decreases monotonically as the magnetic field is strengthened. The wavelength of the most unstable mode is slightly increased by the magnetic field. When the plasma beta at the cloud center is slightly below 2, the fragmentation instability is completely suppressed. When the unstable mode is excited, only the magnetic field lines that thread the high region near the cloud axis move appreciably. We compare our analysis with those for magnetized sheet-like clouds.

Author(s): Tomoyuki Hanawa[1], Takahiro Kudoh[2], Kohji Tomisaka3
Institution(s): *1. Chiba University, 2. Nagasaki University, 3. National Astronomical Observatory Japan*

102.03 – Interferometric Mapping of Perseus Outflows with MASSES

The MASSES (Mass Assembly of Stellar Systems and their Evolution with the SMA) survey, a Submillimeter Array (SMA) large-scale program, is mapping molecular lines and continuum emission about the 75 known Class 0/I sources in the Perseus Molecular Cloud. In this talk, I present some of the key results of this project, with a focus on the CO(2-1) maps of the molecular outflows. In particular, I investigate how protostars inherit their rotation axes from large-scale magnetic fields and filamentary structure.

Author(s): Ian Stephens[1], Michael Dunham[2], Philip C. Myers[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. SUNY Fredonia*
Contributing team(s): the MASSES Team

102.04D – Disk Masses of Class I Protostars in Taurus and Ophiuchus

Recent studies suggest that many protoplanetary disks around pre-main sequence stars with inferred ages of 1-5 Myr (known as Class II protostars) contain insufficient mass to form giant planets. This may be because by this stage much of the material in the disk has already grown into larger bodies, hiding the material from sight. To test this hypothesis, we have observed every protostar in the Taurus and Ophiuchus star forming regions identified as Class I in multiple independent surveys, whose young (< 1 Myr old) disks are more likely to represent the initial mass budget of protoplanetary disks. For my dissertation I have used detailed radiative transfer modeling of CARMA and ALMA millimeter images, broadband SEDs, and near-infrared scattered light images to determine the geometry of the circumstellar material and measure the mass of the disks around these protostars. By comparing the inferred disk mass distribution with results for the existing 1-5 Myr old disk sample, we constrain the initial mass budget for forming planets in protoplanetary disks. We find that the younger Class I disks are, on average, more massive than the older disk sample, but still may be shy of the necessary mass for forming planets. It may be that even by this early stage, planet formation is well underway.

Author(s): Patrick Sheehan[1], Joshua A. Eisner[1]
Institution(s): *1. University of Arizona*

102.05 – The location, clustering, and propagation of massive star formation in giant molecular clouds

Massive stars are key players in the evolution of galaxies, yet their formation pathway remains unclear. In this talk, I will highlight results from a project utilizing data from several galaxy-wide surveys to build an unbiased dataset of ~700 massive young stellar objects (MYSOs), ~200 giant molecular clouds (GMCs), and ~100 young (< 10 Myr) optical stellar clusters (SCs) in the Large Magellanic Cloud. We have employed this data to quantitatively study the location and clustering of massive star formation and its relation to the internal structure of GMCs. The main results are as follows: (1) Massive stars do not typically form at the highest column densities nor centers of their parent GMCs. (2) Massive star formation clusters over multiple generations and on size scales much smaller than the size of the parent GMC. (3) The rate of massive star formation is significantly boosted in clouds near SCs. Yet, comparison of molecular clouds associated with SCs with those that are not reveals no significant difference in their global properties. These results reveal a connection between different generations of massive stars on timescales up to 10 Myr. I will compare our findings with Galactic studies and discuss this in terms of GMC collapse, triggered star formation, and a potential dichotomy between low- and high-mass star formation.

Author(s): Bram Ochsendorf3, Margaret Meixner[2], Jeremy Chastenet[2], A. G. G. M. Tielens[1], Julia Roman-Duval[2]
Institution(s): *1. Leiden University, 2. STScI, 3. The Johns Hopkins University*

102.06D – The Destructive Birth of Massive Stars and Massive Star Clusters

Massive stars play an essential role in the Universe. They are rare, yet the energy and momentum they inject into the interstellar medium with their intense radiation fields dwarfs the contribution by their vastly more numerous low-mass cousins. Previous theoretical and observational studies have concluded that the feedback associated with massive stars' radiation fields is the dominant mechanism regulating massive star and massive star cluster (MSC) formation. Therefore detailed simulation of the formation of massive stars and MSCs, which host hundreds to thousands of massive stars, requires an accurate treatment of radiation. For this purpose, we have developed a new, highly accurate hybrid radiation algorithm that properly treats the absorption of the direct radiation field from stars and the re-emission and processing by interstellar dust. We use our new tool to perform a suite of three-dimensional radiation-hydrodynamic simulations of the formation of massive stars and MSCs. For individual massive stellar systems, we simulate the collapse of massive pre-stellar cores with laminar and turbulent initial conditions and properly resolve regions where we expect instabilities to grow. We find that mass is channeled to the massive stellar system via gravitational and Rayleigh-Taylor (RT) instabilities. For laminar initial conditions, proper treatment of the direct radiation field produces later onset of RT instability, but does not suppress it entirely provided the edges of the radiation-dominated bubbles are adequately resolved. RT instabilities arise immediately for turbulent pre-stellar cores because the initial turbulence seeds the instabilities. To model MSC formation, we simulate the collapse of a dense, turbulent, magnetized $M_{cl} = 10^6$ $M_\odot$ molecular cloud. We find that the influence of the magnetic pressure and radiative feedback slows down star formation. Furthermore, we find that star formation is suppressed along dense filaments where the magnetic field is amplified. Our results suggest that the combined effect of turbulence, magnetic pressure, and radiative feedback from massive stars is responsible for the low star formation efficiencies observed in molecular clouds.

Author(s): Anna Rosen3, Mark Krumholz[1], Christopher F. McKee[2], Richard I. Klein[2], Enrico Ramirez-Ruiz3
Institution(s): *1. Australian National University, 2. University of California, Berkeley, 3. University of California, Santa Cruz*

102.07 – ALMA and VLA Observations of Proplyd Candidates near Sgr A*

Using the VLA, we recently detected a large number of protoplanetary disk (proplyd) candidates lying within a couple of light years of the massive black hole Sgr A*. The bow-shock appearance of proplyd candidates point toward the young massive stars located near Sgr A*. Similar to Orion proplyds, the strong UV radiation from the cluster of massive stars at the Galactic center is expected to photoevaporate and photoionize the circumstellar disks around young, low mass stars, thus allowing detection of the ionized outflows. To confirm this interpretation, ALMA observations detect millimeter emission at 226 GHz from five proplyd candidates that had been detected at 44 and 34 GHz with the VLA. We determine the mass of protoplanetary disks from cool dust emission. These measurements show the presence of on-going star formation with the implication that gas clouds can survive near Sgr A* and the relative importance of high vs low-mass star formation in the strong tidal and radiation fields of the Galactic center.

Author(s): Farhad Yusef-Zadeh3, William D. Cotton4, Marc Royster3, Devaky Kunneriath4, M. Wardle2, D. A Roberts3, Al Wootten4, R. Schoedel1
Institution(s): *1. IAA, 2. Macquarie University, 3. Northwestern Univ., 4. NRAO*

103 – Mergers, AGN, & GRB Host Galaxies

103.01D – Major mergers are not significant drivers of star formation or morphological transformation at z~2

We investigate the contribution of major mergers (mass ratios > 1:5) to stellar mass growth and morphological transformations around the epoch of peak cosmic star formation (z~2). We visually classify a complete sample of massive ($M > 10^{10} M_{Sun}$) galaxies at this epoch, drawn from the CANDELS survey, into late-type galaxies, major mergers, spheroids and disturbed spheroids which show morphological disturbances. Given recent simulation work, which indicates that recent (<0.3-0.4 Gyr) major-merger remnants exhibit clear tidal
features in such images, we use the fraction of disturbed spheroids to probe the role of major mergers in driving morphological transformations. The percentage of blue spheroids (i.e.with ongoing star formation) that show morphological disturbances is only ~21%, indicating that major mergers are not the dominant mechanism for spheroid creation at z~2 - other processes, such as minor mergers or cold accretion are likely to be the main drivers of this process. Taken together, our results show that major mergers are not significant drivers of galaxy evolution at z~2.

Author(s): Emma Lofthouse3, Sugata Kaviraj3, Christopher Conselice4, William Hartley1, Alice Mortlock2
Institution(s): *1. ETH Zurich, 2. University of Edinburgh, 3. University of Hertfordshire, 4. University of Nottingham*

103.02D – Exploring Quenching, Morphological Transformation and AGN-Driven Winds with Simulations of Galaxy Evolution

We present an examination of the spheroid growth and star formation quenching experienced by galaxies since z~3 by studying the evolution with redshift of the quiescent and spheroid-dominated fractions of galaxies from the CANDELS and GAMA surveys. We compare these fractions with predictions from a semi-analytic model which includes prescriptions for bulge growth and AGN feedback due to mergers and disk instabilities. We then subdivide our population into the four quadrants of the specific star-formation rate (sSFR)-Sersic index plane. We find that the fraction of star forming disks declines steadily while the fraction of quiescent spheroids increases with cosmic time. The fraction of star-forming spheroids and quiescent disks are both non-negligible and remain nearly constant. Our model is qualitatively successful at reproducing these fractions, suggesting a plausible explanation for the observed correlations between star formation activity and galaxy structure.
Next, we study the correlation of galaxy structural properties with their location relative to the star-formation rate-stellar mass correlation, or the star forming main sequence. We find that as we move from observed galaxies above the main sequence to those below it, we see a nearly monotonic trend towards higher median Sersic index, smaller radius, lower SFR density and higher stellar mass density. Our model again qualitatively reproduces these trends, supporting a picture in which bulges and black holes co-evolve and AGN feedback plays a critical role in galaxy quenching.
Finally, we examine AGN-driven winds in a suite of cosmological zoom simulations including a novel mechanical and radiation-driven AGN feedback prescription and compare the gas cycle with a matched suite of zoom simulations that include only feedback from supernovae and young stars. We find that while stellar feedback can drive mass out of galaxies, it is unlikely to be able to keep the gas from re-accreting, whereas in our AGN runs it is much more likely for gas to be moved from the inner regions of a galaxy all the way past the virial radius, never to return. We find that this feedback prescription is an efficient way to remove gas and quench galaxies.

Author(s): Ryan Brennan1
Institution(s): *1. Rutgers University*
Contributing team(s): CANDELS

103.03 – Signatures of AGN feedback

Feedback from actively accreting SMBHs (Active Galactic Nuclei, AGN) is now widely considered to be the main driver in regulating the growth of massive galaxies. Observational proof for this scenario has, however, been hard to come by. Many attempts at finding a conclusive observational proof that AGN may be able to quench star formation and regulate the host galaxies' growth have shown that this problem is highly complex.
I will present results from several projects that focus on understanding the power, reach and impact of feedback processes exerted by AGN. I will describe recent efforts in our group of relating feedback signatures to the specific star formation rate in their host galaxies, where our results are consistent with the AGN having a `negative' impact through feedback on the galaxies' star formation history (Wylezalek+2016a,b). Furthermore, I will show that powerful AGN-driven winds can be easily hidden and not be apparent in the integrated spectrum of the galaxy. This implies that large IFU surveys, such as the SDSS-IV MaNGA survey, might uncover many previously unknown AGN and outflows that are potentially very relevant for understanding the role of AGN in galaxy evolution (Wylezalek+2016c)!

Author(s): Dominika Wylezalek1, Nadia L. Zakamska1
Institution(s): *1. Johns Hopkins University*
Contributing team(s): MaNGA-GMOS Team

103.04D – Star Formation and AGN activity of X-ray selected AGN host galaxies in the Chandra-COSMOS Legacy Survey

One of the ongoing issues for understanding the galaxy formation and evolution is how active galactic nuclei (AGNs) affect the growth of their host galaxies. We investigate the correlations between AGN activity and star formation properties of a large sample of ~3700 X-ray selected AGNs over a wide range of luminosities ($42 < \log L_X < 45$) up to z~5 in the Chandra-COSMOS Legacy Survey. We perform a multi-component modeling from the far-infrared, when available, to the near-UV using AGN emission from the big-blue-bump (for Type 1 AGNs), a nuclear dust torus model, a galaxy model and a starburst component for the spectral energy distributions (SEDs). Through detailed analysis of SEDs, we derive AGN host galaxy properties, such as stellar masses, star formation rates (SFRs), and AGN luminosities. We find that AGN host galaxies have, on average, similar SFRs compared to the normal star-forming main sequence galaxies, suggesting no significant enhancement or quenching of star formation. The average SFR of AGN host galaxies shows a flat distribution in bins of AGN luminosity, consistent with recent ideas that the shorter variability timescale of AGN compared to star formation can lead to a flat relationship between the SFR and black hole accretion rates. Our results suggest that both star formation and nuclear activity in the majority of AGN host galaxies might be driven more by internal secular processes at z<3, implying that they have substantially grown at much earlier epoch.

Author(s): Hyewon Suh[1]
Institution(s): *1. Institute for Astronomy, University of Hawaii*

103.05 – A Curious Lack of Evolution in the LGRB Host Metallicity Distribution

Recent improvements in the population of Long-duration Gamma Ray Burst host galaxies with measured metallicities and host masses allows us to investigate how the distributions of both these properties change with redshift. First we examine possible biases in the populations caused by the efficiency of obtaining mass and metallicity measurements at different redshifts. In comparing the redshift distributions of a variety of LGRB populations we find no biases out to a redshift of 2.5 with the exception of a reduced metallicity sampling at redshifts high enough to require a separate IR spectrum (z < 0.5). However observations using X-shooter (which allow for obtaining metallicities across a wide range of redshifts) do not show this bias. We also compare the observed LGRB redshift distribution with recent predictions and find good agreement. Having established that the mass and metallicity samples are unbiased we then find a curious consistency in the metallicity destruction across different redshifts. This is at odds with the general evolution in the mass metallicity relation, which becomes progressively more metal poor with increasing redshift. We do however find that the LGRB host galaxy mass distribution increases with redshift so as to preserve the LGRB metallicity destruction. In fact, converting the measured LGRB host masses to their expected metallicities reproduces reasonably consistent metallicity distribution.

Author(s): John Graham[1], Patricia Schady[1], Thomas Kruehler[1]
Institution(s): *1. Max-Planck-Institut für extraterrestrische Physik*

103.06 – A simple model for black hole growth

We present a simple phenomenological model for black hole growth in the z~0 universe. We show that nuclear activity can be described by two separate, mass-independent Eddington Ratio Distribution Functions (ERDFs) operating in blue and red galaxies, respectively. Our forward-modeling approach constrains these two ERDFs by comparing to the observed X-ray and radio luminosity functions. Alternative ERDFs with mass-dependence, such as those expected from AGN-driven mass-quenching of galaxies, are ruled out. We discuss the implications of this model and outline potential applications

Author(s): Kevin Schawinski[1], Anna K. K. Weigel[1], Neven Caplar[1], Ivy Wong[2]
Institution(s): *1. ETH Zurich, 2. ICRAR/UWA*

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104 – Extrasolar Planets Detection: Transit

104.01 – New Constraints on the Kepler Exomoon Population

The search for exomoons represents an exciting new avenue in exoplanetary science. The discovery of these worlds is expected to reveal much about the formation and evolution of planets and moons beyond our Solar System, just as the first exoplanet discoveries broadened our understanding two decades ago. For the past several years the Hunt for Exomoons with Kepler (HEK) project has been searching for evidence of exomoons, and in previously published work we employed computationally expensive photodynamical methods to survey 60 planets for the presence of moons. We present here new results using an alternative phase-folding approach to compliment this search. While less sensitive on a case-by-case basis, the method is sufficiently quick and easy to implement that hundreds of Kepler planets can be studied en masse, leading to new tighter constraints on the ensemble. As a by-product of this work we present transit timing variation posterior distributions for hundreds of planets which will be available online to the community. Finally, we discuss the exomoon population statistics implied by our analysis.

Author(s): Alexander Teachey[2], David M. Kipping[2], Allan Schmitt[1], Gaspar Bakos[3], Lars A Buchhave[6], Guillermo Torres[3], David Nesvorny[5], Joel Hartman[4], Chelsea Huang[7]
Institution(s): *1. Citizen Scientist, 2. Columbia University, 3. Harvard-Smithsonian CfA, 4. Princeton University, 5. Southwest Research Institute, 6. University of Copenhagen, 7. University of Toronto*

104.02 – K2 Warm Jupiters with the LCOGT TECH team

Many if not most transiting gas giant planets on short orbital periods (so called hot Jupiters) have larger radii than theoretically expected. Although several explanations have been proposed, none have completely solved this puzzle. As the number of known transiting planets grew a correlation was identified between gas giant radius and the stellar incident flux. Still, it is not clear whether this correlation is causation. Several questions remain and answering them will characterize in more detail this observed correlation and in turn the process responsible for the inflated radii, such as: Is the lack of inflated gas giants at longer periods a robust feature? What is the incident flux below which there are no inflated gas giants? How low in incident flux does this correlation stretch? These questions arise since there are only a small number of transiting gas giants with low incident flux, below about 10^8 erg/s/cm^2, corresponding to orbital periods beyond 10 days around a Sun-like host star. We refer to such gas giant planets as warm Jupiters. Discovering and confirming more transiting warm Jupiters is the goal of this project, undertaken by the LCOGT Transiting Exoplanet CHaracterization (TECH) team. We are using K2 as our main source of transiting warm Jupiter candidates, with a few candidates discovered in each K2 campaign. LCOGT telescopes are being used for obtaining additional ground-based transit light curves, which are critical for confirming and refining the K2 transit ephemeris as outliers during ingress or egress of the few transit events observed by K2 can bias the measured ephemeris. Further ground-based follow-up data, including spectroscopy, radial velocities, and high angular resolution imaging, are obtained by facilities directly accessible by LCOGT TECH team members. In addition, LCOGT's Network of Robotic Echelle Spectrographs (NRES) will be deployed during 2017 and will allow obtaining spectroscopy and radial velocities with LCOGT facilities. In addition to studying the inflated hot Jupiter conundrum, confirming a sample of warm Jupiters transiting bright stars will support extending atmospheric characterization and spin-orbit alignment studies beyond the hot Jupiter planet class.

Author(s): Avi Shporer[2], Daniel Bayliss[8], Joao Bento[1], William D. Cochran[11], Knicole D. Colon[7], Diana Dragomir[6], Michael Endl[11], Benjamin James Fulton[10], Howard T. Isaacson[9], Enric Palle[4], Robert Siverd[5], Andrew Vanderburg[3], George Zhou[3]
Institution(s): *1. Australian National University, 2. Caltech, 3. Harvard-Smithsonian CfA, 4. Instituto de Astrofisica de Canarias, 5. LCOGT, 6. MIT Kavli Institute, 7. NASA Ames Research Center, 8. Observatoire Astronomique de l'Université de Genève, 9. UC Berkeley, 10. University of Hawaii, Institute for Astronomy, 11. University of Texas*
Contributing team(s): LCOGT TECH team

104.03 – SuPerPiG's Ultra-Short-Period Planets from K2 Campaigns 6 through 8

The unexpected discoveries of hundreds of exoplanets very close to their host stars have challenged planet formation theories. The most extreme subset of these are the ultra-short-period planets, or USPs, with orbital periods of less than a day. These planets may provide unprecedented insights into planet formation and evolution and serve as sensitive probes for planet-star interactions and the stellar wind. Given their very short periods, such planets are particularly amenable to discovery by the Kepler, K2, and upcoming TESS missions and follow-up efforts. In this presentation, we will discuss our group's ongoing search for ultra-short-period planets, the SuPerPiG effort. We will present our follow-up work and an updated list of candidates from our project, including a system with two small candidate planets, one with a period of about 13 hours and the other with a period of about 13 days.

Author(s): Brian K. Jackson[1], Elisabeth R. Adams[2], Michael Endl3
Institution(s): *1. Boise State University, 2. Planetary Science Institute, 3. University of Texas at Austin*

104.04 – Variable Variability: Understanding How Stars Vary from 4 years of Kepler Data

We present an analysis of the variability of 113,000 stars that were observed nearly continuously for 4.5 years (17 quarters) by the Kepler spacecraft. We will provide an overview of the fraction of stars that are variable as a function of spectral type and the fraction of time that the stars are variable, that is, statistically different than their mean. We explore these regimes OF stellar variability on a variety of timescaleS (0.25 day, 0.5 days, 1 day, 5 days, 10 days, 20 days, 50 days, and 100 days) and discuss the implications of our findings and how they relate to the photometric detection and characterization of exoplanets.

Author(s): David R. Ciardi[1], Steve B. Howell[2]
Institution(s): *1. Caltech, 2. NASA Ames*

104.05 – The Exoplant Migration Timescale from K2 Young Clusters

Planetary Migration models for close-in exoplanets(a < 0.1 AU, P < 20 days) can be loosely divided into three categories: Disk-driven migration, binary-star planet interaction, and planet-planet interaction. Disk migration, occurs over the lifetime of the protoplanetary disk (<5 Myr), while migration involving dynamical multi-body interactions operate on timescales of ~100's of Myr to ~1Gyr, a lengthier process than disk migration. It is unclear which of these is the dominating mechanism.

The K2 mission has measured planet formation timescales and migration pathways by sampling groups of stars at key pre-main-sequence ages: Over the past 10 campaigns, multiple groups of young stars have been observed by K2, ranging from the 10 Myr Upper Scorpius OB association, through the ~120 Myr Pleiades, the ~600-800 Myr Hyades and Praesepe moving groups, to the original Kepler Field. The frequency, orbital and compositional properties of the exoplanet population in these samples of different age, with careful treatment of detection completeness, will be sufficient to address the question of exoplanet migration as their host stars are settling onto the main sequence.

We will present the initial results of a program to directly address the question of planet migration with a uniform injection-recovery tests on a new K2 detrending pipeline that is optimized for the particular case of young, rotationally variable stars in K2 to robustly measure the detectability of planets of differing size and orbit. Initial results point towards a migration timescale of 200-700 Myr, which is consistent with the slower planet-planet scattering or Kozai migration models.

Author(s): Aaron C Rizzuto[2], Andrew Mann[2], Adam L. Kraus[2], Michael Ireland[1]
Institution(s): *1. Australian National University, 2. University of Texas at Austin*

104.06 – The Zodiacal Exoplanets in Time (ZEIT) Survey

Planets and their host stars evolve with time, and the first few hundred million years are thought to be the most formative. However, the majority of known exoplanets orbit stars older than the timescales of interest (>1 Gyr). We have launched the Zodiacal Exoplanets in Time (ZEIT) survey with the goal of identifying and characterizing young (<1 Gyr) transiting planets. To this end, we have utilized high-precision photometry of nearby young clusters and stellar associations taken as part of the K2 mission. Thus far we have discovered transiting planets in the Hyades and Praesepe clusters (~800 Myr), and the Upper Scorpius OB association (~11 Myr), but interestingly none in the Pleiades (~125 Myr). These discoveries can be used to set limits on the migration timescale, estimate atmosphere loss around young planets, and provide independent tests of pre-main sequence stellar models. Here I overview some key science results from our survey and briefly discuss our plans to identify more young planetary systems.

Author(s): Andrew Mann4, Eric Gaidos3, Elisabeth R. Newton[2], Aaron C Rizzuto4, Andrew Vanderburg[1], Gregory N. Mace4, Adam L. Kraus4
Institution(s): *1. Harvard, 2. Massachusetts Institute of Technology, 3. University of Hawaii, 4. University of Texas at Austin*

104.07 – Update on the KELT Transit Survey: Hot Planets around Hot, Bright Stars

The KELT Transit Survey consists of a pair of small-aperture, wide-angle automated telescope located at Winer Observatory in Sonoita, Arizona and the South African Astronomical Observatory (SAAO) in Sutherland, South Africa. Together, they are surveying roughly 60% of the sky for transiting planets. By virtue of their small apertures (42 mm) and large fields-of-view (26 degrees x 26 degrees), KELT is most sensitive to hot Jupiters transiting relatively bright (V~8-11), and thus relatively hot stars. Roughly half of the dwarf stars targeted by KELT are hotter than 6250K; such stars pose novel challenges, but also provide unique opportunities. I will provide an update on the most recent companions discovered by KELT, focusing in detail on a few particularly interesting systems.

KELT is a joint collaboration between the Ohio State University, Vanderbilt University, and Lehigh University. This work was partially supported by NSF CAREER grant AST-1056524.

Author(s): B. Scott Gaudi[1]
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Contributing team(s): The KELT Collaboration

104.08 – A Search for Transits of Proxima b in MOST Photometry

The recent discovery of a potentially rocky planet in the habitable-zone of our nearest star presents exciting prospects for future detailed characterization of another world. If Proxima b transits its star, the road to characterization would be considerably eased. In 2014 and 2015, we monitored Proxima Centauri with the Canadian space telescope MOST for a total of 43 days. As expected, the star presents considerable photometric variability due to flares, which greatly complicate our analysis. Using Gaussian process regression and Bayesian model selection with informative priors for the time of transit of Proxima b, we do find evidence for a transit of the expected depth. However, relaxing the prior on the transit time to an uninformative one returns a distinct solution highlighting the high false-positive rate induced by flaring. Using ground-based photometry from HATSouth, we show that our candidate transit is unlikely to be genuine although a conclusive answer will likely require infrared photometry, such as that from Spitzer, where flaring should be suppressed.

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104.09 – Mission Status for the Transiting Exoplanet Survey Satellite (TESS)

The Transiting Exoplanet Survey Satellite (TESS) will discover thousands of exoplanets in orbit around the brightest stars in the sky. TESS will monitor ~ 200,000 pre-selected bright stars in the solar neighborhood for temporary drops in brightness caused by planetary transits. This first-ever spaceborne all-sky transit survey will identify planets ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances.

TESS stars will typically be 30 — 100 times brighter than those surveyed by the Kepler satellite; thus, TESS planets will be far easier to characterize with follow-up observations. For the first time it will be possible to study the masses, sizes, densities, orbits, and atmospheres of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars.

An additional data product from the TESS mission will be full frame images (FFI) with a cadence of 30 minutes. These FFI will provide precise photometric information for every object within the 2300 square degree instantaneous field of view of the TESS cameras. In total, more than 30 million stars and galaxies brighter than magnitude I=16 will be precisely photometered during the two-year prime mission. In principle, the lunar-resonant TESS orbit could provide opportunities for an extended mission lasting more than a decade.

The baselined long duration survey by TESS of regions surrounding the North and South Ecliptic Poles will provide prime exoplanet targets for characterization with the James Webb Space Telescope (JWST), as well as other large ground-based and space-based telescopes of the future.

TESS will issue data releases every 4 months, inviting immediate community-wide efforts to study the new planets, as well as commensal survey candidates from the FFI. A NASA Guest Investigator program is planned for TESS. The TESS legacy will be a catalog of the nearest and brightest main-sequence stars hosting transiting exoplanets, which should endure as the most favorable targets for detailed future investigations.

TESS is targeted for launch in late 2017 — early 2018 as a NASA Astrophysics Explorer mission. In this talk, a status update for the TESS mission will be presented.

Author(s): George R. Ricker[1]
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Contributing team(s): TESS Science Team

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105 – Galaxy Clusters I

105.01 – Lyman Alpha Blobs: Seeds of Galaxy Groups

Recently, evidence has been mounting that giant Lyman alpha (Lya) nebulae, or "blobs," at high redshift are coincident with regions of galaxy overdensity and likely the progenitors of galaxy groups. These Lya blobs are rare structures found at roughly 1 < z < 6 which have typical diameters of ~100 kpc and Lya luminosities of ~10^42 to 10^44 erg s^-1. Using Hubble Space Telescope (HST) imaging, we explore the environments of three systematically-selected blobs at 1.5 < z < 2.5. Comparing the total surface density of galaxies in a region centered on the blob to the average surface density of galaxies in the field, we find that all three blobs exhibit significant overdensity (up to a factor of 5-10). After narrowing down which galaxies are most likely to be associated with each Lya blob, we confirm that the raw overdensities are enhanced and find evidence of a luminosity gap in at least one of the three systems studied. These results suggest that Lya blobs offer new insight into the early phases of galaxy group and cluster formation.

Author(s): Agnar Hall[1], Moire Prescott[1]
Institution(s): *1. New Mexico State University*

105.02D – Observational Constraints on the Link Between the Intracluster Medium and Brightest Cluster Galaxies

We use data from Chandra, HST, Spitzer, and Herschel to study the nature of feedback in the brightest cluster galaxies (BCGs) of cool core galaxy clusters. Using the 16-band photometry HST available with CLASH in combination with observations taken with Spitzer, Herschel, and Chandra, we study the nature of the feedback mechanism required to offset cooling. While a great deal of progress has been made on this front, there is still much to learn from the feedback-affected stellar populations of cool core BCGs and X-ray observations of the intracluster medium (ICM). With UV through FIR SED fitting, we estimate the star formation rate, dust content, and starburst duration in UV-bright cool core BCGs in CLASH, and examine relationships between these findings and ICM cooling time and free-fall time profiles derived from Chandra X-ray imaging. We present observational evidence constraining the duration of feedback episodes and find a very tight relationship between the BCG star formation rate and the ratio of ICM cooling time to free-fall time (tcool/tff). Our observational results are fully consistent with a scenario where condensation of a depleting supply of thermally instable overdensities of the ICM gas are fueling long-duration (> 1 Gyr) BCG starbursts. We discuss the implications of our findings for theoretical models of BCG-ICM interaction.

Author(s): Kevin Fogarty[1], Marc Postman3, Megan Donahue[2]
Institution(s): *1. Johns Hopkins University, 2. Michigan State University, 3. Space Telescope Science Institute*
Contributing team(s): CLASH

105.03 – Galaxy group dynamics using the GAMA survey and predictions from semi-analytics and cosmological simulation.

We aim to discuss the dynamics of galaxies in group environment. We present our current findings on the contentious issue of the stellar mass segregation in galaxy groups using the Galaxy And Mass Assembly (GAMA) survey, the GALFORM semi-analytic and the EAGLE cosmological hydrodynamical simulation catalogues of galaxy groups. We will discuss our main results that show negligible mass segregation in galaxy groups and also show a lack of redshift evolution.

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Contributing team(s): GAMA, GALFORM, EAGLE

105.04 – The Cluster Environments of Quasar Groups

Quasars are rare astronomical objects, and quasar pairs, triplets and larger groupings are even rarer. The presence of several quasars in the same small volume of space might therefore indicate a region that is exceptionally rich in galaxies, and hence groups of quasars could serve as ueful beacons for identifying distant clusters or protoclusters of galaxies. With this motivation, we compare the cluster environments of single versus multiple quasar systems using data from the Sloan Digital Sky Survey.

Author(s): Michael West[1], Michael Gregg3, Justin Toller[2]
Institution(s): *1. Lowell Observatory, 2. Northern Arizona University, 3. University of California, Davis*

105.05D – Shock Features in Merging Galaxy Clusters

Clusters of galaxies are the largest and the most massive gravitationally collapsed objects in the universe. In the hierarchical scenarios of the large-scale structure formation of the universe, they form by subcluster mergers and infall. Major mergers inject tremendous amounts of energy (~10^{64} erg) into the intracluster medium (ICM), triggering shocks and generating. These hydro-dynamical activities may amplify magnetic fields in the cluster and accelerate relativistic particles. These non-thermal phenomena have been revealed by the detection of Mpc-scale diffuse radio emission. Current studies hint at a correlation between X-ray and Radio morphologies.

To further address this issue, shock properties of 15 galaxy clusters were studied. The sample was divided into two categories: with and without diffuse radio emission. In my dissertation, my goal is to address questions: Do more luminous clusters have stronger shocks?, How continuous gas stripping affect cool cores?, Why some clusters exhibit a stronger correlation between X-ray shocks and radio relic?

Author(s): Sarthak Dasadia[1], Ming Sun[1], Andrea Morandi[1]
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105.06 – Electron Heating at Galaxy Cluster Shocks: Measuring the Temperature of the Bullet Cluster Shock with NuSTAR

The Bullet cluster is famous for driving a shock into an oncoming subcluster's intracluster medium with its cool core (the "bullet"). Chandra data suggest a very high electron temperature right at the front (>30 keV), implying that electrons are directly heated by the passing shock contrary to expectations. However, Chandra's sensitivity to such high temperatures is low, given that its effective area declines swiftly above ~4 keV. NuSTAR, the first focusing hard (>10 keV) X-ray observatory, is much better matched to the emission from gas with high temperatures, assuming its much poorer spatial resolution can be appropriately modeled. We present a demonstration of this technique with joint Chandra-NuSTAR imaging spectroscopy of the Bullet cluster and its shock. On average across its entire length, the shock temperature is in line with both the expectations of no direct heating by the shock (only increased temperature from adiabatic compression) and direct heating; both predictions overlap due to the lower Mach number farther away from the cool core. To compare directly with the Chandra-only measurement, we also constrain the shock temperature immediately ahead of the cool core, possibly to confirm this exciting example of direct electron heating driven by a weak shock. The prospects for future measurements in other clusters with NuSTAR will also be discussed.

Author(s): Daniel R. Wik[1]
Institution(s): *1. University of Utah*

105.07 – Constraining halo energetics using Sunyaev-Zel'dovich measurements

Both feedback and non-thermal processes play important roles in the thermodynamic and star-formation properties of the intracluster medium (ICM). Recently, there have been exciting detections of the kinetic Sunyaez-Zel'dovich (SZ) from galaxy clusters. These measurements and future ones provide new windows into the thermodynamic properties of the ICM. We show how we can constrain the average feedback and non-thermal pressure support through the combination of thermal and kinetic SZ measurements.

Author(s): Nicholas Battaglia[1], Emmanuel Schaan[1], Simone Ferraro[2], David N. Spergel[1]
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106 – Ground Based & Airborne Instruments

106.01 – A new imaging technique for detecting interstellar communications

We report on a unique detection methodology using the Berkeley Visible Image Tube (BVIT) mounted on the 10m Southern African Large Telescope (SALT) to search for laser pulses originating in communications from advanced extraterrestrial (ET) civilizations residing on nearby Earth-like planets located within their habitability zones. The detection technique assumes that ET communicates through high powered pulsed lasers with pulse durations on the order of 5 nanoseconds, the signals thereby being brighter than that of the host star within this very short period of time. Our technique turns down the gain of the optically sensitive photon counting microchannel plate detector such that ~30 photons are required in a 5ns window to generate an imaged event. Picking *a priori* targets with planets in the habitable zone substantially reduces the false alarm rate.

Interplanetary communication by optical masers was first postulated by Schwartz and Townes in 1961. Under the assumption that ET has access to a 10 m class telescope operated as a transmitter then we could detect lasers with a similar power to that of the Livermore Laboratory laser (~1.8Mj per pulse), to a distance of ~ 1000 pc.

In this talk we present the results of 2400 seconds of BVIT observations on the SALT of the star Wolf 1061, which is known to harbor an Earth-sized exoplanet located in the habitability zone. At this distance (4.3 pc), BVIT on SALT could detect a 48 joule per pulse laser, now commercially available as tabletop devices.

Author(s): John Vallerga[2], Barry Welsh[2], Marissa Kotze[1], Oswald Siegmund[2]
Institution(s): *1. South African Astronomical Observatory, 2. University of California, Berkeley*

106.02 – Science capabilities of the Maunakea Spectroscopic Explorer

The Maunakea Spectroscopic Explorer (MSE) project will transform the CFHT 3.6m optical telescope into a 10m class dedicated multiobject spectroscopic facility, with an ability to simultaneously measure thousands of objects with a spectral resolution range spanning 2,000 to 20,000. The project is currently in design phase, with full science operations nominally starting in 2025. MSE will enable transformational science in areas as diverse as exoplanetary host characterization; stellar monitoring campaigns; tomographic mapping of the interstellar and intergalactic media; the in-situ chemical tagging of the distant Galaxy; connecting galaxies to the large scale structure of the Universe; measuring the mass functions of cold dark matter sub-halos in galaxy and cluster-scale hosts; reverberation mapping of supermassive black holes in quasars. MSE is an essential follow-up facility to current and next generations of multi-wavelength imaging surveys, including LSST, Gaia, Euclid, eROSITA, SKA, and WFIRST, and is an ideal feeder facility for E-ELT, TMT and GMT. I will give an update on the status of the project and review some of the most exciting scientific capabilities of the observatory.

Author(s): Daniel Devost[1], Alan McConnachie[1], Nicolas Flagey[1], Patrick Cote[2], Michael Balogh4, Simon P Driver5, Kim Venn3
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106.03D – FLITECAM/SOFIA Commissioning and Early Science and A Study of Late-T Dwarf Color Outliers with NIRSPEC/Keck

My thesis combines the development of infrared instrumentation with the application of infrared imaging and spectroscopy to the characterization of the highest and lowest mass products of the star formation process. I supported the development and commissioning of FLITECAM, a 1-5 μm imager and spectrograph for SOFIA (Stratospheric Observatory for Infrared Astronomy), as the UCLA FLITECAM Instrument Scientist, and used FLITECAM to probe high-mass star formation. In parallel, I used the NIRSPEC spectrograph at Keck Observatory to study the lowest mass products of star formation, brown dwarfs. Here, I present an overview of FLITECAM's in-flight performance in both imaging and spectroscopy modes. I also describe the results of an imaging survey of the NGC 2024 and W3 star-forming regions using FLITECAM's Paschen-α (1.87 μm) and Polycyclic Aromatic Hydrocarbon (PAH; 3.3 μm) filters. These filters provide an effective way to trace the ionized gas emission and the emission from small grains. Additionally, I present the results of a NIRSPEC/Keck spectroscopic follow-up survey of 13 late-type T dwarfs (T6-T9) with unusually red or blue *J-H* colors. Previous work suggests that *J-H* color outliers may represent the high-gravity, low-metallicity (old) and low-gravity, high-metallicity (young) extremes of the late-T dwarf population. I find that the T dwarf color outliers in this sample are more homogenous than expected. Nevertheless, comparisons to spectral standards and publicly available atmospheric models do reveal subtle physical differences in their spectral morphologies.

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106.04 – Update on the Commensal VLA Low-band

Ionospheric and Transient Experiment (VLITE)

The JVLA Low-band Ionospheric and Transient Experiment (VLITE) is a commensal observing system on the NRAO JVLA. The separate optical path of the prime-focus sub-GHz dipole feeds and the Cassegrain-focus GHz feeds provided an opportunity to expand the simultaneous frequency operation of the JVLA through joint observations across both systems. The low-band receivers on 10 JVLA antennas are outfitted with dedicated samplers and use spare fibers to transport the 320-384 MHz band to the VLITE correlator. The initial phase of VLITE uses a custom-designed real-time DiFX software correlator to produce autocorrelations, as well as parallel and cross-hand cross-correlations from the linear dipole feeds. NRL and NRAO have worked together to explore the scientific potential of the commensal low frequency system for ionospheric remote sensing, astrophysics and transients. VLITE operates at nearly 70% wall time with roughly 6200 hours of JVLA time recorded each year.

VLITE data are used in real-time for ionospheric research and are transferred daily to NRL for processing in the astrophysics and transient pipelines. These pipelines provide automated radio frequency interference excision, calibration, imaging and self-calibration of data.

We will review early scientific results from VLITE across all three science focus areas, including the ionosphere, slow (> 1 sec) transients, and astrophysics. We also discuss the future of the project, that includes its planned expansion to eVLITE including the addition of more antennas, and a parallel capability to search for fast (< 1 sec), dispersed transients, such as Fast Radio Bursts and Rotating Radio Transients. We will also present early results of commissioning tests to utilize VLITE data products to complement NRAO’s 3 GHz VLA Sky Survey (VLASS). Revised pipelines are under development for operation during the on-the-fly operation mode of the sky survey.

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106.05 – DEdicated MONitor of EXotransits and Transients (DEMONEXT): Low-Cost Robotic and Automated Telescope for Followup of Exoplanetary Transits and Transients

We present the design, development, and early science from the DEdicated MONitor of EXotransits and Transients (DEMONEXT), an automated and robotic 20 inch telescope jointly funded by The Ohio State University and Vanderbilt University. The telescope is a PlaneWave CDK20 f/6.8 Corrected Dall-Kirkham Astrograph telescope on a Mathis Instruments MI-750/1000 Fork Mount located at Winer Observatory in Sonoita, AZ. DEMONEXT has a Hedrick electronic focuser, Finger Lakes Instrumentation (FLI) CFW-3-10 filter wheel, and a 2048 x 2048 pixel FLI Proline CCD3041 camera with a pixel scale of 0.90 arc-seconds per pixel and a 30.7 x 30.7 arc-minute field-of-view. The telescope's automation, controls, and scheduling are implemented in Python, including a facility to add new targets in real time for rapid follow-up of time-critical targets. DEMONEXT will be used for the confirmation and detailed investigation of newly discovered planet candidates from the Kilodegree Extremely Little Telescope (KELT) survey, exploration of the atmospheres of Hot Jupiters via transmission spectroscopy and thermal emission measurements, and monitoring of select eclipsing binary star systems as benchmarks for models of stellar evolution. DEMONEXT will enable rapid confirmation imaging of supernovae, flare stars, tidal disruption events, and other transients discovered by the All Sky Automated Survey for SuperNovae (ASAS-SN).

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107 – Black Holes I

107.01D – Testing SMBH scaling relations using cosmological simulations and optical/near-IR imaging data

The strong correlation between supermassive black hole (SMBH) mass and a number of measurable features of the host galaxies has generated great interest in the notion that galaxy formation and SMBH growth are closely linked. My dissertation has focused primarily on the SMBH-host galaxy scaling relations and their implications for galaxy evolution. First, we use the statistically tightest correlations with SMBH mass, which are the Sersic index for early-type galaxies and pitch angle for spiral galaxies, to predict the SMBH masses in our volume-limited sample, and derive the SMBH mass function (BHMF), and quantify the SMBH space density in our local universe.
I will present the observational simplicity of our approach to estimate the local BHMF through imaging data only as well as our BHMF estimate and its implications. Our result is as of a particular interest because it is derived from a nearly complete sample within set limits and provides reliable data, especially for the low-mass end of the local BHMF.

Next, we study the data from Illustris simulation project, which is a large cosmological simulation of galaxy formation. This simulation provides a statistically large and representative sample of objects, and makes it possible to disentangle the physical link between black holes and their host galaxies. We derive the spiral arm morphology in the multi-wavelength, and test the theories of spiral structure in the simulated disk galaxies. We further study the Illustris prediction for the SMBH mass-spiral arm pitch angle relation and check if the result produces the slope and normalization of the observed SMBH mass-spiral arm pitch angle relation. A careful assessment of the agreement/disagreement with observations is the primary test of the physics implemented in the simulation. I will present our results from the Illustris spiral galaxies, and discuss the implications on which galaxy types are strongly physically linked with their central SMBHs
and which are much less affected by the presence of a SMBH in their center.

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107.02D – Exploring mass-scaling physics and outflow geometry in accreting black holes

One of the main tasks facing studies of black hole accretion in both black hole X-ray binaries (XRB) and Active Galactic Nuclei (AGN) is to break spectral model-fitting degeneracies. We explore two methods of simultaneous spectral modelling to reduce these degeneracies: (a) simultaneous fitting of XRBs and AGN, and (b) folding in timing properties in a novel way to better understand the outflow evolution of XRBs during outburst.

It is a long-standing idea that AGN are scaled up versions of XRBs, such that the physics of accretion cares only about accretion rate, and not the black hole mass. We show that this principle of scale-invariance may provide us with a way to break degeneracies in broadband spectral modelling of both XRBs and AGN, focusing primarily on low-luminosity sources where degeneracies are more prevalent. We simultaneously model the broadband spectra of the two most quiescent ($L_X \sim 10^{-9} L_{Edd}$) accreting black holes on opposite ends of the mass scale, the XRB A0620-00 and Sgr A*, the Galactic centre supermassive black hole (during bright flaring). We use an outflow-dominated model capable of reproducing the broadband spectrum from radio to X-ray frequencies, co-evolving parameters that are representative of the mass-scaling properties. Such a method reduces the degeneracies in our model parameters, contributing to answering this question regarding the dominant emission mechanisms.

We adopt a similar technique to investigate how spatial parameters of an XRB outflow can be better understood by tracking our model parameters as a function of the XRB variability properties during outburst, focusing in particular on GX 339-4. I shall discuss how utilising a novel characterisation of the timing properties of XRBs allows us to do this in a simple, quantitative way.
We are currently developing our models further to incorporate the most up-to-date disc reflection routines in order to describe the jet/disc interaction more accurately. I shall briefly discuss this work and its importance, as well as further model extensions we are currently working on.

Author(s): Riley Michael Thomas Connors[1]
Institution(s): *1. Anton Pannekoek Institute, University of Amsterdam*

107.03 – Diagnosing the Black Hole Accretion Physics of Sgr A*: *Spitzer/Chandra* Observations

The Galactic center offers the closest opportunity for studying accretion onto a supermassive black hole. The fluctuating source, Sgr A*, is detected across the electromagnetic spectrum and its flux may originate in either the accretion flow or a jet, or both. Disentangling the power source and emission mechanisms of the flares is a central challenge to our understanding of the Sgr A* accretion flow. Recent general relativistic magneto–hydrodynamic (GRMHD) models indicate that variability can be produced by a tilted inner disk, gravitational lensing of bright spots in the disk by the hole, or particle acceleration in reconnection events. These models produce different flare characteristics, and better characterization of flares may enable us to distinguish between strong and weakly magnetized disks. Following our successful *Spitzer* observations of the variability of Sgr A* in 2013 and 2014, we have undertaken a program of simultaneous IRAC (4.5 micron) and *Chandra* (2–10 keV) observations to (1) probe the accretion physics of Sgr A* on event–horizon scales and (2) detect any effect of the object G2 on Sgr A*. In addition, several ground-based observatories participated in the campaigns, at wavelengths including radio, sub-mm, and the near-infrared. We will present initial *Spitzer/Chandra* results from the two 24-hour epochs in 2016 July. Only such long–duration, continuous, multi–wavelength observations can achieve a comprehensive view of the dominant emission process(es) and quantify the physical properties near the event horizon.

Author(s): Joseph L. Hora[1], Giovanni G. Fazio[1], Steven P. Willner[1], Mark A. Gurwell[1], Howard Alan Smith[1], Matthew Ashby[1], Frederick K. Baganoff[3], Gunther Witzel[6], Mark Morris[6], Andrea M. Ghez[6], Leo Meyer[6], Eric E. Becklin[4], James G. Ingalls[5], William J. Glaccum[5], Sean J. Carey[5], Daryl Haggard[2], Daniel P. Marrone[7], Charles F. Gammie[8]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. McGill University, 3. MIT, 4. SOFIA Science Center, 5. Spitzer Science Center, 6. UCLA, 7. University of Arizona, 8. University of Illinois*

107.04 – Strongly Magnetized Accretion Disks Around Black Holes

Recent observations are suggestive of strongly magnetized accretion disks around black holes. Performing local (shearing box) simulations of accretion disks, we investigate how a strong magnetization state can develop and persist. We demonstrate that poloidal flux is a necessary prerequisite for the sustainability of strongly magnetized accretion disks. We also show that black hole spin measurements can become unconstrained if magnetic fields provide a significant contribution to the vertical pressure support of the accretion disk atmosphere.

Author(s): Greg Salvesen[2], Philip J. Armitage[3], Jacob B. Simon[1], Mitchell C. Begelman[3]
Institution(s): *1. Southwest Research Institute, 2. University of California, Santa Barbara, 3. University of Colorado Boulder*

107.05 – A Black Hole Mass Measurement from Adaptive Optics Spectroscopy for the Compact Galaxy Mrk 1216

Over the past decade it has become increasingly clear that supermassive black holes are essential components of galaxies, as demonstrated by the correlations connecting black hole masses and large-scale galaxy properties. Gaining a deeper understanding of the physical mechanisms that drive such relations requires the measurement of black holes in a wider range of galaxy types with diverse evolutionary histories. In this talk, we focus on the nearby, early-type, compact galaxy Mrk 1216. Using integral field spectroscopy assisted by adaptive optics from the Gemini North telescope and Hubble Space Telescope imaging observations, along with orbit-based dynamical models, we find a black hole mass of 5 billion solar masses. The black hole in Mrk 1216 is well above the expectations from the local black hole mass - bulge luminosity relation. With remarkable similarities to the z~2 quiescent galaxies, Mrk 1216 may be a passively evolved descendant, and perhaps reflects a previous time when galaxies contained over-massive black holes and the growth of host galaxies had yet to catch up.

Author(s): Jonelle Walsh[2], Remco van den Bosch[1], Karl Gebhardt[4], Akin Yildirim[1], Kayhan Gultekin[3], Bernd Husemann[1], Douglas O. Richstone[3]
Institution(s): *1. Max Planck Institute for Astronomy, 2. Texas A&M University, 3. University of Michigan, 4. University of Texas, Austin*

107.06 – Model for coeval growth of bulges and their seed black holes in presence of radiative feedback

The discovery of billion solar mass accreting black holes at high redshift poses a great challenge for the modeling of the seed black hole (BH) formation and growth. Radiation-hydrodynamic simulations represent a crucial test of plausible scenarios by providing estimated growth rates for the seeds in the intermediate-mass black hole range. Previous works show that radiative feedback from black holes suppresses the cold gas accretion rate dramatically, making it difficult to explain the rapid growth of seed black holes. We however find that the fueling rate of black holes embedded in bulges can increase with the bulge-to-BH mass ratio when the bulge mass is greater than the critical value of $\sim 10^6$ $M_\odot$. The critical bulge mass is independent of the central black hole mass, thus the growth rate of light seeds (< 10^2 $M_\odot$) and heavy seed black holes (> 10^5 $M_\odot$) exhibits distinct dependencies on the bulge-to-BH mass ratio. Our results imply that heavy seeds, that may form via direct collapse, can grow efficiently and coevally with the host galaxies despite radiative feedback whereas the growth of light seeds is stunted. We present the results of an extended semi-analytic model based on the radiation-hydrodynamic simulations, which follows the coeval growth of black holes and their bulges.

Author(s): KwangHo Park[1], Tamara Bogdanovic[1], John Wise[1]
Institution(s): *1. Georgia Institute of Technology*

107.07 – CXB and CIB joint fluctuations in COSMOS, EGS, UDS and HDFN

I will present new results on the joint CIB and CXB joint fluctuations in the COSMOS, EGS, UDS and HDFN surveys. We used the deepest wide Chandra, XMM and Spitzer data available so far and cross-correlate with known optical galaxies. We demonstrate that the these joint fluctuations are produced by extremely faint sources m_{AB}>28. We tested the hypothesis that early supermassive black holes could produce the observed signal

Author(s): Nico Cappelluti4, Yanxia Li3, Rachel Ann Cooper4, Joyce Guo4, C. Megan Urry4, Guenther Hasinger3, Richard G. Arendt2, Alexander Kashlinsky1
Institution(s): *1. NASA GSFC, 2. UMBC, 3. University of Hawaii, 4. Yale University*

108 – HEAD I: Astronomy Across the Gravitational Wave Spectrum

The historic detection of a pair of merging black holes by the LIGO-Virgo Scientific Collaboration marks the emergence of gravitational wave science as a bona fide field of astronomy. The detection of GW150914 represents only the beginning, both in terms of the additional events and sources that ground based detectors will uncover, as well as the other regions of the gravitational wave spectrum that will soon become accessible to astronomers. This session consists of three invited talks covering three bands of the gravitational wave spectrum. The first talk, representing the decahertz band accessible from the ground, will focus on the hunt for electromagnetic counterparts to gravitational wave triggers and the efforts to follow them using a wide array of electromagnetic observatories. The second talk, representing the nanohertz band accessible with pulsar timing arrays, will demonstrate how the formation and evolution of supermassive black holes and their host galaxies can be informed through gravitational wave observations and highlight both recent results and near-term prospects. The final talk, representing the millihertz band accessible from space-based detectors, will discuss the science case for the LISA instrument in the context of the LIGO and LISA Pathfinder successes.

108.01 – GW astronomy, EM observations, and the interactions between them

I present an overview of the types of low latency searches operated by the LIGO-Virgo collaboration, focusing on the products produced by each and how they tie into the broader astronomical community. This includes both automated and manual follow-up to characterize the source localization as well as statements about the data quality surrounding the candidate. In broad strokes, I'll also describe the internal and external communication mechanisms put in place to announce candidates and report follow-up activities, with particular emphasis placed on how GW and EM data are mutually beneficial. Time permitting, I will also describe some consequences of observed diurnal cycles governing when the LIGO detectors are likely to record data and studies comparing localizations from different algorithms.

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Institution(s): *1. Massachusetts Institute of Technology*
Contributing team(s): LIGO-Virgo Collaboration

108.02 – The Gravitational-Wave Universe seen by Pulsar Timing Arrays

Galaxy mergers are a standard aspect of galaxy formation and evolution, and most (likely all) large galaxies contain supermassive black holes. As part of the merging process, the supermassive black holes should in-spiral together and eventually merge, generating a background of gravitational radiation in the nanohertz to microhertz regime. Processes in the early Universe such as relic gravitational waves and cosmic strings may also generate gravitational radiation in the same frequency band. An array of precisely timed pulsars spread across the sky can form a galactic-scale gravitational wave detector in the nanohertz band. I describe the current efforts to develop and extend the pulsar timing array concept, together with recent limits which have emerged from North American and international efforts to constrain astrophysical phenomena at the heart of supermassive black hole mergers.

Author(s): Chiara M. F. Mingarelli1
Institution(s): *1. Max Planck Institute for Radio Astronomy*
Contributing team(s): The International Pulsar Timing Array

108.03 – LISA: Science and Prospects for Gravitational Wave Detection in Space

Spaceborne gravitational wave observatories with million kilometer armlengths will probe gravitational waves with kilosecond periods. This part of the spectrum is populated by a diverse menagerie of high energy astrophysical systems that will give new insights into stellar evolution, the formation and evolution of super-massive black holes, and the growth of structure in the Universe. LISA is a laser interferometric observatory that will be sensitive to gravitational wave frequencies from about 10 microHertz to about 1 Hertz, providing gravitational wave observations of these phenomena that will enable population studies, detailed characterization of the structure and bulk motion of matter in these systems, as well as enabling new, detailed tests of physics in strong gravitational fields. The core LISA measurement has been demonstrated by the successful flight of LISA Pathfinder, paving the way for the start of LISA mission design and planning. In this talk, we will discuss the science that low-frequency gravitational wave observations will reveal and enable, as well as the current technology status and progress forward toward an eventual LISA flight.

Author(s): Shane L. Larson1
Institution(s): *1. Northwestern University*

109 – New, Fundamental, Cutting-Edge Science from Arecibo Observatory

Arecibo Observatory celebrated its 50th anniversary in 2013. Historically, many important discoveries were made there in both radio and radar astronomy, but this session is about discoveries made since this milestone anniversary. Arecibo is by far the best telescope for detecting the faintest millisecond pulsars in exotic binary orbits, and only Arecibo has the potential to time radio pulsars at the highest possible precision. This makes it a crucial element in the worldwide Pulsar Timing Array which could lead to the first-ever detection of gravitational waves in the very-low frequency domain from supermassive black hole binaries. The participation of Arecibo is crucial to the success of fundamental VLBI science. The resolution of the Pleiades distance controversy required Arecibo, and only the Arecibo-Radioastron baseline can search for the physical components of active galactic nuclei responsible for intraday variability. With the world's largest collecting area and a sensitive multi-beam receiver, Arecibo can observe HI deeper, faster, and more precisely than any other telescope in the world. Survey maps not only reveal Galactic HI filaments but also show that these structures are aligned with the magnetic field. Arecibo is the only telescope that can detect galaxies that consist largely of dark matter, which are predicted by recent models of the formation of structures in the universe. Arecibo's Planetary Radar system is the world's most powerful instrument for the characterization and orbital refinement of NEOs. Where traditional observations provide only plane-of-sky information, Arecibo can determine the full 3D orbit as well as the object's size, shape, mass, and spin, information essential for the assessment of impact hazards. The Arecibo radar is also the most sensitive instrument for investigations of internal structures of solid planets and for constraining surface activity of the Moon and Mercury.

109.01 – Cutting-Edge Science from Arecibo Observatory: Introduction

The Arecibo Observatory is home to the largest radio telescope in the world operating above 2 GHz, where molecule emission pertaining to the origins of life proliferate. It also houses the most powerful radar system on the planet, providing crucial information for the assessment of impact hazards of near-Earth asteroids (NEA). It was built to study the ionosphere with a radar system that can also monitor the effects of Space Weather and climate change. Arecibo has a proven track record for doing excellent science, even after 50 years of operations. This talk will include brief summaries of several Arecibo astronomy topics including the (1) latest attempts to resolve the Pleiades distance controversy, which include VLBI and Gaia; (2) galactic and extragalactic molecules; and (3) Arecibo 3D orbit determinations of potentially hazardous asteroids, and the crucial observation required to select Bennu as the target for the recently launched NASA OSIRIS-REx mission. This introduction will set the stage for the invited talks in this session, which include such topics as Fast Radio Bursts, galactic and extragalactic HI results, the pulsar emission problem, and NANOGrav. This work is supported by NSF and NASA.

Author(s): Joan T. Schmelz[1]
Institution(s): *1. Arecibo Observatory*

109.02 – The Enigmatic Fast Radio Burst FRB121102

Fast Radio Bursts (FRBs) are millisecond-duration radio flashes, whose large dispersion measures suggest that they originate at extragalactic distances in extremely energetic environments. Once a phenomenon only observed with the Parkes telescope, the discovery of FRB121102 using Arecibo solidified the astrophysical origin of the FRBs. More recently, Arecibo has enabled the astonishing discovery that FRB121102 sporadically produces additional bursts. This immediately rules out the various cataclysmic models - at least for this particular FRB - and is enabling deep, targeted follow-up observations which aim to localize the source to sub-arcsecond precision and to, ultimately, determine its physical origin. I will present our latest understanding of FRB121102 and its relevance for interpreting the FRB phenomenon in general.

Author(s): Jason Hessels[1]
Institution(s): *1. ASTRON*
Contributing team(s): PALFA Survey Team, VLA+AO FRB121102 Simultaneous Campaign Team, EVN FRB121102 Campaign Team

109.03 – GALFA-HI and the Discovery of Magnetically Aligned Neutral Hydrogen Fibers

Arecibo observations of neutral hydrogen have revealed a new way to study cosmic magnetism. The Galactic Arecibo L-Band Feed Array Survey (GALFA-HI) is a sensitive, high dynamic range survey of the 21-cm neutral hydrogen line over 13,000 square degrees of sky. GALFA-HI revealed that much of the Milky Way's diffuse neutral hydrogen is organized into slender linear "fibers" that are extremely well aligned with the interstellar magnetic field. This discovery means that neutral hydrogen observations provide a new way to study gas-magnetic field interactions, and to constrain the magnetized dust foreground that obscures our view of cosmic microwave background polarization. High-resolution observations of neutral hydrogen morphology are a powerful probe of the physics of the magnetized interstellar medium.

Author(s): Susan Clark[1]
Institution(s): *1. Columbia University*
Contributing team(s): GALFA-HI Collaboration

109.04 – Cutting-edge HI science with the Arecibo Telescope

Arecibo has long been at the forefront of extragalactic HI astronomy. This continues today with the results coming out of blind surveys with the ALFA multi-pixel receiver, pointed surveys with the L-band wide receiver, and many other HI projects. I will present some of the exciting HI science to emerge from Arecibo in the last year, which include a giant ring of gas found in the Local Group, the most metal-poor, gas-rich galaxy known, and many others.
The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation (AST-1100968), and in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association.

Author(s): Robert F. Minchin[1]
Institution(s): *1. NAIC, Arecibo Observatory*

109.05 – Observing the Plasma-Physical Processes of Pulsar Radio Emission with Arecibo

With their enormous densities and fields, neutron stars entail some of the most exotic physics in the cosmos. Similarly, the physical mechanisms of pulsar radio emission are no less exotic, and we are only now beginning to understand them. The talk will provide an introduction to the phenomenology of radio pulsar emission and focus on those aspects of the exquisite Arecibo observations that bear on their challenging emission physics.

The commonalities of the radio beamforms of most slow pulsars (and some millisecond pulsars) argue strongly that their magnetic fields have a nearly dipolar structure at the height of their radio emission regions. These heights can often be determined by aberration/retardation analyses. Similarly, measurement of the orientation of the polarized radio emission with respect to the emitting magnetic field facilitates identification of the physical (X/O) emission modes and study of the plasma coupling to the electromagnetic radiation.

While the physics of primary plasma generation above the pulsar polar cap is only beginning to be understood, it is clear that the radio pulsars we see are able to generate copious amounts of electron-positron plasma in their emission regions. Within the nearly dipolar field structure of these emission regions, the plasma density is near to that of the Goldreich-Julian model, and so the physical conditions in these regions can be accurately estimated. These conditions show that the plasma frequencies in the emission regions are much higher than the frequency of the emitted radiation, such that the plasma couples most easily to the extraordinary mode as observed. Therefore, the only surviving emission mechanism is curvature radiation from charged solitons, produced by the two-stream instability. Such soliton emission has probably been observed directly in the Crab pulsar; however, a physical theory of charged soliton radiation does not yet exist.

Author(s): Joanna M. Rankin[1]
Institution(s): *1. Univ. of Vermont*

109.06 – Recent results of the NANOGrav Physics Frontiers Center

The NANOGrav Physics Frontiers Center uses the Arecibo Observatory and the Green Bank Telescope (the two most sensitive radio telescopes in the world) to monitor high-precision millisecond pulsars. Our goal is to directly detect low frequency gravitational waves, which cause small correlated changes in the times of arrival of radio pulses from pulsars, and use them to study the low-frequency gravitational-wave universe. Our access to these observatories has allowed us to reach unprecedented sensitivities and we expect to make a detection soon. In this talk I will discuss the most recent results of our searches for gravitational waves in pulsar timing data.

Author(s): Xavier Siemens[1]
Institution(s): *1. University of Wisconsin -- Milwaukee*
Contributing team(s): NANOGrav Physics Frontiers Center

110 – Geoengineering the Atmosphere to Fight Climate Change: Should Astronomers Worry about It?

The AAS Sustainability Committee invites you to attend this Special Session on an issue that may be of growing concern to astronomers: "geoengineering", or large-scale engineering plans to modify the atmosphere in an attempt to offset the effects of global warming, such as by injecting aerosols globally to reflect sunlight. The session will be run in an interactive debate and panel forum format. Several researchers studying geoengineering, including astronomers, will present widely divergent views on the merits and risks of geoengineering and other climate interventions, both for ground-based astronomy, which of course must peer through the atmosphere, and for the long-term stability of the Earth's climate system. There will be ample time for Q and A discussion between attendees and the panelists.

111 – HAD II: Some Notes on the History of

Infrared Astronomy from Above the Atmosphere

111.01 – From Single Pixels to Many Megapixels: Progress in Astronomical Infrared Imaging from Space-borne Telescopes

In the 1960s, rocket infrared astronomy was in its infancy. The Cornell group planned a succession of rocket launches of a small cryogenically cooled telescope above much of the atmosphere. Cornell graduate students were tasked with hand-making single pixel detectors for the focal plane at wavelengths ranging from ~5 microns to just short of 1 mm. “Images” could only be constructed from scans of objects such as HII regions/giant molecular clouds, the galactic center, and of diffuse radiation from the various IR backgrounds. IRAS and COBE, followed by the KAO utilized ever more sensitive single IR detectors, and revolutionized our understanding of the Universe. The first IR arrays came onto the scene in the early 1970s – and in 1983 several experiments for the space mission SIRTF (later named Spitzer Space Telescope following launch 20 years later) were selected, all boasting (relatively small) arrays. Europe’s ISO and Herschel also employed arrays to good advantage, as has SOFIA, and now, *many*-megapixel IR arrays are sufficiently well-developed for upcoming space missions.

Author(s): Judith Pipher[1]
Institution(s): *1. Univ. of Rochester*

111.02 – NASA’s Kuiper Airborne Observatory 1974-1995 - Twenty One Years of Discovery

The Gerard P. Kuiper Airborne Observatory (KAO) forged a unique record in the annals of astronomy. Teams of scientists developed and flew with their specialized, state-of-the-art instruments to make observations not possible from the ground, at wavelengths from 0.3 µm to 1.6 mm. The talk will describe the KAO and its legacy of scientific findings, infrared instrumentation technology, experience for young astronomers and their impact on the field of infrared astronomy – and the rationale for SOFIA.

Author(s): Edwin F. Erickson[1]
Institution(s): *1. NASA Ames Research Center*

111.03 – Small Can Be Beautiful: The NASA Lear Jet and the Initiation of Astronomical Far-Infrared Fine-Structure-Line Spectroscopy

In the early 1970s, NASA offered infrared astronomers two new facilities --- a 30-cm telescope aboard the NASA Lear Jet, and a 91-cm telescope aboard the Kuiper Airborne Observatory --- for conducting far-infrared astronomical observations from altitudes ranging up to 12 km above sea level. Here I will describe the exceptional opportunities the Lear Jet offered our community for advancing the study of both cool/neutral and hot/ionized interstellar clouds through studies of previously inaccessible atomic and ionic far-infrared fine-structure cooling lines.

Author(s): Martin Harwit[1]
Institution(s): *1. Cornell University*

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112 – The Solar System

112.01 – Creating an Isotopically Similar Earth and Moon from a Giant Impact with Correct Angular Momentum

The giant-impact hypothesis is the dominant theory as to how the Earth-Moon system was formed, but angular momentum concerns have cast a shadow on its validity. Computer generated impacts have been successful in producing virtual Earth-Moon systems that possess many of the properties of the observed system, but when tasked with addressing the isotopic similarities between the Earth and Moon they result in systems with excessive angular momentum. Evection resonance between the Moon and the Sun has been put forth as a means of removing the excess angular momentum, but this reasoning was rejected by The Royal Society at a special session called to discuss the origin of the Moon. We show here how to use impactor spins to create an impact that preserves all the favorable aspects of previous simulations and produces an Earth-Moon system with the correct angular momentum. Evection resonance is not needed.

Author(s): William Sumpter[1]
Institution(s): *1. Tarleton State University*

112.02 – Dynamics of the Giant Planets due to a Fully Self-gravitating Planetesimal Disk

Specific features of our solar system can be well-explained with an early orbital instability among the giant planets driven by interactions between the planets and a massive planetesimal disk. These features include the the dynamical architecture of the Trans-Neptunian objects and the 'Late Heavy Bombardment' inferred from the lunar cratering record. Most previous studies of this process have been forced to neglect the interactions between members of the primordial planetesimal disk, but advances in GPU accelerated dynamical modelling have allowed us to perform simulations of the giant planet instability that include fully self-interacting disk. With these simulations, we explore the timing and mass conditions for the giant planet instability using different versions of the Nice model that include up to six giant planets. Using a large ensemble of numerical simulations of this giant planet instability, we directly model the evolution of the giant planets and a massive planetesimal disk. In particular, we seek to determine what sets of initial conditions do and do not permit a delayed scattering event on the correct timescale to be attributed to a `Late Heavy Bombardment'.

Author(s): Billy L. Quarles[1], Nathan A. Kaib[1]
Institution(s): *1. University of Oklahoma*

112.03 – Sources of Chaos in Planetary Systems Formed Through Numerical Methods

The formation of the solar system’s terrestrial planets has been numerically modeled in countless works, and many other studies have been devoted to char- acterizing our modern planets’ chaotic dynamical state. However, it is still not known whether our planets fragile chaotic state is an expected outcome of terrestrial planet accretion. We use a large suite of numerical simulations to present a detailed analysis and characterization of the dynamical chaos in 145 different systems produced via terrestrial planet formation in Kaib & Cowan (2015). These systems were created in the presence of a fully formed Jupiter and Saturn, using a variety of different initial conditions. We provide the first analysis of the dynamical states of fully evolved (4.5 Gyr) planetary systems formed using numerical simulations. We find that dynamical chaos is preva- lent in roughly half of the systems, with the largest source of the chaos being perturbations from Jupiter. Chaos is most prevalent in systems that form 4 or 5 terrestrial planets. Additionally, an eccentric Jupiter and Saturn is shown to enhance the prevalence of chaos in systems. Furthermore, systems with a center of mass highly concentrated between 0.8–1.2 AU generally prove to be less chaotic than systems with more exotic mass distributions. Through the process of evolving systems to the current epoch, we show that late instabilities are quite common in our systems. Of greatest interest, many of the sources of chaos observed in our own solar system (such as the secularly driven chaos between Mercury and Jupiter) are shown to be common outcomes of terrestrial planetary formation. Thus, the solar system’s marginally stable, chaotic state may naturally arise from the process of terrestrial planet formation.

Author(s): Matthew S Clement[1]
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112.04 – Assessing the Main-Belt Comet Population with Comet Hunters

Cometary activity in the asteroid belt is a recent discovery. Evidence suggests recent collisions play a role excavating subsurface water ice in these Main Belt Comets (MBCs). MBCs may be an alternative source of Earth's water. The properties and origins of the MBCs remain elusive. To date ~15 MBCs are known, but only with many tens to 100s of MBCs can we fully explore this new reservoir and its implications for the early Earth.

Automated routines identify cometary objects by comparing the point spread functions (PSFs) of moving objects to background stars. This approach may miss cometary activity with low-level dust comae or trails that are too weak or extended to affect an object's near-nucleus PSF profile. Direct visual inspection of moving objects by survey team members can often catch such unusual objects, but such an approach is impractical for the largest surveys to date, and will only become more intractable with the next generation wide-field surveys.

With the Internet, tens of thousands of people can be engaged in the scientific process. With this citizen science approach, the combined assessment of many non-experts often equals or rivals that of a trained expert and in many cases outperforms automated algorithms. The Comet Hunters (http://www.comethunters.org) project enlists the public to search for MBCs in data from the Hyper Suprime-Cam (HSC) wide survey. HSC is to date the largest field-of-view camera (covering a 1.5 degree diameter circle on sky) on a 8-10-m class telescope. The HSC wide survey provides the sensitivity to detect cometary activity at lower levels than have been possible for previous surveys.

We will give an overview of the Comet Hunters project. We will present the results from the first ~10,000 HSC asteroids searched and provide an estimate on the frequency of cometary activity in the Main Asteroid belt

Acknowledgements: This work uses data generated via the Zooniverse.org platform, development of which was supported by a Global Impact Award from Google, and by the Alfred P. Sloan Foundation. The HSC collaboration includes the astronomical communities of Japan and Taiwan, and Princeton University.

Author(s): Megan E. Schwamb1, Henry H. Hsieh3, Zhi-Wei Zhang2, Ying-Tung Chen2, Chris Lintott4, Shiang-Yu Wang2, Ishan Mishra2
Institution(s): *1. Gemini Observatory, 2. Institute of Astronomy & Astrophysics, Academia Sinica (ASIAA), 3. Planetary Science Institute, 4. University of Oxford*

112.06 – An Empirical Examination of the NEOWISE Results and Data analysis

Asteroid observations by the WISE space telescope and accompanying analysis by the NEOWISE project have provided information about the diameter, albedo, and other properties of approximately 157,000 asteroids—more than all prior sources combined. The raw data set from this mission is one of the largest and most important of its kind, and it will likely remain so for many years. Properly harnessing this treasure trove of data requires an understanding of its strengths and weaknesses, as well as application of clear and reproducible methods for analyzing the data. The NEOWISE group's methods of data analysis are re-examined, and systematic issues are found in raw data processing, thermal modeling, model fitting, and error analysis. Moreover, NEOWISE (along with previous asteroid studies) does not correctly account for Kirchhoff's law. An empirical analysis of the data using Monte Carlo simulations is used to show that violation of Kirchhoff's law causes increased error in diameter estimates and erroneous values for the near-IR albedo . Furthermore, most NEOWISE "best-fit" curves do not pass near the data points they purport to fit. As a separate issue, for 123 cases the diameter estimates published as NEOWISE fits are identical to prior results from radar, stellar occultation, and spacecraft visits, raising the possibility that some NEOWISE values were not derived independently. These results suggest that asteroid science would benefit from further analysis of WISE/NEOWISE data.

Author(s): Nathan P Myhrvold1
Institution(s): *1. Intellectual Ventures*

112.07 – Observing near-Earth objects with LBT

The Large Binocular Telescope (LBT), with its twin comounted 8.4-meter telescopes, has a unique potential for observations of faint and fast moving objects. Thanks to a collaboration between INAF-Observatory of Rome and the ESA SSA-NEO Coordination Centre, over the past years we were able to use the telescope to obtain a few challenging observations of Near-Earth Objects (NEOs), which clearly demonstrated the potential of the system. From an astrometric perspective, LBT is one of the very few 8-meter-class telescopes equipped with a wide-field imager. Its Large Binocular Cameras (LBCs), mounted on each "eye" of the telescope and optimized to be sensitive to the blue and red side of the visible spectrum, each cover approximately 23'x25', allowing easy recoveries of large-uncertainty objects by covering a wide area of the sky with a single exposure. At the same time, the acquisition of simultaneous images by the two telescopes is extremely useful to cross-validate detections in case of extremely faint targets. The excellent non-sidereal tracking is also useful when observing fast moving targets. We will present our recovery observations of very faint asteroid 2014 KC46, the first observation of an NEO with impact solutions obtained with the telescope, which led to the removal of all impact solutions for the object.
We exploited the exceptional capabilities of LBT for physical observations in the framework of the EU NEOShield-2 project aimed at obtaining taxonomical information on NEOs. The large aperture of the two telescopes allows color observations of faint NEOs, and the possibility of simultaneous imaging in two passbands through the two eyes allows for instantaneous color determination without the need for lightcurve corrections, making the process more accurate and significantly more efficient in terms of telescope time. We will present some results of color photometry obtained with LBT, and in particular we will discuss the case of 333P/2007 VA85, the first case of transient retrograde NEO. Originally classified as an asteroid, it was observed in March 2016 with a large cometary coma and presents a complex coma morphology and a peculiar color distribution.

Author(s): Marco Micheli2, Elisabetta Dotto5, Elena Mazzotta Epifani5, Olivier Hainaut3, Simone Ieva5, Andrea Di Paola5, Gerhard Hahn1, Detlef Koschny2, Ettore Perozzi2, Roberto Speziali5, Giovanni B. Valsecchi4
Institution(s): *1. DLR, 2. ESA SSA-NEO Coordination Centre, 3. ESO, 4. INAF-IAPS, 5. INAF-OAR*

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113 – Intergalactic Medium, QSO Absorption Line Systems

113.01 – Limits on Intergalactic Dust during Reionization

We constrain the dust-to-gas ratio in the intergalactic medium (IGM) at high redshifts. We employ models for dust in the local universe to constrain the dust-to-gas ratio during the epoch of reionization at redshifts z~6-10. The observed level of reddening of high redshift galaxies implies that the IGM was enriched to an intergalactic dust-to-gas ratio of less than 3% of the Milky Way value by a redshift of z = 10.

Author(s): Nia Imara1, Abraham Loeb1
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113.02D – The Vulture Survey: Analyzing the Evolution of MgII and CIV Absorbers

We present the results of an archival VLT/UVES and Keck/HIRES quasar absorption line survey. We examine over 600 quasar lines of sight in order to inventory the cosmic properties of MgII and CIV absorbers. We employ an accurate, automated approach to line detection which consistently detects absorption lines with rest-frame equivalent widths less than 0.02 Å in S/N > 40 spectra. We determine redshift path densities, equivalent width and column density distributions, and cosmic mass densities as a function of redshift. We find that the evolution in the universal distribution of this metal absorbing gas correlates strongly with the cosmic star formation history of galaxies. We measure a significant enhancement in the comoving opacity of strong MgII and CIV absorbers around z=2. We also measure the pixel two-point velocity correlation function and find broader, higher velocity signatures around z=2. We examine possible causes for these trends, and determine that at z=2 galaxies transport significantly higher quantities of metal enriched gas into and out of their halos through star formation than at other times.

Author(s): Nigel Mathes[1], Christopher W. Churchill[1], Michael Murphy[2]
Institution(s): *1. New Mexico State University, 2. Swinburne University of Technology*

113.03 – Searching for Variability of NV Intrinsic Narrow Absorption Line Systems

The majority of quasar absorption line systems with NV detected are found within the associated region (within 5000km/s of the quasar redshift) and many/most are believed to be related to the quasar accretion disk wind or outflows. The most definite evidence that these NV absorbers are "intrinsic" is partial covering of the quasar continuum source and/or broad line region. Over 50 quasars containing NV narrow absorption lines have observations obtained at different times with the Keck/HIRES and the VLT/UVES spectrographs at high resolution. The interval between these observations range from months to a decade in the quasar rest frame. While variability is common for intrinsic broad and mini-broad absorption lines, intrinsic narrow absorption lines have been found to be less likely to vary, though systematic studies with large, high quality datasets have been limited. The variability timescales are useful for deriving gas densities and thus the distances from the central engines. This is important in mapping the quasar surroundings, understanding the accretion disk wind mechanism, and assessing the effect the wind has on the galaxy surroundings. We report on the results of a systematic study of variability of NV NALs, exploiting the overlap of targets for observations in the archives of Keck and VLT, and discuss the consequences for interpretation of the origin of intrinsic narrow absorption lines.

Author(s): Michael Rodruck[1], Jane C. Charlton[1], Rajib Ganguly[2]
Institution(s): *1. Penn State University, 2. University of Michigan-Flint*

113.04D – Galaxy-environment Interactions as Revealed by the Circumgalactic Medium

Galaxies do not live in isolation, and their star formation activity and gas supply are closely tied to the density of the environment in which they reside. The circumgalactic medium (CGM) serves as the point of first contact between a galaxy and its environment and mediates the gas accretion and outflow processes that regulate the galaxy ecosystem. Employing a combination of ultraviolet QSO spectroscopy, optical galaxy surveys, and X-ray imaging and spectroscopy, I will show that the metal-enriched gas and cool, photoionized H I in the CGM gas reflect the galaxy's large-scale environment from scales of modest groups to clusters. Thus, QSO absorption line spectroscopy provides uniquely sensitive multiphase gas diagnostics of the physical conditions at the sites of galaxy-environment interactions. By shock-heating or stripping the CGM gas, as is indicated by its absorption, these interactions may deplete or deprive the galaxy's gas supply and quench its star formation.

Author(s): Joseph Burchett5, Todd M. Tripp5, Daniel Wang5, Christopher Willmer[2], Jason X. Prochaska4, Jessica Werk[6], Rongmon Bordoloi[1], Neal Katz5, Jason Tumlinson3
Institution(s): *1. MIT, 2. Steward Observatory (U. of Arizona), 3. STScI, 4. UC-Santa Cruz, 5. University of Massachusetts, 6. University of Washington*

113.05 – The Metallicity of the Circumgalactic Medium of z<1 Galaxies: How low can you go?

Accretion from the intergalactic medium and large-scale outflows are thought to drive a galaxy's evolution, including its star formation rate and its metal content. Studying the circumgalactic medium (CGM), the host of these processes, provides insights into the balance of these competing mechanisms. The cool, dense CGM has integrated H I column densities typical of optically-thick Lyman limit systems (LLSs, 17.2 <= log N(H I) < 19.0) and optically-thin partial-LLSs (pLLSs, 16 < log N(HI) < 17.2). With our Cosmic Origins Spectrograph (COS) survey of 44 pLLSs and 11 LLSs at z<1, we show that the metallicity distribution of the pLLSs is bimodal, with peaks at 1.3% and 48% of the solar metallicity. This strengthens our earlier findings and demonstrates unambiguously that low-metallicity gas is prevalent around z<1 galaxies, which provides the best-yet observational evidence for cold accretion flows like those present in numerical simulations of galaxies. For the LLSs, the sample is still small but there is a hint that the metallicity distribution changes to a unimodal distribution. It is also in this N(HI) regime that we found the lowest metallicity LLS at z<1, with <0.3% solar metallicity. Here I will present briefly these early results as well as our ongoing follow-up survey of ~40 strong pLLSs/LLSs (16.9 <= log N(H I) < 18.5) where we are systematically estimating the metallicity with COS and ground-based MgII spectra. With this new sample, we will robustly determine the metallicity distribution of the LLSs and how frequently extremely low-metallicity gas (<0.3% solar metallicity) is present at z<1. This extremely low-metallicity gas could be possible evidence for remnants of Population III enrichment at low redshift, and only in the LLS regime is the HI absorption strong enough to be sensitive to <0.3% solar metallicity.

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Institution(s): *1. Saint Michael's College, 2. UC, Santa Cruz, 3. University of Notre Dame*

114 – Elliptical & Spiral Galaxies

114.01D – The Black Hole Mass – Pitch Angle Relation of Type I AGN In Spiral Galaxies

A relationship between the mass of supermassive black holes, M, at the center of galaxies and the pitch angle, P, a measure of tightness of spiral arms, was recently reported by Berrier, et al. (2013 ApJ 769, 132) for late type galaxies. The relationship, established for a local sample, shows that spiral galaxies with tighter pitch angles host higher mass black holes. In this work, we explore the M-P relation for a sample of 50 low to moderate redshift (0.04<z<1.4) spiral galaxies that host Type 1 Active Galactic Nuclei, AGN. These objects were selected from the SDSS quasar catalog and various studies involving HST imaging. Broad Hβ, Hα, and MgII and narrow [OIII]λ5007 emission lines were used with established mass scaling relations to estimate black-hole mass. Pitch angles were measured using a 2DFFT technique (Davis, et al., 2012 ApJS 199, 33). We find that the M-P relation for the higher redshift, AGN sample differs from that of the local sample and discuss the possibility of AGN feedback by looking at a proposed Fundamental Plane for late-type galaxies - a correlation between bulge mass, disk mass, and spiral-arm pitch angle (Davis, et al. 2015, ApJ 802, L13).

Author(s): Amanda Schilling[1], Logan Jones3, John A. Hughes[1], R. Scott Barrows[2], Julia D. Kennefick[1]
Institution(s): *1. University of Arkansas, Fayetteville, 2. University of Colorado Boulder, 3. University of Wisconsin - Madison*

114.02D – Spirality: A Noval Way to Measure Spiral Arm Pitch Angle

We present the MATLAB code Spirality, a novel method for measuring spiral arm pitch angles by fitting galaxy images to spiral templates of known pitch. Computation time is typically on the order of 2 minutes per galaxy, assuming 8 GB of working memory. We tested the code using 117 synthetic spiral images with known pitches, varying both the spiral properties and the input parameters. The code yielded correct results for all synthetic spirals with galaxy-like properties. We also compared the code's results to two-dimensional Fast Fourier Transform (2DFFT) measurements for the sample of nearby galaxies defined by DMS PPak. Spirality's error bars overlapped 2DFFT's error bars for 26 of the 30 galaxies. The two methods' agreement correlates strongly with galaxy radius in pixels and also with i-band magnitude, but not with redshift, a result that is consistent with at least some galaxies' spiral structure being fully formed by z=1.2, beyond which there are few galaxies in our sample. We also analyze apparent spiral structure of three galaxies beyond z=2. The Spirality code package also includes GenSpiral, which produces FITS images of synthetic spirals, and SpiralArmCount, which uses a one-dimensional Fast Fourier Transform to count the spiral arms of a galaxy after its pitch is determined.

Author(s): Douglas Shields[1]
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Contributing team(s): Arkansas Galaxy Evolution Survey

114.03D – Strong Evidence for the Density-Wave Theory of Spiral Structure Based on Variations in Pitch Angle When Viewed Across Optical and non-Optical Wavelengths

The density-wave theory of spiral structure, though first proposed as long ago as the mid-1960s by C.C. Lin and F. Shu, continues to be challenged by rival theories, such as the manifold theory. One test between these theories which has been proposed is that the pitch angle of spiral arms for galaxies should vary with the wavelength of the image in the density wave theory, but not in the manifold theory. Density waves are believed to create a spiral-shaped region of star formation in the gas of galactic disks. Stars born in the spiral arms of the galaxies move ahead of the density wave inside the co-rotation radius, and fall behind outside of it. This implies that stars should exhibit tighter arms than the density wave itself does. Thus wavelengths which image starlight should have measurably tighter pitch angles than wavelengths which image the star forming region itself (inside of which most starlight is obscured by gas and dust). Previous work, restricted to optical or near-optical wavelengths, either failed to find any significant variation in pitch angle or only limited evidence for it in two or three cases.
In this research, we took advantage of Spitzer and GALEX data to measure pitch angles of infrared and ultraviolet, in addition to optical, images of galaxies. We also used a larger sample size than any previously used to study this issue. For each galaxy we used four images with different pass bands (B-Band at around 445 nm, infrared at 3.6 and 8.0μm and ultraviolet at 151nm) and we measured the pitch angle in each of the four wavelengths with two independent algorithms (the 2DFFT code and Spirality). Each wavelength that we used images a different component or population of the disk. We find that for both sets of measurements (2DFFT and Spirality) the 8.0 micron and ultraviolet images agree in their pitch angle measurements, suggesting that they are, in fact, sensitive to the same region. By contrast the 3.6 micron and B-band images are uniformly tighter in pitch angle measurements than these wavelengths, suggesting that the density wave picture is correct.

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114.04 – On the Origin of Exponential Radial Profiles in Galaxy Disks

Exponential radial profiles are ubiquitous in galaxy disks with radial extents sometimes reaching 10 scale lengths or more. Proposed origins include stellar scattering off of bars and spirals, but unbarred, spiral-free dwarf irregular galaxies have exponential profiles too. We propose that the origin of this structure is related to stellar scattering off of interstellar structures, such as clouds and holes. We show 3D simulations and analytical derivations of this effect. The key seems to be the prevalence of random stellar scattering with an average inward bias. The scale length is derived in terms of this bias and the mean free path for scattering. Connections between the theory and observations will be discussed.

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114.05 – Measuring the extent of x-ray emitting hot gas haloes around elliptical galaxies

The hot, x-ray emitting gas halos around galaxies can serve as tracers of previous merger history, and provide insight into the formation processes of elliptical galaxies. In order to better understand the relationship between a galaxy's local environment and its x-ray emitting hot gas corona, we examine the x-ray emission from 117 early type galaxies selected from SDSS DR12 that have been observed with Chandra's ACIS detector. We have developed a new methodology for determining the effective and Petrosian radii of the x-ray emission from the hot coronae of these galaxies, and with it find a positive correlation between fifth nearest neighbour density and corona size. Notably, we do not see a corresponding correlation between size and other galaxy properties such as mass, r-band Petrosian radius, and metallicity. These results suggest that the physical processes that drive the extension of the hot gas halo do not significantly influence the stellar content of the elliptical galaxy.

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114.06 – Circumnuclear Disks in Early-type Galaxies: 12CO(2-1) and Continuum Properties

Black hole masses in early-type galaxies (ETGs) can be precisely measured using the kinematics of circumnuclear gas. About 10% of nearby ETGs possess round, morphologically regular nuclear dust disks. The accompanying molecular gas is expected to be in uniform, circular rotation and therefore be a good dynamical tracer of the inner galaxy potential. Using ALMA, we have obtained 0.3”-resolution observations of thirteen ETGs which were selected based on the presence of nuclear dust disks seen in HST images. Most are detected in CO(2-1), and we find that these molecular gas disks are in dynamically cold rotation with a few showing clear evidence of rapid central rotation. We present the gas distributions and kinematics of these molecular disks, as well as the continuum properties of the dusty disks and the prevalence of low-luminosity active galactic nuclei at their centers. We discuss the suitability of molecular gas disks in ETGs for making precision measurements of black hole masses.

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115 – Supernovae & Planetary Nebulae

115.01 – SuperNovae Analysis aPplication (SNAP): A revolutionary method for understanding the physics of supernovae

The explosive death of massive stars, known as supernovae (SNe), are responsible for chemically enriching the universe in heavy elements. Presently, we discover ~300 SNe per year. By 2020 new all sky surveys will be on-line and this will increase to 100,000 discovered annually. How do we know which need follow up observations? Additionally, the mechanics and physics of the explosion itself are not solved problems. With more sophisticated models, we need a rapid way to compare to observations. SNAP is a comparative data base system that contains archived observations, light curve models, and correlation software. Newly discovered SNe can be input and immediately compared to all available models. Alternately, new models can be correlated against available observations. Thus, we will be able to study SNe events as a class to determine degeneracies in parameters and determine the important physics needed to describe these catastrophic events.

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115.02D – Fermi and Swift as supernova alarms: Alert, localization, and diagnosis of future Galactic Type Ia explosions

A Galactic SNIa event could go entirely unnoticed due to the large optical and near-IR extinction in the Milky Way plane, low radio and X-ray luminosities, and a weak neutrino signal. But the recent SN2014J confirms that Type Ia supernovae emit nuclear γ- ray lines, from the ^{56}Ni → ^{56}Co → ^{56}Fe radioactive decay. The energy released in these decays powers the SNIa UVOIR light curve at times after ~1 week, leading to an exponential decline. Importantly for Swift and Fermi, these decays are accompanied by γ-ray line emission, with distinct series of lines for both the ^{56}Ni and ^{56}Co decays, spanning 158 keV to 2.6 MeV. These lines are squarely within the Fermi/GBM energy range, and the ^{56}Ni 158 keV line is detectable by Swift/BAT. The Galaxy is optically thin to γ-rays, so the supernova line flux will suffer negligible extinction. Both GBM and BAT have continuous and nearly all-sky coverage. Thus GBM and BAT are ideal Galactic SNIa monitors and early warning systems. We will illustrate expected GBM and BAT light curves and spectra, based on our model for SNIa γ-ray emission and transfer. We show that the supernova signal emerges as distinct from the GBM background within days after the explosion in the SN2014J shell model. Therefore, if a Galactic SNIa were to explode, there are two possibilities of confirming and sounding the alert: 1) Swift/BAT discovers the SNIa first and localizes it within arcminutes; 2) Fermi/GBM finds the SNIa first and localizes it to within ~1 degree, using the Earth occultation technique, followed up by BAT to localize it within arcminutes. After the alert of either BAT or GBM, Swift localizes it to take spectra in optical, UV, soft and hard X-rays simultaneously with both XRT and UVOT instruments.

Author(s): Xilu Wang[2], Brian D. Fields[2], Amy Y. Lien[1]
Institution(s): *1. NASA Goddard Space Flight Center, 2. University of Illinois at Urbana-Champaign*

115.03D – Decontaminating Cosmology: Towards Measuring Dark Energy with Photometrically Classified Pan-STARRS Supernovae

The Pan-STARRS (PS1) Medium Deep Survey discovered over 5,000 likely supernovae (SNe) but obtained spectral classifications for just 10% of its SN candidates. We measured spectroscopic host galaxy redshifts for 2,979 of these likely SNe and estimate that ~1,100 are Type Ia SNe (SNe Ia) with light-curve quality sufficient for a cosmological analysis. We then use these data with simulations to determine the impact of core-collapse SN (CC SN) contamination on measurements of the dark energy equation of state, w. With the method of Bayesian Estimation Applied to Multiple Species (BEAMS), we can simultaneously determine distances to SNe Ia and the contaminating CC SN distribution as a function of redshift. We use light-curve based SN classification priors for BEAMS as well as a new classification method based on host galaxy spectra and the association of SN type with host type. From simulations of 1,000 PS1 SNe, we find that w is biased by just -0.005 due to CC SN contamination, 10% of its statistical uncertainty. By applying several independent SN classification methods and CC SN parameterizations, we estimate w can be measured with a systematic error of 0.014, 30% of the statistical uncertainty on w. We find that BEAMS determines the SALT2 color and shape coefficients, α and β, and the SNIa dispersion with ~1σ bias. We also draw Monte Carlo samples from real PS1 SNe without spectroscopic classifications and find measurements of w from these SNe are fully consistent with the PS1 spectroscopic sample. Finally, the abundance of bright CC SNe in our sample implies that the luminosity functions of Ia-like CC SNe may be ~1 mag brighter than expected from previous measurements.

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115.04 – K2 High-cadence Light Curves of Transients

I will give an overview of the Kepler Extra-Galactic Survey (KEGS), a program using Kepler to search for supernovae, active galactic nuclei, and other transients in galaxies. To date we have found 22 supernova, and with 2 more years (through 2018) planned, including the forward-facing C16/C17, we hope to discover 20 - 30 more SN. The 30-minute cadence of Kepler has reveales subtle features in the light-curves of these supernova not detectable with any other survey, including, shock break-out in a large number of SN, improving our understanding of supernova progenitors. We can also search in nearby galaxies for very fast and faint transients, filling in a previously unaccessible parameter space.

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115.05 – New extended gamma-ray sources in the Galactic Plane using 6 years of Fermi Large Area Telescope data above 10 GeV

Although many of the Galactic sources found at GeV energies using the Fermi Large Area Telescope are unresolved pulsars, the majority of Galactic gamma-ray sources found at TeV energies are associated with pulsar wind nebulae and supernova remnants. Additionally, many of these sources are close enough and large enough to be resolved. Their extended spatial structures trace the regions where electrons and, in some cases, ions are accelerated to high energy and interact with surrounding matter and radiation fields. The advent of the LAT Pass 8 data, which enhances acceptance and angular resolution, supports greater sensitivity for the detection of extended sources in the energy regime where supernova remnants and pulsar wind nebulae are expected to become prominent. We present the results of a search specifically targeting extended sources located within 7 degrees of the Galactic Plane using 6 years of Pass 8 LAT data above 10 GeV. We find 46 extended sources in this band, 15 of them newly detected as extended, and characterize their morphological and spectral properties. This constitutes the first catalog of hard-spectrum, extended LAT sources, and allows a thorough study of the properties of Galactic sources in the sub-TeV domain.

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Contributing team(s): Fermi LAT Collaboration

115.06D – Spatial Analysis of Spectra from Galactic Planetary Nebulae and Extragalactic H II Regions: Testing for Abundance Variations

Presented here is a spatial analysis of spectra for seven planetary nebulae (NGC 2440, NGC 3242, NGC 5315, NGC 5882, NGC 7662, IC 2165, and IC 3568) as well as H II regions from six nearly face-on, spiral galaxies (NGC 2403, NGC 3310, NGC 4321, NGC 5194, NGC 5236, and NGC 5457). The two main goals of the study were (1) to investigate whether or not each planetary nebula (PN) is chemically homogeneous; and (2) to search for evidence of azimuthal abundance gradients in the disks of the galaxies. Each of these test the validity of assumptions commonly made for these two object types, i.e., (1) Ejecta from asymptotic giant branch stars are well mixed and (2) elements returned to the interstellar medium of a spiral galaxy are “instantaneously” distributed around the disk for a fixed distance from the center.

The PN homogeneity problem was addressed by spatially dividing each long-slit HST/STIS spectrum into many smaller regions across each object and calculating the abundances of each region. The major result is that the ejecta are indeed homogeneous in each planetary nebula for the elements probed. A secondary goal was to constrain the temperature and luminosity of each PN central star, which was accomplished by modeling each object using the photoionization code CLOUDY.
The spectra for the galaxies are from the VIRUS-P spectrograph, an integral field unit consisting of 246 fibers arranged in a square, with the observations centered on or near the nuclear bulge, covering a full 360 degrees around each galaxy and encompassing numerous H II regions located near the bulge. Additional goals for each galaxy included obtaining radial abundance gradients and accurate carbon and neon abundances for high metallicity H II regions.

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116 – Planetary Environments & Habitability

116.02D – The UV Surface Environment on Young Planets: Implications for Prebiotic Chemistry & Life on Other Worlds

Understanding the origin of life (abiogenesis) on Earth is key to understanding how it might start elsewhere. Recent laboratory studies suggest UV light may have played a critical role in the synthesis of molecules relevant to abiogenesis (prebiotic chemistry), such as RNA. I show that UV light interacts with prebiotic chemistry in ways that may be sensitive to the spectral shape and overall amplitude of irradiation. I use radiative transfer models to constrain the UV environment on early Earth (3.9 Ga). I find that the surface UV is insensitive to much of the considerable uncertainty in the atmospheric state, enabling me to constrain the UV environment for prebiotic chemistry on early Earth. Some authors have suggested Mars as a venue for prebiotic chemistry. Therefore, I explore plausible UV spectral fluences on Mars at 3.9 Ga. I find that the early Martian UV environment is comparable to Earth's under conventional assumptions about the atmosphere. However, if the atmosphere was dusty or SO_2 levels were high, UV fluence would have been strongly suppressed. Intriguingly, despite overall attenuation of UV fluence, SO_2 preferentially attenuates destructive FUV radiation over prebiotically-useful NUV radiation, meaning high-SO_2 epochs may have been more clement for the origin of life. Better measurements of the spectral dependence of prebiotic photoprocesses are required to constrain this hypothesis. Finally, I calculate the UV fluence on planets orbiting M-dwarfs. I find that UV irradiation on such planets is low compared to Earth. Laboratory studies are required to understand whether prebiotic photoprocesses that worked on Earth can function on low-UV M-dwarf planets. My work 1) provides initial conditions for laboratory studies of prebiotic chemistry, 2) constrains the inhabitability of Mars and planets orbiting M-dwarfs, and 3) demonstrates the need for laboratory studies to characterize the impact of variations in irradiating intensity and spectral shape on prebiotic photochemistry. All software associated with these studies, including models and data inputs, are publically available for validation and extension. I acknowledge support from the NSF GRFP and the Simons Foundation.

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Contributing team(s): Simons Collaboration on the Origin of Life, Harvard Origins of Life Initiative

116.03 – Habitability in the Local Universe

Long term habitability on the surface of planets has as a prerequisite a minimum availability of elements to build rocky planets, their atmospheres, and for life sustaining water. They must be within the habitable zone and avoid circumstances that cause them to lose their atmospheres and water. However, many astrophysical sources are hazardous to life on the surfaces of planets. Planets in harsh environments may require strong magnetic fields to protect their biospheres from high energy particles from the host star(s). Planets in harsh environments may additionally require a strong astrosphere to be sufficiently able to deflect galactic cosmic-rays. Supernovae (SNe) play a central role in the habitability of planets in the disks of star forming galaxies. Currently, the SNe rate maintains a relativistic galactic wind shielding planets in the disk from extragalactic cosmic rays. However, if the density of SNe in the disk of the galaxy were significantly higher, as it was 6-8 GYA, the frequency of nearby catastrophic events and often prolonged harsh environment may have strongly constrained life in the early history of the Milky Way. Active galactic nuclei (AGN) may remain quiescent for hundreds of millions of years only to activate for some time due extraordinary accretion episode due to for instance a galactic merger. The starburst galaxy M82 is currently undergoing a merger, probably strongly compromising habitability within that galaxy. The giant elliptical M87 resides in the center of the Virgo supercluster and has probably consumed many such spiral galaxies. We show that super-Eddington accretion onto the supermassive black hole in M87, even for a short while, could compromise the habitability for a large portion of the central supercluster. We discuss environments where these effects may be mitigated.

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116.04 – The Breakthrough Listen Initiative and the Future of the Search for Intelligent Life

Unprecedented recent results in the fields of exoplanets and astrobiology have dramatically increased the interest in the potential existence of intelligent life elsewhere in the galaxy. Additionally, the capabilities of modern Searches for Extraterrestrial Intelligence (SETI) have increased tremendously. Much of this improvement is due to the ongoing development of wide bandwidth radio instruments and the Moore's Law increase in computational power over the previous decades. Together, these instrumentation improvements allow for narrow band signal searches of billions of frequency channels at once.
The Breakthrough Listen Initiative (BL) was launched on July 20, 2015 at the Royal Society in London, UK with a charge to conduct the most comprehensive and sensitive search for advanced life in humanity's history. Here we detail important milestones achieved during the first year of the program, describe the key BL SETI surveys and briefly describe current facilities, including the Green Bank Telescope, the Automated Planet Finder and the Parkes Observatory.
Complementary to the BL initiative (at a smaller scale), pioneering SETI work at low radio frequencies (20-250 MHz) is being undertaken with the LOw Frequency ARray (LOFAR). This program uses simple fixed-stationary antennas and multiple phased-array beams formed in a supercomputer to search many targets at once and will lay the groundwork for future searches with SKA1-low and mid frequency aperture array pathfinders. We will present the results of a volume complete sample of nearby stars (< 5pc) observed with LOFAR, searching for drifting narrow band signals with expected Doppler drifts covering a wide range of potential transmitter host planets.
We conclude with a brief view towards future SETI searches with upcoming next-generation radio facilities such as SKA and ngVLA.

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116.05D – The Search for Stellar Coronal Mass Ejections

Coronal mass ejections (CMEs) may dramatically impact habitability and atmospheric composition of planets around magnetically active stars, including young solar analogs and many M dwarfs. Theoretical predictions of such effects are limited by the lack of observations of stellar CMEs. My thesis addresses this gap through a search for the spectral and spatial radio signatures of CMEs on active M dwarfs.

Solar CMEs produce radio bursts with a distinctive spectral signature, narrow-band plasma emission that drifts to lower frequency as a CME expands outward. To search for analogous events on nearby stars, I worked on system design, software, and commissioning for the Starburst project, a wideband single-baseline radio interferometry backend dedicated to stellar observations. In addition, I led a survey of nearby active M dwarfs with the Karl G. Jansky Very Large Array (JVLA), detecting 12 bright (>10 mJy) radio bursts in 58 hours. This survey's ultra-wide bandwidth (0.23-6.0 GHz) dynamic spectroscopy, unprecedented for stellar observations, revealed diverse behavior in the time-frequency plane. Flare star UV Ceti produced complex, luminous events reminiscent of brown dwarf aurorae; AD Leo sustained long-duration, intense, narrow-band "storms"; and YZ CMi emitted a burst with substructure with rapid frequency drift, resembling solar Type III bursts, which are attributed to electrons moving at speeds of order 10% of the speed of light.

To search for the spatial signature of CMEs, I led 8.5-GHz observations with the Very Long Baseline Array simultaneous to 24 hours of the JVLA survey. This program detected non-thermal continuum emission from the stars in all epochs, as well as continuum flares on AD Leo and coherent bursts on UV Ceti, enabling measurement of the spatial offset between flaring and quiescent emission.

These observations demonstrate the diversity of stellar transients that can be expected in time-domain radio surveys, especially with the advent of large low-frequency radio telescopes. Wide bandwidth radio dynamic spectroscopy, complemented by high-resolution imaging of the radio corona, is a powerful technique for detecting stellar eruptions and characterizing dynamic processes in the stellar corona.

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Contributing team(s): Starburst Program Team

117 – Annie Jump Cannon Award: The Tumultuous Lives and Deaths of Stars, Laura Lopez (Ohio State University)

117.01 – The Tumultuous Lives and Deaths of Stars

Massive stars have a profound astrophysical influence throughout their tumultuous lives and deaths. Stellar feedback - the injection of energy and momentum by stars to the interstellar medium (ISM) - occurs through a variety of mechanisms: radiation, photoionization heating, winds, jets/outflows, supernovae, and cosmic-ray acceleration. Despite its importance, stellar feedback is cited as one of the biggest uncertainties in astrophysics today, stemming from a dearth of observational constraints and the challenges of considering many feedback modes simultaneously. In this talk, I will discuss how a systematic approach to multiwavelength observations can be used to overcome these issues. I will summarize results from application of these methods to massive-star regions in the Milky Way and nearby galaxies, where feedback processes are best resolved. Finally, I will highlight exciting prospects of using current and upcoming facilities to explore feedback in diverse conditions.

Author(s): Laura A. Lopez[1]
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120 – Extrasolar Planets: Characterization & Theory I

120.01 – Characterizing Exoplanets with WFIRST

The Wide-Field Infrared Survey Telescope (WFIRST) mission is expected to be equipped with a Coronagraph Instrument (CGI) that will study and explore a diversity of exoplanets in reflected light. Beyond being a technology demonstration, the CGI will provide our first glimpses of temperate worlds around our nearest stellar neighbors. In this presentation, we explore how instrumental and astrophysical parameters will affect the ability of the WFIRST/CGI to obtain spectral and photometric observations that are useful for characterizing its planetary targets. We discuss the development of an instrument noise model suitable for studying the spectral characterization potential of a coronagraph-equipped, space-based telescope. To be consistent with planned technologies, we assume a baseline set of telescope and instrument parameters that include a 2.4 meter diameter primary aperture, an up-to-date filter set spanning the visible wavelength range, a spectroscopic wavelength range of 600–970 nm, and an instrument spectral resolution of 70. We present applications of our baseline model to a variety of spectral models of different planet types, emphasizing warm jovian exoplanets. With our exoplanet spectral models, we explore wavelength-dependent planet-star flux ratios for main sequence stars of various effective temperatures, and discuss how coronagraph inner and outer working angle constraints will influence the potential to study different types of planets. For planets most favorable to spectroscopic characterization—gas giants with extensive water vapor clouds—we study the integration times required to achieve moderate signal-to-noise ratio spectra. We also explore the sensitivity of the integration times required to detect key methane absorption bands to exozodiacal light levels. We conclude with a discussion of the opportunities for characterizing smaller, potentially rocky, worlds under a "rendezvous" scenario, where an external starshade is later paired with the WFIRST spacecraft.

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120.02 – Key Exoplanets in the Era of JWST

In 2018, exoplanet science will enter a new era with the launch of the James Webb Space Telescope (JWST). With JWST's observing power, several studies have sought to characterize how the instruments will perform and what atmospheric spectral features could theoretically be detected using transmission spectroscopy. With just two years left until launch, it is imperative that the exoplanet community begins to digest and integrate these studies into their observing plans and strategies. In order to encourage this and to allow all members of the community access to JWST simulations, we present here an open source tool for creating observation simulations of all observatory-supported time-series spectroscopy modes. We describe our tool, PandExo and use it to calculate the expected signal-to-noise ratio (SNR) for every confirmed planetary system with $J<12$. Assuming chemical equilibrium, we then determine how many observation hours are needed to attain a SNR of 5 on key molecular absorption bands of H_2O, CH_4, and CO. We end by determining the number of planets (hot Jupiters, warm Neptunes, super-Earths, etc.) that are currently attainable with JWST.

Author(s): Natasha Batalha[2], Avi Mandell[1], Nikole K. Lewis[3], Klaus Pontoppidan[3]
Institution(s): *1. Goddard Space Flight Center, 2. Pennsylvania State University, 3. Space Telescope Science Institute*

120.03 – Proxima Centauri b: Environmental States and Observational Discriminants

Proxima Centauri b provides an unprecedented opportunity to understand the evolution and nature of terrestrial planets orbiting M dwarfs. Although Proxima Cen b orbits within its star's habitable zone, multiple plausible evolutionary paths could have generated different environments that may or may not be habitable. We have used 1D coupled climate-photochemical models to generate self-consistent atmospheres for several of the predicted evolutionary scenarios. These include high-O_2, high-CO_2, and more Earth-like atmospheres, with either oxidizing or reducing compositions. We show that these modeled environments can be habitable or uninhabitable at Proxima Cen b's position in the habitable zone. In some cases a habitable surface temperature is obtained, but the planet is desiccated, precluding habitability. We have use radiative transfer models to generate synthetic spectra and thermal phase curves for these simulated environments, and instrument models to explore our ability to discriminate between possible planetary states. These results are applicable not only to Proxima Cen b, but to other terrestrial planets orbiting M dwarfs. Thermal phase curves may provide the first constraint on the existence of an atmosphere, and JWST observations longward of 7 µm could characterize atmospheric heat transport and molecular composition. Detection of ocean glint is unlikely with JWST, but may be within the reach of larger aperture telescopes. Direct imaging spectra may detect O_4 absorption, which is diagnostic of massive water loss and O_2 retention, rather than a photosynthetic biosphere. Similarly, strong CO_2 and CO bands at wavelengths shortward of 2.5µm would indicate a CO_2-dominated atmosphere. Direct imaging can potentially probe the volatile-rich lower atmosphere and surface, and is better than transmission for detection of planetary habitability. If Proxima Centauri b is terrestrial, a microbial biosphere could be sought by looking for CH_4 in conjunction with either photosynthetically produced O_2 or a hydrocarbon haze, and by searching for and excluding signs of possible abiotic planetary processes that could mimic the impact of a biosphere.

Author(s): Victoria Meadows[5], Giada Arney[5], Edward Schwieterman[5], Jacob A Lustig-Yaeger[5], Andrew Lincowski[5], Tyler D. Robinson[4], Shawn Domagal-Goldman[3], Rory Barnes[5], David P Fleming[5], Russell Deitrick[5], Rodrigo Luger[5], Peter E. Driscoll[1], Thomas R. Quinn[5], David Crisp[2]
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120.04 – Beyond Proxima b: Investigating the next nearest Potentially Habitable Exoplanets: Kapteyn b (13 LY) and Wolf 1061 c (14 LY) - Assessing their Suitabilty for Life

The discovery of an Earth-size (~1.3 Me) planet, Proxima b, orbiting in the Habitable Zone (HZ) of the nearest star (d = 4.25 LY), has provided great impetus for the study of the potential habitability of other nearby HZ planets. Ribas et al. (2016, A&A in press) have shown, that in spite of the relatively high levels of magnetic-dynamo generated X-ray & UV radiation from its M5.5 V host star that the planet endures, there are pathways for the Proxima b to possess an atmosphere, water and climate conditions to be potentially habitable. At a distance of 13 LY, the old (11.5 Gyr) Pop II M1.5 star, Kapteyn Star, has been found to hosts two large earth mass planets, one of which - Kapteyn b (M= 4.8 Me; a = 0.17 AU) is located near the mid-HZ of host star (see Englada-Escude' et al. 2014). Unlike Proxima b, the Kapteyn b planet receives significantly less high energy radiation from its host star due the star's lower magnetic activity and the planet's greater distance from its host star (see Guinan et al. 2016). Recently three large earth size planets have been found orbiting the nearby (14 LY) solar-age M3 V star - Wolf 1061 (Wright et al. 2016). One of these planets, Wolf 1061 c (M = 4.6 Me; a = 0.084 AU) is located in the star's HZ. As in the case of Kapteyn b, Wolf 1061 appears to receive less high energy radiation than Proxima b. Here we provide preliminary assessments of the effects of the host star's high energy X-ray and UV photo-ionization radiation on the atmospheres and water inventories of the hosted planets. We compare the suitability of these three nearest planets for potential habitability and suitability for life.
This research is supported by grants from NSF (RUI) and NASA.

Author(s): Edward F. Guinan[1], Scott G. Engle[1]
Institution(s): *1. Villanova Univ.*

120.05 – Improving Habitability of Earth-sized Proxima Centauri b by an Exomoon

In an unprecedented discovery, an Earth-sized exoplanet was discovered on a stable, low-eccentricity orbit located in the habitable zone of our nearest neighbor, Proxima Centauri. While the exoplanet, called Proxima Centauri b, is located within the region that may support liquid water on its surface, its habitability has been questioned because of dangerous flares generated by the M dwarf host star and also because of possible tidal locking. The main goal of this work is to understand the constraints under which an exomoon can maintain stable orbits around the exoplanet and how its presence can improve the habitability of the exoplanet. We utilize an N-body integrator, REBOUND, which is a software package that can integrate the motion of particles under the influence of gravity, to perform exomoon's orbital evolution studies. We present the results of numerical simulations of exomoons of different sizes, determine locations of their stable orbits around Proxima Centauri b, and discuss the effects caused by their presence on the exoplanet's habitability.

Author(s): Sergio Garza[1], Marialis Rosario Franco[1], Niyousha Davachi[1], Zdzislaw E. Musielak[1]
Institution(s): *1. University of Texas at Arlington*

120.06 – Stable Orbits for Exomoons in Earth's Cousin (Kepler-452b) Orbiting a Sun-like Star

Kepler 452b, also nicknamed Earth's cousin, was discovered orbiting the habitable zone (HZ) of a G2 Star (Jenkins et al. 2015). This exoplanet is considered a super Earth, with a mass of 5 ± 2 Mass of Earth and a radius of 1.11 Radius of Earth; and is arguably the first rocky, habitable exoplanet to orbit a sun-like star. With a period of 385 days, conditions are prompt to be similar to those of Earth, and while Kepler-452b orbits the HZ of its parent star, its habitability could also be affected by the presence of an exomoon. Motivated by the need to understand conditions of habitability and orbital stability of Kepler-45b, we have performed a series of N-body integrations to examine the possibility of the exoplanet hosting an exomoon(s). Our results give a range of physical parameters leading to stable orbits for exomoons around this habitable super Earth.

Author(s): Niyousha Davachi[1], Marialis Rosario Franco[1], Sergio Garza[1], Zdzislaw E. Musielak[1]
Institution(s): *1. University of Texas At Arlington*

120.07D – Emerging Science Capabilities of Modern Adaptive Optics Systems for Exoplanet and Stellar Astrophysics

In this dissertation talk, I discuss new science capabilities enabled by the latest generation of adaptive optics systems in the context of faint companion detection and characterization. I address two regimes of adaptive optics: 1) extreme-AO systems that are combined with coronagraphs to detect companions many times fainter than their parent stars; 2) AO systems that are designed to maximize observing efficiency. GPI and SPHERE, two recent extreme-AO high contrast spectro-polarimeters, embody the first regime. These instruments' design and sensitivity open up the possibility of a new observable for exoplanet characterization: polarized radiation from self-luminous, directly imaged exoplanets in the near-infrared. As part of my dissertation, I demonstrated that GPI can detect linear polarizations on the 1% scale predicted for cloudy, oblate gas giant exoplanets. Future polarimetric surveys will provide the empirical data needed to build the next generation of cloudy atmospheric models, shedding new light on the compositions of exoplanet atmospheres. The second regime of efficiency-optimized adaptive optics is embodied by Robo-AO, a robotic laser guide star AO system newly installed at the Kitt Peak 2.1-m telescope. Capable of observing over 1000 targets per week, Robo-AO enables LGS-AO surveys of unprecedented scale. I exploited Robo-AO's efficiency to study the origins of stellar angular momentum: by resolving binaries from among the 700+ Pleiades members observed by K2, I related binary separations to K2's photometrically determined rotation periods. In this talk, I will also describe Robo-AO's commissioning at the 2.1-m and subsequent pipeline development.

Author(s): Rebecca M. Jensen-Clem[1]
Institution(s): *1. Caltech*

120.08 – Direct Imaging Discovery of a Remarkably Red Planetary-Mass Companion

High-contrast imaging surveys have uncovered a growing number of planets orbiting young stars, but the evolution of giant planet atmospheres from dusty L dwarfs to cloud-free T dwarfs remains poorly constrained. We present the discovery of an 11-14 Mjup late-L dwarf companion to a likely member of the ~120 Myr AB Dor moving group as part of a large adaptive optics imaging program to find and characterize planets at Keck Observatory. The near-infrared colors of this new object are redder than the young giant planets HR 8799 bcde and nearly all free-floating red L dwarfs currently known. In color-magnitude diagrams, this object is located at the tip of the red L dwarf sequence and marks the ``elbow'' of the AB Dor substellar isochrone, implying that giant planets can retain thick clouds even at relatively old ages (>100 Myr). Altogether, this new benchmark offers important clues about the evolutionary timescales and physical properties of clouds in giant planet atmospheres.

Author(s): Brendan P. Bowler[8], Michael C. Liu7, Dimitri Mawet[2], Henry Ngo[2], Lison Malo3, Gregory N. Mace[8], Jacob McLane[8], Jessica Lu[6], Isaiah Tristan5, Sasha Hinkley4, Lynne Hillenbrand[2], Evgenya L Shkolnik[1], Björn Benneke[2], William M. J. Best7
Institution(s): *1. Arizona State University, 2. Caltech, 3. CFHT, 4. Exeter, 5. Rice University, 6. UC Berkeley, 7. University of Hawaii, 8. UT Austin*

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121 – AGN, QSO, Blazars: Obscured

121.01 – Discovering highly obscured AGN with the Swift-BAT 100-month survey

In this talk, I present a new technique to find highly obscured AGN using the 100-month Swift-BAT survey. I will show the results of the combined Chandra and BAT spectral analysis in the 0.3-150 keV band of seven Seyfert 2 galaxies selected from the 100-month BAT catalog. We selected nearby (z<0.03) sources lacking of a ROSAT counterpart and never previously observed in the 0.3-10 keV energy range. All the objects are significantly obscured, having NH>1E23 cm^{-2} at a >99% confidence level, and one to three sources are candidate Compton thick Active Galactic Nuclei (CT-AGN), i.e., have NH>1E24 cm^{-2}.
Since the selection criteria we adopted have been extremely effective in detecting highly obscured AGN, further observations of these and other Seyfert 2 galaxies selected from the BAT 100-month catalog will allow us to create a statistically significant sample of highly obscured AGN, therefore better understanding the physics of the obscuration processes.

Author(s): Stefano Marchesi[1], Marco Ajello[1], Andrea Comastri3, Giancarlo Cusumano[2], Valentina La Parola[2], Alberto Segreto[2]
Institution(s): *1. Clemson University, 2. INAF-IAFSC Palermo, 3. INAF-OABO*

121.02D – A multi-wavelength survey of obscured and reddened quasars at the peak of galaxy formation

While in the nearby universe the unification model seems firmly established, we are now seeing hints that at the peak of quasar activity and black hole growth (z~2.5) both obscured and reddened quasars may represent not just a specific quasar orientation but instead a unique stage of quasar evolution. Our group has developed several observational techniques to identify obscured and highly reddened quasars at z~2.5 using a combination of the SDSS spectroscopy and WISE photometry. Our sample contains objects with some of the most extreme ionized gas velocities observed (> 5000 km/s), indicating wind speeds too large to be contained by the galaxy potential though they are radio quiet. I will present both our sample selection and initial results from multi-wavelength follow-up of this sample using near-infrared spectroscopy, Keck spectropolarimentry and the VLA to test the AGN unification model and search for evidence of galaxy-wide quasar winds. High levels of polarized light (reaching ~20% of the total continuum emission in some cases) and changes in the polarization fraction and position angle across emission lines may argue for the presence of dusty outflows in our objects. This is supported by evidence from stacking analysis in the radio that presents a correlation between the observed outflow speeds in ionized gas (as measured by [OIII]) and the radio luminosity —arguing for a wind origin for the radio emission in these objects as well. The most extreme of these objects may thus represent the “blowout phase” of AGN evolution that proceeds or accompanies the cessation of star formation in the host galaxy due to the effects of radiatively-driven quasar driven winds.

Author(s): Rachael Alexandroff[1]
Institution(s): *1. Johns Hopkins University*

121.03D – Hard X-ray Spectroscopy of Obscured AGN with NuSTAR

The Nuclear Spectroscopic Telescope Array (NuSTAR) has enabled studies of the local active galactic nuclei (AGN) to extend into the hard X-ray band, up to 79 keV, with unprecedented spatial resolution and sensitivity. As a part of its extragalactic program, NuSTAR is surveying the nearby population of AGN detected at hard X-ray energies by the Swift Burst Alert Telescope (Swift/BAT), selecting even the most obscured local AGN. I will highlight some of the results based on broadband X-ray spectroscopy of individual targets and present my work on the large representative sample of more than a hundred nearby obscured AGN, which constitutes the largest available atlas of hard X-ray spectra of obscured AGN to date. The high quality of the data allows us to probe the details of AGN structures such as the X-ray-emitting corona and the toroidal obscurer in the under-explored spectral window above 10 keV. I will present both phenomenological results important for synthesis models of the cosmic X-ray background, and a novel approach for constraining the geometry of the gas surrounding the supermassive black hole (including the accretion disk, the broad-line region, and the torus) from the hard X-ray band. Finally, I will discuss how what we learned from this survey of local AGN relates to deeper high-redshift X-ray surveys and AGN structure probes at other wavelengths.

Author(s): Mislav Balokovic[1], Fiona Harrison[1]
Institution(s): *1. California Institute of Technology*
Contributing team(s): NuSTAR Extragalactic Surveys Team

121.04 – Extreme Obscuration and Circumnuclear Star-Formation Revealed in AGN NGC 4968

NGC 4968 is a nearby (z=0.00986) Seyfert 2 galaxy which has X-ray signatures of heavy obscuration. From a recent *Chandra* observation, we discovered extended thermal emission on ~1 kpc scales, emanating from hot gas (kT ~ 0.7 keV) associated with star-formation. We measure an extreme Fe Kα equivalent width (EW) of 2.4 keV, which is an indication that the source is completely enshrouded in Compton-thick material. We highlight that other Type 2 AGN with extreme Fe Kα EWs also have on-going circumnuclear star-formation. We posit that in these systems gas associated with star-formation may provide material for the obscuring medium around the AGN.

Author(s): Stephanie M. LaMassa[2], Tahir Yaqoob4, Nancy A. Levenson[1], Peter Boorman5, Timothy M. Heckman3, Poshak Gandhi5, Jane R. Rigby[2], C. Megan Urry[6], Andrew Ptak[2]
Institution(s): *1. Gemini Observatory, 2. NASA GSFC, 3. The Johns Hopkins University, 4. UMBC, 5. University of Southampton, 6. Yale University*

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122 – GW-SMBH-Lensing-PTA

122.01D – Black Hole Accretion Discs on a Moving

Mesh

We present multi-dimensional numerical simulations of black hole accretion disks relevant for the production of electromagnetic counterparts to gravitational wave sources. We perform these simulations with a new general relativistic version of the moving-mesh magnetohydrodynamics code DISCO which we will present. This open-source code, GR-DISCO uses an orbiting and shearing mesh which moves with the dominant flow velocity, greatly improving the numerical accuracy of the thermodynamic variables in supersonic flows while also reducing numerical viscosity and greatly increasing computational efficiency by allowing for a larger time step. We have used GR-DISCO to study black hole accretion discs subject to gravitational torques from a binary companion, relevant for both current and future supermassive binary black hole searches and also as a possible electromagnetic precursor mechanism for LIGO events. Binary torques in these discs excite spiral shockwaves which effectively transport angular momentum in the disc and propagate through the innermost stable orbit, leading to stress corresponding to an alpha-viscosity of 10^{-2}. We also present three-dimensional GRMHD simulations of neutrino dominated accretion flows (NDAFs) occurring after a binary neutron star merger in order to elucidate the conditions for electromagnetic transient production accompanying these gravitational waves sources expected to be detected by LIGO in the near future.

Author(s): Geoffrey Ryan[1]
Institution(s): *1. New York University*

122.02 – The Effect of Supermassive Black Hole Binary Environments on Time to Detection for the Stochastic Background

Pulsar timing arrays (PTAs) are sensitive to the gravitational wave (GW) stochastic background produced by supermassive black hole binaries (SMBHBs). Environmental effects such as gas and stars accelerate the evolution of SMBHBs and may deplete the stochastic background at low frequencies. How much this effects the sensitivity of PTAs to the stochastic background depends on the astrophysical mechanism and where the binary's evolution transitions from being driven by environmental effects to driven by GW emission. We will discuss how these issues impact our observing strategy and estimated time-to-detection.

Author(s): Sarah Vigeland[1], Xavier Siemens[1]
Institution(s): *1. University of Wisconsin -- Milwaukee*

122.03 – Effectiveness of Null Signal Sky Localization in Pulsar Timing Arrays

A null stream is constructed from the timing residuals of three pulsars by noting that the same source polarization amplitudes appear in the data stream from each pulsar. Linear combinations of a set of individual pulsar data streams can be shown to be a two-parameter family (the two sky position angles of the source) that can be minimized to determine the location of the source on the sky. Taking the product of a number of null streams allows for an even stronger localization of the gravitational wave's source; a large advantage in a PTA where there are more independent signals than other gravitational wave detectors. While a null stream contains the same information as any other data stream with the same number of pulsars, the statistics of a product of noisy signals is inherently different than for a sum of those same signals.

A comparison of how null signal searches compare to other techniques for sky localization of PTA sources will be discussed, as well as an assessment of the types of searches for which the method may be useful.

Author(s): Jeffrey Shafiq Hazboun[1]
Institution(s): *1. Center for Advanced Radio Astronomy*

122.04 – Inferring the mass and density profile of dark matter subhalos in gravitational lens galaxies

In the past several years, dark matter subhalos of elliptical galaxies have been found by detecting their perturbations of gravitationally lensed images, and their corresponding masses are thereby inferred. We demonstrate that the subhalo mass inferred by this method depends critically on the assumed density profile of the subhalo as well as assumptions about its tidal radius. The reported masses of subhalos detected thus far are likely to have large systematic errors (>100%) due to these uncertainties. We analyze simulated lenses to outline what is required to obtain rigorous mass constraints on subhalos detected in gravitational lens galaxies and to constrain their density profiles.

Author(s): Quinn Minor[1], Manoj Kaplinghat[2]
Institution(s): *1. Borough of Manhattan Community College, 2. University of California, Irvine*

122.05 – DeepLensing: The Use of Deep Machine Learning to Find Strong Gravitational Lenses in Astronomical Surveys

Strong gravitational lenses have potential as very powerful probes of dark energy and cosmic structure. However, efficiently finding lenses poses a significant challenge—especially in the era of large-scale cosmological surveys. I will present a new application of deep machine learning algorithms to find strong lenses, as well as the strong lens discovery program of the Dark Energy Survey (DES).

Strong lenses provide unique information about the evolution of distant galaxies, the nature of dark energy, and the shapes of dark matter haloes. Current and future surveys, like DES and the Large Synoptic Survey Telescope, present an opportunity to find many thousands of strong lenses, far more than have ever been discovered. By and large, searches have heretofore relied on the time-consuming effort of human scanners. Deep machine learning frameworks, like convolutional neural nets, have revolutionized the task of image recognition, and have a natural place in the processing of astronomical images, including the search for strong lenses.

Over five observing seasons, which started in August 2013, DES will carry out a wide-field survey of 5000 square degrees of the Southern Galactic Cap. DES has identified nearly 200 strong lensing candidates in the first two seasons of data. We have performed spectroscopic follow-up on a subsample of these candidates at Gemini South, confirming over a dozen new strong lenses. I will present this DES discovery program, including searches and spectroscopic follow-up of galaxy-scale, cluster-scale and time-delay lensing systems.

I will focus, however, on a discussion of the successful search for strong lenses using deep learning methods. In particular, we show that convolutional neural nets present a new set of tools for efficiently finding lenses, and accelerating advancements in strong lensing science.

Author(s): Brian Nord[1]
Institution(s): *1. Fermi National Accelerator Laboratory*

122.06 – Precession-averaged evolution of the orbital and total angular momenta in binary black-hole systems

In the post-Newtonian regime, the timescale on which binary black-hole (BBH) spins precess is much less than the radiation-reaction timescale on which they inspiral to smaller separations. For a given binary system, the angle between total and orbital angular momenta oscillates with precessional period tau, during which the orbital angular momentum precesses about the total angular momentum by an angle alpha. This defines two different frequencies associated with these two periodicities: the nutation frequency nu = 2*pi/tau and the precession frequency Omega = alpha/tau. This allows us to derive Fourier expansions for the total and orbital angular momenta. We found that during the inspiral, BBHs can encounter nutational resonances where Omega = n*nu for integer n. At such resonances, the total angular momentum changes direction by a tilt angle. We derive an approximate expression for this tilt angle for BBHs with arbitrary masses and spins satisfying this resonance condition. Our new approach to studying the evolution of binary black-hole systems on long timescales may be more computationally efficient than previous methods, which might be helpful for calculating waveforms in the future.

Author(s): Xinyu Zhao[2], Michael H. Kesden[2], Davide Gerosa[1]
Institution(s): *1. California Institute of Technology, 2. University of Texas at Dallas*

122.07 – Bayesian model-emulation of stochastic gravitational-wave spectra for probes of the final-parsec problem with pulsar-timing arrays

The final parsec of supermassive black-hole binary evolution is subject to the complex interplay of stellar loss-cone scattering, circumbinary disk accretion, and gravitational-wave emission, with binary eccentricity affected by all of these. The strain spectrum of gravitational-waves in the pulsar-timing band thus encodes rich information about the binary population's response to these various environmental mechanisms. Current spectral models have heretofore followed basic analytic prescriptions, and attempt to investigate these final-parsec mechanisms in an indirect fashion. Here we describe a new technique to directly probe the environmental properties of supermassive black-hole binaries through "Bayesian model-emulation". We perform black-hole binary population synthesis simulations at a restricted set of environmental parameter combinations, compute the strain spectra from these, then train a Gaussian process to learn the shape of the spectrum at any point in parameter space. We describe this technique, demonstrate its efficacy with a program of simulated datasets, then illustrate its power by directly constraining final-parsec physics in a Bayesian analysis of the NANOGrav 5-year dataset. The technique is fast, flexible, and robust.

Author(s): Stephen R Taylor[2], Joseph Simon3, Laura Sampson[1]
Institution(s): *1. CIERA, Northwestern University, 2. Jet Propulsion Laboratory, 3. University of Wisconsin-Milwaukee*

123 – Dwarf & Irregular Galaxies I

123.01 – Accretion phenomena onto star-forming dwarf-galaxies.

I will present our recent discovery (Annibali et al. 2016, ApJL, 826 L27), based on the combination of deep wide-field LBT imaging from the ground and HST data, of a stellar stream and substructures associated to the very metal-poor star-forming dwarf galaxy DDO 68, located in a Void at ~12.7 Mpc from us. DDO 68 is very light (only 10^8 M_{sun} in stars), yet it shows evidence for the accretion of at least two smaller satellites. DDO 68 is one of the very few cases where the hierarchical formation process is caught in action at such small galactic scales. This study is part of a large ongoing project based on an approved 2-year strategic program with LBT to search for stellar streams around a sample of ~50 nearby star-forming dwarf galaxies. Our result demonstrates the high potential of wide-field instrumentation at 8–10 m telescopes in combination with HST (and with JWST in the near future) for the study of accretion phenomena onto dwarf-galaxies.

Author(s): Francesca Annibali[1]
Institution(s): *1. INAF- Osservatorio Astronomico Bologna*

123.02 – The Star-Forming Main Sequence at Low Galaxy Mass

We present an investigation of the star-forming main sequence at the low mass end. The relation between galaxy stellar mass and star formation rate has been well-studied in the recent literature for a range of redshifts and galaxy type, but almost all of these studies are limited to galaxies with stellar masses above the dwarf galaxy range (109 Msun). Our work, based on the panchromatic TiNy Titans survey of interacting dwarf galaxies, shows that dwarf galaxies extend the well-established main sequence at z=0 down to lower masses. Furthermore, like their more massive counterparts, dwarf mergers appear on an elevated main sequence with higher star formation rates for a given stellar mass. Finally we show that star formation is enhanced to a greater extent in low mass galaxy mergers than for higher mass systems.

Author(s): Sabrina Stierwalt[2], Kelsey E. Johnson5, David R. Patton3, Gurtina Besla4, Nitya Kallivayalil5, Sandra Liss5, Sarah Pearson[1], George C. Privon5, Mary E. Putman[1]
Institution(s): *1. Columbia University, 2. National Radio Astronomy Observatory, 3. Trent University, 4. University of Arizona, 5. University of Virginia*

123.03D – Large-scale environmental dependence of chemical abundances in dwarf galaxies and implications for connecting star formation history and halo mass

We study how the cosmic environment affects galaxy evolution in the Universe by comparing the gas-phase metallicities and abundance ratios of dwarf galaxies in voids with dwarf galaxies in more dense regions. Using spectroscopic observations from Sloan Digital Sky Survey Data Release 7, we estimate the oxygen and nitrogen abundances of 1014 void dwarf galaxies and 787 dwarf galaxies in more dense regions. We develop an alternate calculation for the oxygen abundance that does not use the [OII] λ3727 doublet, permitting oxygen abundance estimates of SDSS dwarf galaxies with the Direct T_e method at all redshifts. We find that void dwarf galaxies ($M_r > -17$) have 9% higher average oxygen abundances and 9% lower average nitrogen abundances than dwarf galaxies in more dense regions. There is a 23% difference in the relative abundances of nitrogen and oxygen in the dwarf galaxies between the two environments. We also find similar N/O abundance ratio shifts in a larger sample (2050 void galaxies and 3883 galaxies in dense regions) of somewhat brighter galaxies ($-17 > M_r > -20$). These abundance shifts in galaxies fainter than L* may indicate retarded star formation and larger dark matter halo mass to stellar mass ratios in void galaxies, as seen in high-resolution hydrodynamic simulations.

Author(s): Kelly Douglass[1], Michael S. Vogeley[1]
Institution(s): *1. Drexel University*

123.04 – APOGEE Chemical Abundances of the Sagittarius Dwarf Galaxy

The Apache Point Observatory Galactic Evolution Experiment (APOGEE) provides elemental abundances for C, N, O, Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, and Ni. We analyze the chemical abundance patterns of these elements for ~ 350 stars belonging to the Sagittarius Dwarf Galaxy (Sgr). This is the largest sample of Sgr stars with detailed chemical abundances and the first time C, N, P, K, V, Cr, Co, and Ni have been studied in the dwarf galaxy. For Sgr stars with [Fe/H] > -0.9, we find that Sgr is deficient in all elemental abundance ratios (expressed as [X/Fe]) relative to the Milky Way, which suggests that Sgr stars observed today were formed from gas that was less enriched by both Type II and Type Ia SNe. By examining the relative deficiencies of the hydrostatic (O, Mg, and Al) and explosive (Si, K, and Mn) elements , we find support that previous generations of Sgr stars were formed with a top-light IMF, lacking the most massive stars that would normally pollute the ISM with the hydrostatic elements.

Author(s): Sten Hasselquist3, Matthew D. Shetrone[11], Verne V. Smith4, Katia M. L. Cunha5, Andrew McWilliam[8], Jon A. Holtzman3, Steven R. Majewski[13], Jennifer Sobeck[13], Peter M. Frinchaboy7, Alexandre Roman-Lopes9, Inese I. Ivans[12], Carlos Allende-Prieto[1], Vinicius M Placco[10], Richard Lane[6], Gail Zasowski[2]
Institution(s): *1. IAC, 2. Johns Hopkins University, 3. New Mexico State University, 4. NOAO, 5. Observatorio Nacional, 6. Pontificia Universidad Católica de Chile, 7. Texas Christian University, 8. The Observatories of the Carnegie Institute of Washington, 9. Universidad de La Serena, 10. University of Notre Dame, 11. University of Texas at Austin, 12. University of Utah, 13. University of Virginia*
Contributing team(s): APOGEE

123.05 – The HI Chronicles of LITTLE THINGS BCDs: VII Zw 403's External Gas Cloud

Blue compact dwarf (BCD) galaxies are characterized by their concentrated bursts of star formation. Yet, for many BCDs, it is unclear what has triggered this activity. VII Zw 403 is a well-known BCD that is relatively isolated from other galaxies. Using the high angular and velocity resolution Very Large Array (VLA) atomic hydrogen (HI) data from the LITTLE THINGS[1] survey, we study the detailed kinematics and morphology of VII Zw 403's HI gas. High sensitivity HI Green Bank Telescope (GBT) observations were also used to search the surrounding area for companion galaxies and extended HI emission, but they did not result in detections of either. The VLA data show a kinematically and morphologically disturbed HI disk. From the VLA HI data cubes, we have separated out most of the emission from what is likely an external gas cloud that is in the line of sight of the HI disk. This external gas cloud appears to be accreting onto the disk and could trigger a future burst of star formation.

[1]Local Irregulars That Trace Luminosity Extremes, The HI Nearby Galaxy Survey; https://science.nrao.edu/science/surveys/littlethings

Author(s): Trisha L. Ashley[1], Caroline E. Simpson3, Bruce Elmegreen4, Megan C. Johnson[2], Nau Raj Pokhrel3
Institution(s): *1. Bay Area Environmental Research Institute and NASA Ames, 2. CSIRO, 3. Florida International University, 4. IBM*

123.06D – Baryons and their Effects on Planes of Satellites Around Milky Way-Mass Galaxies

Both the Milky Way and Andromeda have thin, coherently rotating planes of satellites. In this study I try to find similar satellite planes around four different Milky Way-mass simulations, each run both as dark matter-only and with baryons included. In all halos I am able to identify a planar configuration that significantly maximizes the number of satellites that are members of a plane. The member satellites that make up this maximum plane are consistently different between the dark matter-only and baryonic versions of the same run. In the baryonic runs, satellites are more likely to be destroyed through interactions with the disk, and substructure tends to infall later. Hence, studying satellite planes in dark matter-only simulations is misleading, because they will be composed of different satellite members than those that would exist if baryons were included. Additionally, baryonic runs tend to have less radially concentrated satellite distributions. Since all planes pass through the center of the galaxy, it is much harder to create a plane containing a large number of satellites from a random distribution if the satellites have a low radial concentration. Andromeda's low radial satellite concentration is possibly a key reason behind why the plane in Andromeda is highly significant. Despite this, when co-rotation is considered, none of the satellite planes identified for the simulated galaxies are as statistically significant as the observed planes around the Milky Way and Andromeda. I will then show that co-rotation in our satellite planes can be attributed to how the satellites are accreted through filaments from the cosmic web. When two sets of opposing filaments contribute, coherent planes are more likely to form, when there are no well-defined filaments, there is a lack of coherent satellite rotation.

Author(s): Sheehan H Ahmed[1]
Institution(s): *1. Rutgers, The State University of New Jersey*

123.07 – Galactic Building Blocks: Dwarf Galaxies Near and Far

The work I have done during my thesis has consisted of both observational and theoretical projects involving dwarf galaxies and Cold Dark Matter (CDM) sub-structure both around the Milky Way and in redshift z~0.1 galaxies. The dwarf galaxies around the Milky Way are distributed in a so-called vast polar structure (VPOS) that may be in conflict with ΛCDM simulations. For this project, we seek to investigate two key questions to determine if the VPOS poses a serious challenge to the ΛCDM paradigm on galactic scales. First, we ask which dwarf galaxy satellites drive the fit to the VPOS and create planar structure. Second, we ask if the VPOS remains coherent as a function of time. Using the measured HST proper motions and associated uncertainties, we integrate the orbits of the classical Milky Way satellites backwards in time and find that for the mean of the measured HST proper motions, the VPOS deteriorates in less than a dynamical time and resembles an isotropic structure. We also explore the effect of the uncertainties on the HST proper motions on the coherence of the VPOS as a function of time. We find that nine of the eleven classical dwarfs have reliable proper motions; for these nine, the VPOS also deteriorates in less than a dynamical time, indicating that the VPOS is not a dynamically stable structure. I will also briefly discuss the observational work that I have done during my thesis, including HI observations of lensed spiral galaxies to constrain CDM sub-structure.

Author(s): Andrew Lipnicky[1], Sukanya Chakrabarti[1]
Institution(s): *1. Rochester Institute of Technology*

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124 – Star Associations, Star Clusters - Galactic & Extragalactic I

124.01D – Testing Theories of in situ Nuclear Star Formation in M31

The nucleus of M31 has a number of unusual characteristics. There is an eccentric disk of old stars that extends out to a radius of less than 10 pc from the supermassive black hole (SMBH), a smaller disk of young (100-200 Myr) stars within 0.4 pc, and almost no gas. Questions abound as to how the young stars formed and how the eccentric disk remains coherent. Outflows from red giants and AGB stars in the old stellar eccentric disk could provide the material necessary to form the observed young circumnuclear stellar population. However, in order for this gas to be removed from the old stellar disk and funneled into the young star cluster, simulations by Chang et al. (2007) show that the old disk must precess slowly enough to allow the orbits of material in this disk to intersect. The colliding gas can then shock, cool, and fall into the circumnuclear star cluster. We use Keck/OSIRIS integral field spectroscopy in conjunction with dynamical models to constrain the precession rate of the old stellar eccentric disk in the nucleus of M31 and calculate the frequency of in situ star formation events in the young nuclear cluster.

Author(s): Kelly Lockhart7, Jessica Lu5, Hiranya Peiris4, Robert Michael Rich[6], Antonin H. Bouchez[2], Keith Matthews[1], Andrea M. Ghez[6], Scott D. Tremaine3
Institution(s): *1. California Institute of Technology, 2. Giant Magellan Telescope, 3. Institute for Advanced Study, 4. University College London, 5. University of California, Berkeley, 6. University of California, Los Angeles, 7. University of Hawaii*

124.02 – Multiple Populations in M31 Globular Clusters: Clues from Infrared High Resolution Integrated Light Spectroscopy

Abundance variations are a common feature of Milky Way globular clusters. The globular clusters in M31 are too distant for detailed abundance studies of their individual stars; however, cluster abundances can be determined through high resolution, integrated light (IL) spectroscopy. In this talk, I discuss how IL abundances can be interpreted in the context of multiple populations. In particular, I will present new infrared abudances of 25 M31 globular clusters, derived from IL spectra from the Apache Point Observatory Galactic Evolution Experiment (APOGEE). These H band spectra allow determinations of C, N, and O from molecular features, and Fe, Na, Mg, Al, Si, Ca, Ti, and K from atomic features. The integrated abundance ratios are then investigated with cluster [Fe/H] and mass.

Author(s): Charli Sakari[1]
Institution(s): *1. University of Washington*
Contributing team(s): The APOGEE team

124.03D – The Open Cluster Chemical Abundances and Mapping (OCCAM) Survey: Galactic Neutron Capture Abundance Gradients

The evolution of elements, as a function or age, throughout the Milky Way disk provides a key constraint for galaxy evolution models. In an effort to provide these constraints, we have conducted an investigation into the r- and s- process elemental abundances for a large sample of open clusters as part of an optical follow-up to the SDSS-III/APOGEE-1 survey. Stars were identified as cluster members by the Open Cluster Chemical Abundance & Mapping (OCCAM) survey, which culls member candidates by radial velocity, metallicity, and proper motion from the observed APOGEE sample. To obtain data for neutron capture elements in these clusters, we conducted a long-term observing campaign covering three years (2013-2016) using the McDonald Observatory Otto Struve 2.1-m telescope and Sandiford Cass Echelle Spectrograph (R ~ 60,000). We present Galactic neutron-capture abundance gradients using 30+ clusters, within 6 kpc of the Sun, covering a range of ages from ~80 Myr to ~10 Gyr .

Author(s): Julia O'Connell[3], Peter M. Frinchaboy[3], Matthew D. Shetrone[4], Matthew Melendez[3], Katia M. L. Cunha[2], Steven R. Majewski[5], Gail Zasowski[1]
Institution(s): *1. Johns Hopkins University, STSci, 2. Observatorio Nacional, 3. Texas Christian University, 4. University of Texas, 5. University of Virginia*
Contributing team(s): APOGEE Team

124.04D – The Photometric Study of Globular Cluster Systems in the Coma, Fornax, and Virgo Clusters of Galaxies with the *HST* WFC3/IR

We present new *HST* WFC3/IR observations of a cD galaxy NGC 4874 in the Coma and 16 early-type galaxies spanning a wide range of luminosities and colors in the Fornax and Virgo clusters of galaxies. Combining these NIR data with new *HST* ACS optical photometry for NGC 4874 and existing ACS globular cluster (GC) catalogs from the ACS Fornax and Virgo Cluster Surveys, we have examined for the first time the GC systems in a statistically significant sample of galaxies using high-resolution WFC3/IR and ACS data. A primary goal of this dissertation is to explore empirically whether the distributions of purely optical and hybrid optical–NIR color indices for GCs have different forms and whether the relations between these color indices are nonlinear, indicating that they behave differently with underlying metallicity. We find that some GC systems of large galaxies in our sample show color bimodalities that differ between the optical and optical–NIR colors, in the sense that they have disparate ratios of red and blue GCs, as well as differing ratios in their color dispersions. Consistent with these results, we find empirically that the dependence of hybrid optical–NIR color on purely optical color is nonlinear, with an inflection at intermediate metallicities. These findings show the importance of understanding the nature of variations in the GC color distributions and color—color relations as a function of galaxy properties, as well as the exact forms of the color—metallicity transformations, in interpreting the observational data on GC color bimodality. Finally, we discuss the very steep color—magnitude trend, or "blue tilt", for the blue GCs in NGC 4874 and the spatial offset of the center of its GC distribution from the galaxy's luminosity center.

Author(s): Hyejeon Cho[2], John P. Blakeslee[1], Young-Wook Lee[2]
Institution(s): *1. NRC Herzberg Astronomy and Astrophysics, 2. Yonsei University*

124.05 – Hierarchical Star Formation in Turbulent Media: Evidence from Young Star Clusters

We present an analysis of the positions and ages of star clusters in eight local galaxies and find a correlation between the age difference and separation of cluster pairs. We infer that cluster formation is correlated in time such that clusters that are close to each have similar ages. In addition, the age between cluster pairs increases with their separation to the 0.3 - 0.6 power, close to the expected slope of 0.5 that would arise in a turbulent-driven interstellar medium. This suggests that not only is star formation hierarchical both in space and in time, but that the duration of star formation depends on the region of interest: smaller regions will form stars over a shorter time frame whereas larger regions form stars over a longer time frame.

Author(s): Kathryn Grasha[2], Bruce Elmegreen[1], Daniela Calzetti[2]
Institution(s): *1. Thomas J. Watson Research Center, 2. University of Massachusetts - Amherst*

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125 – Cosmology I

125.01 – Measuring the Epoch of Reionization using [CII] Intensity Mapping with TIME-Pilot

TIME-Pilot (the Tomographic Ionized carbon Intensity Mapping Experiment) is a new instrument designed to probe the epoch of reionization (EoR) by measuring the 158 um ionized carbon emission line [CII] from redshift 5 - 9. TIME-Pilot will also probe the molecular gas content of the universe during the epoch spanning the peak of star formation (z ~ 1 -3) by making an intensity mapping measurement of the CO transitions in the TIME-Pilot band (CO(3-2), CO(4-3), CO(5-4), and CO(6-5)). I will describe the instrument we are building which is an R of ~100 spectrometer sensitive to the 200-300 GHz radiation. The camera is designed to measure the line emission from galaxies using an intensity mapping technique. This instrument will allow us to detect the [CII] clustering fluctuations from faint galaxies during EoR and compare these measurements to predicted [CII] amplitudes from current models. The CO measurements will allow us to constrain models for galaxies at lower redshift. The [CII] intensity mapping measurements that will be made with TIME-Pilot and detailed measurements made with future more sensitive mm-wavelength spectrometers are complimentary to 21-cm measurements of the EoR and complimentary to direct detections of high redshift galaxies with HST, ALMA, and, in the future, JWST.

Author(s): Abigail Crites[1], James Bock[1], Matt Bradford[1], Bruce Bumble[3], Tzu-Ching Chang[1], Yun-Ting Cheng[1], Asantha R. Cooray[6], Steve Hailey-Dunsheath[1], Jonathon Hunacek[1], Chao-Te Li[2], Roger O'Brient[3], Erik Shirokoff[7], Zachary Staniszewski[3], Corwin Shiu[4], Bade Uzgil[1], Michael B. Zemcov[5], Guochao Sun[1]
Institution(s): *1. California Institute of Technology, 2. Caltech, 3. Jet Propulsion Laboratory, 4. Princeton, 5. RIT, 6. UCIrvine, 7. University of Chicago*

125.02D – Cosmic infrared background fluctuations of the COSMOS field in the SPLASH survey: new measurements and the cosmological explanations

The cosmic infrared background (CIB) is the integrated emission of all sources through cosmic time and carries an abundance of information about the star formation and galaxy growth in the Universe. Due to significant and complex foregrounds from our Galaxy, the optimal way to study the unresolved background is to actually study its fluctuations, especially at large angular scales where they reflect the clustering of unresolved galaxies. Our new measurements of the CIB fluctuations reach the largest angular scale to date for such a study, thanks to new observations of the COSMOS field from the Spitzer Large Area Survey with Hyper-Suprime-Cam (SPLASH). We analyzed Spitzer IRAC 3.6 and 4.5 um data of the whole field, with an average depth of 1.33 hour/pixel over 4 epochs spanning 2 years. We found that the auto-power spectra are consistent among various epochs and are correlated at the two channels. We confirmed the previously detected excess flux at large scales of the power spectra.
The cross-correlation of the CIB fluctuations with backgrounds at other wavelengths is an extremely useful technique to understand the excess flux. The previously seen CIB and X-ray background (CXB) cross-correlation suggests significant contribution to the CIB fluctuations from accreting black holes that is much higher than among any known populations, and such a cross-correlation is also used as an evidence for the existence of direct collapse black

holes in the early Universe.
In this talk, we will present the first CIB fluctuation measurements of the COSMOS field using the new SPLASH data and we will also revisit the CIB and CXB cross-correlation in this field, which is about 20 times larger than the previous study and therefore with much improved significance levels. Measuring CIB fluctuations is a powerful tool to study the large-scale structure of the Universe. The CIB and CXB cross-correlation can not only provide observational constrains on the theoretical modeling of the CIB fluctuations but also stands as a unique way to study the formation of the early black holes and therefore unveil the early Universe.

Author(s): Yanxia Li[1]
Institution(s): *1. University of Hawaii*

125.03 – Early Science from the Hydrogen Epoch of Reionization Array

The Hydrogen Epoch of Reionization Array (HERA) is a radio interferometer targeting 21cm emission from the primordial intergalactic medium. Observing across a broad redshift range HERA will directly measure the IGM as it is heated and ionized by the first galaxies and black holes. HERA is tuned to make a precision measurement of the HI power spectrum through redshifts 6 to 12, capturing, at high significance, the spatial and temporal pattern of fluctuations imprinted by early objects and will explore beyond to redshift 20 to epochs driven by the very first objects. When completed, the array will have 250 14m dishes packed into a regular hexagonal pattern for roughly 10 times the sensitivity of previous such arrays. HERA is an official Square Kilometer Array precursor operated out of the South African SKA site. It is a staged experimental program that is building out in steps; 19 dishes are operating at the , the next expansion to 37 is under way in parallel with commissioning experiments. Here we report on these tests which have focused on optimizing feed design and calibration techniques and discuss their impact on isolation of foreground emission.

Author(s): Daniel Jacobs[1]
Institution(s): *1. Arizona State University*
Contributing team(s): HERA Team

125.04 – Data Simulation for 21 cm Cosmology Experiments

21 cm cosmologists seek a measurement of the hyperfine line of neutral hydrogen from very high redshifts. While this signal has the potential to provide an unprecedented view into the early universe, it is also buried under exceedingly bright foreground emission. Over the last several years, 21 cm cosmology research has led to an improved understanding of how low frequency radio interferometers will affect the separation of cosmological signal from foregrounds. This talk will describe new efforts to incorporate this understanding into simulations of the most realistic data sets for the Precision Array for Probing the Epoch of Reionization (PAPER), the Murchison Widefield Array (MWA), and the Hydrogen Epoch of Reionization Array (HERA). These high fidelity simulations are essential for robust algorithm design and validation of early results from these experiments.

Author(s): Jonathan Pober[1]
Institution(s): *1. Brown University*

125.05 – Constraining compensated isocurvature perturbations using the CMB

Compensated isocurvature perturbations (CIPs) are variations in the cosmic baryon fraction which leave the total non-relativistic matter (and radiation) density unchanged. They are predicted by models of inflation which involve more than one scalar field, such as the curvaton scenario. At linear order, they leave the CMB two-point correlation function nearly unchanged: this is why existing constraints to CIPs are so much more permissive than constraints to typical isocurvature perturbations. Recent work articulated an efficient way to calculate the second order CIP effects on the CMB two-point correlation. We have implemented this method in order to explore constraints to the CIP amplitude using current Planck temperature and polarization data. In addition, we have computed the contribution of CIPs to the CMB lensing estimator which provides us with a novel method to use CMB data to place constraints on CIPs. We find that Planck data places a constraint to the CIP amplitude which is competitive with other methods.

Author(s): Tristan L. Smith[1]
Institution(s): *1. Swarthmore College*
Contributing team(s): Rhiannon Smith, Kyle Yee, Julian Munoz, Daniel Grin

125.06 – Testing gravity theories using tensor perturbations

Primordial gravitational waves constitute a promising probe of the very early universe physics and the laws of gravity. We study the changes to tensor-mode perturbations that can arise in various modified gravity theories. These include a modified friction and a nonstandard dispersion relation. We introduce a physically motivated parametrization of these effects and use current data to obtain excluded parameter spaces. Taking into account the foreground subtraction, we then perform a forecast analysis focusing on the tensor-mode modified-gravity parameters as constrained by future experiments COrE, Stage-IV and PIXIE. For the tensor-to-scalar ratio r=0.01, we find the minimum detectible modified-gravity effects. In particular, the minimum detectable graviton mass is about $7.8\sim9.7\times10^{-33}$ eV, which is of the same order of magnitude as the graviton mass that allows massive gravity to produce late-time cosmic acceleration. Finally, we study the tensor-mode perturbations in modified gravity during inflation. We find that, the tensor spectral index would be additionally related to the friction parameter ν_0 by $n_T=-3\nu_0-r/8$. In some cases, the future experiments will be able to distinguish this relation from the standard one. In sum, primordial gravitational waves provide a complementary avenue to test gravity theories.

Author(s): Weikang Lin[1], Mustapha B. Ishak-Boushaki[1]
Institution(s): *1. University of Texas at Dallas*

125.07 – Effect of Self-Calibration of Intrinsic Alignment on the Cosmological Parameter Constraints for LSST

Weak gravitational lensing (WL) is a powerful cosmological probe, however it is contaminated by the Intrinsic Alignment (IA) signal. The IA signal is now one of the major systematics in the present and future WL surveys. It can affect the lensing power spectrum at ~10% level and cause a misestimation of the cosmological parameters, especially in the dark energy equation of state where the misestimation can be up to 50% and the amplitude of matter power spectrum by up to 30% . The Self-Calibration (SC) technique has been introduced to subtract the shear intrinsic (GI) IA contamination in a photometric redshift (photo-z) survey, at a level of ~90%. In this work, we present a forecast analysis on the effect of using Self-Calibration to subtract the IA signal for an LSST like survey. We show the effect of constraining contours of cosmological parameters using the IA Self-Calibration.

Author(s): Ji Yao[2], Mustapha Ishak[2], Michael A. Troxel[1], Weikang Lin[2]
Institution(s): *1. Ohio State University, 2. The University of Texas at Dallas*

125.08 – Planck SZ Cluster Mass Calibration using HSC Weak Lensing

The Planck satellite has delivered an SZ cluster catalog from which precise cosmological constraints, in particular on σ_8, have been derived. However, SZ does not provide a direct mass observable, and needs to be calibrated via independent methods. In the calibration of the Planck SZ masses, X-ray mass measurements from XMM-Newton assuming hydrostatic equilibrium have been used, and the subsequent constraint on σ_8 is in mild tension with CMB-temperature derived values (Planck collaboration 2015). Weak lensing (WL) provides a direct measure of the total halo mass, regardless of the underlying physics or dynamics of the system. Here, we make use of the first ~240 deg^2 Subaru Hyper Suprime-Cam (HSC) survey data and stack the shear around ~10 Planck clusters, yielding ~20σ detection of the mean Planck cluster mass profile and calibrate the SZ-WL mass scaling relation. Once the HSC survey has finished to observe ~1400 deg^2, we expect to have a ~60σ detection, which will enable constraints on σ_8 to a level of 1%. We will test whether the Planck tension stems from systematics in the cluster mass calibration, or whether this tension is due to some cosmological origin, e.g. massive neutrinos.

Author(s): Elinor Medezinski[5], Nicholas Battaglia[5], Michael A. Strauss[5], David N. Spergel[5], Hironao Miyatake[3], Rachel Mandelbaum[2], Masamune Oguri[4], Keiichi Umetsu[1]
Institution(s): *1. ASIAA, 2. Carnegie-Mellon University, 3. Jet Propulsion Laboratory, 4. Kavli/IPMU, 5. Princeton University*
Contributing team(s): HSC

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126 – Science with the Discovery Channel Telescope and Beyond

Lowell Observatory's Discovery Channel Telescope saw first light in 2012 and began full-time operations the following year. This state-of-the-art 4.3-meter telescope, located at an elevation of 7,740 feet in Happy Jack, AZ, has a growing suite of optical and near-infrared instruments. Lowell's DCT partners include Boston University, the University of Maryland, the University of Toledo, Northern Arizona University, Yale University, and the University of Texas/Korean Astronomy and Space Science Institute IGRINS team. This special session will showcase scientific highlights from the first few years of DCT operations as well as synergies with telescopes on nearby Anderson Mesa, including the Navy Precision Optical Interferometer. Talks will cover the diverse research being done with the DCT, from studies of solar system objects to distant GRBs. This is an opportunity to learn more about the newest 4-meter-class telescope in the United States and perhaps to stimulate new scientific collaborations.

126.01 – Lowell Observatory's Discovery Channel Telescope

Lowell Observatory broke ground on its 4.3-meter Discovery Channel Telescope (DCT) in July 2005 and celebrated first light for the telescope in July 2012. In this overview to this special session, I will discuss the origin and development of the project, the telescope's general specifications and performance, its current operating status, and the initial instrument suite.

Author(s): Jeffrey C. Hall[1]
Institution(s): *1. Lowell Obs.*

126.02 – Follow-Up Discovery Channel Telescope Observations of Transients and Variables from Optical Time Domain Surveys

We highlight the capabilities of the Discovery Channel Telescope (DCT) for follow-up observations of transients and variables discovered by optical time-domain surveys. We present two DCT programs: 1) extended-baseline imaging with the Large Monolithic Imager of periodically variable quasars from the Pan-STARRS1 survey to identify binary supermassive black hole candidates, and 2) spectroscopic classification with the DeVeny spectrograph of nuclear transients from the iPTF survey to identify tidal disruption event candidates. We demonstrate that DCT is well-matched to the magnitude ranges of the transients and variables discovered by these surveys, and has played an important role in their classification and characterization.

Author(s): Suvi Gezari[1], Tingting Liu[1], Tiara Hung[1]
Institution(s): *1. University of Maryland*

126.03 – Target of Opportunity Observations with the Discovery Channel Telescope

With the capability for 5 instruments simultaneously mounted and readily available on the instrument cube, the Discovery Channel Telescope (DCT) was designed to be a powerful tool for time-domain astronomy. I will describe our efforts at Goddard Space Flight Center and the University of Maryland to conduct target-of-opportunity (ToO) observations with the DCT in 2016. Our focus has been on studies of gamma-ray bursts and young supernova, and I will show results from both of these areas. I will also describe the soon-to-installed RIMAS instrument, a moderate resolution NIR spectrograph designed to study gamma-ray bursts from the epoch of reionization.

Author(s): Stephen B. Cenko[1], Sylvain Veilleux[2], Vicki Toy[2], John Capone[2], Eleonora Troja[1], Antonino Cucchiara[3], Suvi Gezari[2], Tiara Hung[2]
Institution(s): *1. NASA Goddard Space Flight Center, 2. University of Maryland, 3. University of the Virgin Islands*

126.04 – EXPRES: the EXtreme PREcision Spectrograph at the Discovery Channel Telescope

In 2017, we will commission EXPRES at the DCT to carry out a high precision radial velocity planet search. The instrument has a resolution of R=150,000 and spans a wavelength range from 390 - 680 nm. There are several features designed to ensure high fidelity spectra: a well scrambled fiber coupling, vibration isolation, a vacuum enclosure to maintain temperature stability to better than 1 mK and pressure stability better than 1 mTorr. The spectrometer has a unique flat-fielding system and a wavelength-dependent exposure meter. The laser frequency comb provides wavelength precision better than 5 cm/s and the overall instrumental error budget is 17 cm/s for a single observation. The fully characterized CCD detector has 9-micron pixels and a 10K by 10K format. The instrument will be commissioned for facility use with a fully automated extraction and Doppler analysis pipeline.
This instrument and our analytial techniques aim to push the experiemental frontier on extreme Doppler precision toward 10 cm/s. Progress on RV precision is critical for measuring masses of exoplanets so that we can derive densities for small transiting planets and interpret the spectra of exoplanet atmospheres. We will carry out a survey of 50 bright stars in the first year after commissioning EXPRES.

Author(s): Debra Fischer[1], Colby Jurgenson[1], Tyler McCracken[1], David Sawyer[1], Ryan Blackman[1], Andrew E. Szymkowiak[1]
Institution(s): *1. Yale University*

126.05 – Proper Motions and Parallaxes of Very Low-Mass Stars using DCT Astrometry

Very low-mass stars (VLMs) are the smallest, least luminous stars in our galaxy, but nonetheless form one of the dominant (baryonic) populations. Precise distances and kinematics of VLMs can provide constraints on the smallest extremes of star formation, as well as important boundary constraints on the star formation process in general. However, Gaia will only be ~70% complete at the faint magnitudes of these objects. We present preliminary results from a program to measure parallaxes and proper motions for a nearby sample of 85 VLMs using the Large Monolithic Imager at the 4.3m Discovery Channel Telescope. We present proper motions for the entire sample and preliminary parallaxes for a few sources. These measurements will complement Gaia observations and allow us to construct high quality luminosity and mass functions, which will help to distinguish between VLM formation scenarios.

Author(s): Julie N. Skinner[1], Andrew A West[1], Jacqueline K. Faherty[2], Philip Steven Muirhead[1]
Institution(s): *1. Boston University, 2. Carnegie Institute of Washington*

126.06 – IGRINS on the DCT

Through an agreement with the University of Texas at Austin and the Korea Astronomy and Space Science Institute, the Immersion Grating Infrared Spectrograph (IGRINS) saw first light on the Lowell Observatory 4.3 m Discovery Channel Telescope (DCT) telescope on September 8, 2016. IGRINS, originally commissioned at the McDonald Observatory 2.7 m telescope, provides a spectral resolution of 45,000 and a simultaneous spectral grasp of 1.45 to

2.45 microns, recording all of the H and K bands with no gaps in wavelength coverage on two H2RG detectors in a single exposure. The instrument design minimizes optical surfaces, optimizing throughput, and has no moving parts, key for stability. IGRINS on the DCT attains a signal to noise of 100 per resolution element in one hour of integration time on a K=12 magnitude source, currently making it the most sensitive high-resolution spectrograph in the world at H and K. Science programs in the fourth quarter, 2016, include such diverse topics as abundance measurements in M dwarfs and population II stars, studies of ices and atmospheres in outer solar system bodies, measurement of fundamental properties of pre-main sequence stars, calibrating young star evolution, defining the substellar boundary at the youngest ages, outflow characteristics in Wolf-Rayet stars, finding the first generation of exoplanets, gas dynamics in planetary nebulae, and structure of the ISM in molecular clouds. In this talk I will report on initial results from selected programs.

Author(s): Lisa A. Prato[1]
Institution(s): *1. Lowell Observatory*

126.07 – The Puzzling Atmospheres of Low-mass Stars, Brown Dwarfs and Exoplanets Revealed by the Discovery Channel Telescope

The Large Monolithic Imager (LMI) on the Discovery Channel Telescope (DCT) enables high-precision photometry with a scriptable interface and rapid cycling between photometric bands, all while guiding off-axis. Using LMI, scientists at Boston University have undertaken a number of investigations into low-mass stars, brown dwarfs and extrasolar planets. We will report on recent results from these investigations, including (1) measurements of transiting asteroids orbiting a white dwarf, (2) refined ephemerides for long-period transiting exoplanets, (3) investigations revealing biases in space-based exoplanet light curves, (4) investigations of the nature of activity in low-mass stars and brown dwarfs and (5) investigations of low-mass eclipsing binary stars. We will also propose future studies of low-mass stars, brown dwarfs and exoplanets using current and future DCT instrumentation.

Author(s): Philip Steven Muirhead[1], Bryce Croll[1], Paul A. Dalba[1], Mark Veyette[1], Eunkyu Han[1], Aurora Kesseli[1], Brian Healy[1]
Institution(s): *1. Boston University*

126.08 – Characterizing Mid-Type M Dwarfs in the Kepler Field with the Discovery Channel Telescope and WIYN

Planet occurrence rates increase with decreasing stellar mass (later spectral types); therefore, M dwarf systems are our most promising targets in the search for exoplanets. The identification and characterization of stars in the original Kepler field was accomplished using photometry alone, resulting in large uncertainties for late-type stars like M dwarfs. In order to more accurately compute the planet occurrence rate around mid-type M dwarfs, we need to better constrain their stellar radii and masses, properties which strongly correlate with other stellar parameters such as temperature and metallicity. These measurements need to be performed on a statistically significant population of stars including systems with and without planets. Therefore, we have begun to spectroscopically characterize the properties of the 559 probable mid-type M dwarfs in the Kepler field using red optical spectra obtained with the DeVeny Spectrograph on the Discovery Channel Telescope (DCT) and Hydra on the WIYN telescope in order to constrain the planet occurrence rate for such stars. We will be presenting initial results from our DCT and WIYN observations, including new temperature, radius, and mass estimates which we can use in occurrence rate calculations.

Author(s): Kevin Hardegree-Ullman[2], Michael Cushing[2], Philip Steven Muirhead[1]
Institution(s): *1. Boston University , 2. University of Toledo*

126.09 – Speckle Interferometry at Lowell's Discovery Channel Telescope

The high-spatial-resolution technique of speckle interferometry has been in use at Lowell Observatory's Discovery Channel Telescope since 2014 with the Dual-channel Stellar Speckle Imager (DSSI; Horch et al. 2009) as a visiting instrument. Using its standard bandpasses of 692 and 880nm, we have used highly efficient DSSI instrument to inspect over a thousand stellar systems over the course of 2014 (Horch et al. 2015). We have also demonstrated the usefulness of the DSSI@DCT system for resolved observations of high-altitude (>1,000 miles) man-made satellites in highly non-sidereal rate orbits.

Author(s): Gerard van Belle[1], Elliott Horch[2]
Institution(s): *1. Lowell Observatory, 2. Southern Connecticut State University*

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127 – Linking the Scales of Star Formation

Could the relationships between the properties of star formation on two fundamental scales – on those of galaxy disks over kiloparsecs, and individual stars, stellar clusters and associations over parsecs – provide new key insights into the mechanisms that control star formation? In this session we will probe this missing piece in the grand puzzle of star formation by reporting new results from the Hubble Space Telescope (HST) Treasury program LEGUS (Legacy ExtraGalactic Ultraviolet Survey), and related projects. LEGUS has obtained complete five band HST imaging in NUV, U, B, V and I, for 50 nearby galaxies. The galaxies have been carefully selected to cover the full range of galaxy mass, morphology, star formation rate (SFR), SSFR (specific SFR=SFR/mass), metallicity, internal structure (rings, bars), and interaction state found in the Local Volume where HST can resolve and age-date young stellar populations on pc-scales. Well-known, archetypal galaxies with the largest suites of multi-wavelength data available have been targeted, to ensure that the dataset will have exceptional legacy value. High resolution UV imaging, which was not previously available for >90% of the sample, is critical for the age-dating and identification of young massive stars and clusters; the reconstruction of the recent star formation histories (SFH) at requisite accuracies (~10 Myr); and the breaking of the age-extinction degeneracies on small scales. The talks in this session will touch upon a full range of star formation science pursued by LEGUS and related projects, from studies of the demographics of star clusters to the environments of supernovae. We anticipate that the LEGUS dataset will also support a significant amount of community science, and the session will showcase the higher-level data products (multiband drizzled images; catalogs of the physical and observed properties of stars and star clusters) which have been and will be released to the community.

127.01 – HST LEGUS - Legacy Extragalactic UV Survey

LEGUS (Legacy ExtraGalactic UV Survey) is a cycle 21 Hubble Space Telescope Treasury program designed to provide a definite characterization of the links between star formation on two fundamental scales: those of individual stars, stellar clusters and associations on parsec scales, and of galaxy disks on kilo-parsec scales.

In order to achieve this goal, LEGUS has obtained multi-color images of 50 nearby star-forming galaxies, in the distance range 3-16 Mpc. Wavelength coverage spans five bands (NUV, U, B, V, and I) by combining new WFC3 observations with archival ACS imaging data, when available. The galaxies were carefully selected to sample the full range of galaxy mass, morphology, star formation rate (SFR), sSFR (specific SFR=SFR/mass), metallicity, internal structure (rings, bars), and interaction state found in the Local Volume where HST can resolve and age-date young stellar populations on parsec scales. Many of the galaxies are well-known, iconic ones, with a wealth of additional information available in a number of archives. The multi-color HST images are being used to secure complete inventories of the young stars, star clusters, and structures of the galaxies, together with the characterization of their ages, masses, and extinctions.

I will briefly introduce a few highlights on the scientific results obtained so far by the LEGUS team, in addition to describing the high-level science products the team plans to release to the community, in order to enable a wide range of additional scientific applications.

Author(s): Daniela Calzetti[1]
Institution(s): *1. Univ. of Massachusetts*
Contributing team(s): and the LEGUS Team

127.03 – Star Cluster Luminosity Functions and Cluster Formation Efficiencies in LEGUS Dwarf Galaxies

We present preliminary results of star cluster luminosity functions (LFs) and cluster formation efficiencies (Γ) in the LEGUS dwarf galaxy sub-sample. We have used a combination of automated and visual identification techniques to allow us to construct a more complete sample of clusters in these low-mass, low-SFR environments compared to previous studies of dwarf galaxies. Cluster properties are derived from fitting UV and optical (NUV-I) HST photometry to both deterministic and stochastic single-aged stellar populations models. We compare the cluster formation efficiencies and LF slopes to those of previous studies in both dwarf and massive spiral galaxy environments. Recent studies have found that both the LF slope and Γ form trends with galaxy environment. Our LF slope and Γ measurements in the LEGUS dwarfs will allow us to test these trends in the extreme, low-SFR regime and provide a better understanding of the star formation process.

Author(s): David O. Cook[1], Janice C. Lee4, Angela Adamo3, Hwiyun Kim[2], Jenna E Ryon5
Institution(s): *1. Caltech, 2. McDonald Observatory - UT Austin, 3. Stockholm University, 4. StSci, 5. University of Wisconsin - Madison*
Contributing team(s): LEGUS Team

127.04 – The Fraction of Stars Formed In A Diverse Sample of 8 Galaxies

We have estimated the fraction of stars born in compact star clusters, Gamma, in a diverse sample of 8 galaxies, including two irregulars, two dwarf starbursts, two spirals, and two mergers. We find an average value for our sample of Gamma ~30 +/- 12 %. We also calculate the fraction of stars found in clusters that have survived to older ages, and find values of 4.6 +/- 2.5% for 10-100 Myr clusters, and 2.4+/-1.1 % for 100-400 Myr clusters. Intriguingly, Gamma does not appear to vary with the star formation rate (SFR), the SFR density or the gas density in our sample. These new results are at odds with the well-established picture where a higher fraction of stars form in clusters when the star formation and gas densities are high. We explore reasons for the differences between our results and previous work, and describe how the LEGUS plus Halpha-LEGUS surveys will be used to help settle the issue of whether or not Gamma varies with galaxy property.

Author(s): Rupali Chandar[1]
Institution(s): *1. University of Toledo*

127.05 – The Hierarchical Distribution of Young Stellar Clusters in Nearby Galaxies

We investigate the spatial distributions of young stellar clusters in six nearby galaxies to trace the large scale hierarchical star-forming structures. The six galaxies are drawn from the Legacy ExtraGalactic UV Survey (LEGUS). We quantify the strength of the clustering among stellar clusters as a function of spatial scale and age to establish the survival timescale of the substructures. We separate the clusters into different classes, compact (bound) clusters and associations (unbound), and compare the clustering among them. We find that younger star clusters are more strongly clustered over small spatial scales and that the clustering disappears rapidly for ages as young as a few tens of Myr, consistent with clusters slowly losing the fractal dimension inherited at birth from their natal molecular clouds.

Author(s): Kathryn Grasha[1], Daniela Calzetti[1]
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127.06 – Single Star HII Regions in nearby LEGUS Galaxies

It is believed that O stars typically form in clustered environments, however past observations have shown that there are a few O stars in the field that are fairly far from clusters and have low space velocities. The goal of this project is to determine whether these O stars can be born in situ or whether they are runaways ejected from their parent clusters due to binary supernova explosions or other dynamic interactions. To do this, we select candidate hot stars and compute an isolation metric based on distance from other hot stars and clusters. We then deploy Zooniverse citizen scientists to classify the isolated sources and their associated nebulae. The detected presence of an HII region allows us to confirm a candidate as a true O star. We use the Zooniverse classification system to study the morphology of these HII regions and determine the runaway status of the O stars.

Author(s): Bridget Kayitesi[2], Janice C. Lee[2], David A. Thilker[1]
Institution(s): *1. Johns Hopkins University, 2. Space Telescope Science Institute*
Contributing team(s): LEGUS Team

127.07 – Multi-scale, Hierarchically Nested Young Stellar Structures in LEGUS Galaxies

The study of star formation in galaxies has predominantly been limited to either young stellar clusters and HII regions, or much larger kpc-scale morphological features such as spiral arms. The HST Legacy ExtraGalactic UV Survey (LEGUS) provides a rare opportunity to link these scales in a diverse sample of nearby galaxies and obtain a more comprehensive understanding of their co-evolution for comparison against model predictions. We have utilized LEGUS stellar photometry to identify young, resolved stellar populations belonging to several age bins and then defined nested hierarchical structures as traced by these subsamples of stars. Analagous hierarchical structures were also defined using LEGUS catalogs of unresolved young stellar clusters. We will present our emerging results concerning the physical properties (e.g. area, star counts, stellar mass, star formation rate, ISM characteristics), occupancy statistics (e.g. clusters per substructure versus age and scale, parent/child demographics) and relation to overall galaxy morphology/mass for these building blocks of hierarchical star-forming structure.

Author(s): David A. Thilker[1]
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Contributing team(s): LEGUS Team

127.08 – Extinction Mapping of Nearby Galaxies Using LEGUS

Extinction by dust affects studies of star formation and stellar evolution in galaxies. There are different ways to measure the distribution of dust column densities across galaxies. Here we present work based on extinctions measured towards individual massive stars.
Isochrones of massive stars lie in the same location on a color-color diagram with little dependence on metallicity and luminosity class, so the extinction can be directly derived from the observed photometry. We develop a method for generating extinction maps using photometry of massive stars from the Hubble Space Telescope for the nearly 50 galaxies observed by the Legacy Extragalactic Ultraviolet Survey (LEGUS). The derived extinction maps will allow us to correct ground-based and HST Halpha maps for extinction, and will be used to constrain changes in the dust-to-gas ratio across the galaxy sample and in different star formation, metallicity and morphological environments. Previous studies have found links between galaxy metallicity and the dust-to-gas mass ratio. Dust abundance and gas metallicity are critical constraints for chemical and galaxy evolution models. We present a study of LEGUS galaxies spanning a range of distances, metallicities, and galaxy morphologies, including metal-poor dwarfs Holmberg I and II and giant spirals NGC 6503 and NGC

628. We see clear evidence for changes in the dust-to-gas mass ratio with changing metallicity. We also examine changes in the dust-to-gas mass ratio with galactocentric radius. Ultimately, we will provide constraints on the dust-to-gas mass ratio across a wide range of galaxy environments.

Author(s): Lauren Kahre[1], Rene A.M. Walterbos[1], Daniela Calzetti[3], Elena Sabbi[2], Leonardo Ubeda[2]
Institution(s): *1. New Mexico State University, 2. Space Telescope Science Institute, 3. University of Massachusetts*
Contributing team(s): LEGUS Collaboration

127.09 – SN Environments in LEGUS

From the LEGUS multi-band data we can analyze the stellar environments of recent supernovae (SNe), attempt to recover emission from the aging SNe, and search for light echoes around them. We can attempt to constrain the properties of the SN progenitor, based on age estimates for stellar populations in the immediate SN environments. The sites of 15 SNe of various types can be isolated in these images. I will briefly provide a summary of what we have learned about these SNe from their LEGUS environments. A few of these environments have been analyzed and published by other teams. In addition, two SNe occurred shortly after observations were made of two of the galaxies in our sample, NGC 4258 and NGC 1566. I will talk about the inferences we can make regarding the progenitors of these two core-collapse events. In general, the LEGUS dataset will be a valuable resource for identifying the progenitors of future SNe.

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Contributing team(s): the LEGUS Team

127.10 – Star Formation at Low Rates: How a Lack of Massive Stars Impacts the Evolution of Dwarf Galaxies

In recent years dedicated observations have uncovered star formation at extremely low rates in dwarf galaxies, tidal tails, ram-pressure stripped gas clouds, and the outskirts of galactic disks. At the same time, numerical simulations of galaxy evolution have advanced to higher spatial and mass resolutions, but have yet to account for the underfilling of the uppermost mass bins of stellar initial mass function (IMF) at low star-formation rates. In such situations, simulations may simply scale down the IMF, without realizing that this unrealistically results in
fractions of massive stars, along with fractions of massive star feedback energy (e.g., radiation and SNII explosions). Not properly accounting for such parameters has consequences for the self-regulation of star formation, the energetics of galaxies, as well as for the evolution of chemical abundances.
Here we present numerical simulations of dwarf galaxies with low star-formation rates allowing for two extreme cases of the IMF: a "filled" case with fractional massive stars vs. a truncated IMF, at which the IMF is built bottom-up until the gas reservoir allows the formation of a last single star at an uppermost mass. The aim of the study is to demonstrate the different effects on galaxy evolution with respect to self-regulation, feedback, and chemistry. The case of a stochastic sampled IMF is situated somewhere in between these extremes.

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128 – Surveys & Data - Catalogs, Archives, Searched

128.01 – From Sky to Archive: Long Term Management of Sky Survey Data

Sky survey data may remain scientifically valuable long beyond the end of a survey's operational period, both for continuing inquiry and for calibrating and testing instruments for subsequent generations of surveys. Astronomy infrastructure has many stakeholders, including those concerned with data management. Research libraries are increasingly partnering with scholars to sustain access to data.

The Sloan Digital Sky Survey (SDSS) was among the first major scientific projects to partner with libraries in this way, embarking on a data transfer process with two university libraries. We report on a qualitative case study of this process.

Ideally, long-term sustainability of sky survey data would be a key part of planning and construction, but rarely does this occur. Teams are under pressure to deliver a project on time and on budget that produces high-quality data during its operational period, leaving few resources available to plan long-term data management. The difficulty of planning is further compounded by the complexity of predicting circumstances and needs of the astronomy community in future decades. SDSS team members regarded libraries, long-lived institutions concerned with access to scholarship, as a potential solution to long-term data sustainability.

As the SDSS data transfer was the first of this scale attempted – 160 TB of data – astronomers and library staff were faced with scoping the range of activities involved. They spent two years planning this five-year process. While successful overall as demonstration projects, the libraries encountered many obstacles. We found all parties experienced difficulty in articulating their notions of "scientific data," "archiving," "serving," and "providing access" to the datasets. Activities and interpretations of the data transfer process varied by institutional motivations for participation and by available infrastructure. We conclude several, rather than a single, "library solutions" for long-term data management should be considered. Life cycle models popular in the library community are insufficient to conceptualize data management at this scale. We also identify institutional and policy challenges for curating large scientific datasets.

Author(s): Peter T Darch[2], Ashley E. Sands[1], Christine Borgman[1], Milena S. Golshan[1], Sharon Traweek[1]
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128.02D – A Mass Census of the Nearby Universe with RESOLVE and ECO

The low-mass slope of the galaxy stellar mass function is significantly shallower than that of the theoretical dark matter halo mass function, leading to several possible interpretations including: 1) stellar mass does not fully represent galaxy mass, 2) galaxy formation becomes increasingly inefficient in lower mass halos, and 3) environmental effects, such as stripping and merging, may change the mass function. To investigate these possible scenarios, we present the census of stellar, baryonic (stars + cold gas), and dynamical masses of galaxies and galaxy groups for the RESOLVE and ECO surveys. RESOLVE is a highly complete volume-limited survey of ~1500 galaxies, enabling direct measurement of galaxy mass functions without statistical completeness corrections down to baryonic mass Mb ~ 10^9 Msun. ECO provides a larger data set (~10,000 galaxies) complete down to Mb ~ 10^9.4 Msun. We show that the baryonic mass function has a steeper low-mass slope than the stellar mass function due to the large population of low-mass, gas-rich galaxies. The baryonic mass function's low-mass slope, however, is still significantly shallower than that of the dark matter halo mass function. A more direct probe of total galaxy mass is its characteristic velocity, and we present RESOLVE's preliminary galaxy velocity function, which combines ionized-gas rotation curves, stellar velocity dispersions, and estimates from scaling relations. The velocity function also diverges from the dark matter halo velocity function at low masses. To study the effect of environment, we break the mass functions into different group halo mass bins, finding complex substructure, including a depressed and flat low-mass slope for groups with halo masses ~10^11.4-12 Msun, which we refer to as the nascent group regime, with typical membership of 2-4 galaxies. This substructure is suggestive of efficient merging or gas stripping in nascent groups, which we find also have large scatter in their cold-baryon fractions, possibly pointing to diversity in hot halo gas content in this regime. This work is supported by NSF grant AST-0955368, the NC Space

Grant Graduate Research Fellowship Program, and a UNC Royster Society Dissertation Completion Fellowship.

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Contributing team(s): RESOVE team

128.03 – What Time Is Sunrise? Revisiting the Refraction Component of Sunrise/set Prediction Models

Algorithms that predict sunrise and sunset times currently have an error of one to four minutes at mid-latitudes (0° - 55° N/S) due to limitations in the atmospheric models they incorporate. At higher latitudes, slight changes in refraction can cause significant discrepancies, even including difficulties determining when the Sun appears to rise or set. While different components of refraction are known, how they affect predictions of sunrise/set has not yet been quantified. A better understanding of the contributions from temperature profile, pressure, humidity, and aerosols could significantly improve the standard prediction. We present a sunrise/set calculator that interchanges the refraction component by varying the refraction model. We then compare these predictions with data sets of observed rise/set times to create a better model. Sunrise/set times and meteorological data from multiple locations will be necessary for a thorough investigation of the problem. While there are a few data sets available, we will also begin collecting this data using smartphones as part of a citizen science project. The mobile application for this project will be available in the Google Play store. Data analysis will lead to more complete models that will provide more accurate rise/set times for the benefit of astronomers, navigators, and outdoorsmen everywhere.

Author(s): Teresa Wilson[1], Jennifer L. Bartlett[2], James Lindsay Hilton[2]
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128.04 – Testing LSST Dither Strategies for Large-scale Structure Systematics

The Large Synoptic Survey Telescope (LSST) will start a ten-year survey of the southern sky in 2022. Since the telescope observing strategy can lead to artifacts in the observed data, we undertake an investigation of implementing large telescope-pointing offsets (called dithers) as a means to minimize the induced artifacts. We implement various types of dithers, varying in both implementation timescale and the dither geometry, and examine their effects on the r-band coadded depth after the 10-year survey. Then we propagate the depth fluctuations to galaxy counts fluctuations, which are a systematic for large-scale structure studies. We show that the observing strategies induce window function uncertainties which set a constraint on the level of information we can extract from an optimized survey to precisely measure Baryonic Acoustic Oscillations at high redshifts. We find that the best dither strategies lead to window function uncertainties well below the minimum statistical uncertainty after the 10 years of survey, hence not requiring any systematics correction methods. While the systematics level is considerably higher after the first year of the survey, dithering can play a critical role in reducing it. We also explore different cadences, and demonstrate that the best dither strategies minimize the window function uncertainties for various cadences.

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128.05D – A Search for Miras in M33 Using Sparsely-Sampled Time Series Photometry

The Mira Period-Luminosity relations (PLRs) at near- and mid-infrared wavelengths are promising distance indicators, with brighter absolute magnitudes than Cepheids, comparable PLR dispersions and ubiquitous presence in all galaxy types. We developed a semi-parametric Gaussian process periodogram method for sparsely-sampled Mira light curves and applied it to I-band observations of M33. We discovered more than 1800 Miras, which were subsequently classified using machine-learning techniques. We present an overview of the Gaussian process model, the Random Forest classifiers, and the resulting PLRs.

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128.06 – Astronomical Methods for Nonparametric Regression

I will discuss commonly used techniques for nonparametric regression in astronomy. We find that several of them, particularly running averages and running medians, are generically biased, asymmetric between dependent and independent variables, and perform poorly in recovering the underlying function, even when errors are present only in one variable. We then examine less-commonly used techniques such as Multivariate Adaptive Regressive Splines and Boosted Trees and find them superior in bias, asymmetry, and variance both theoretically and in practice under a wide range of numerical benchmarks. In this context the chief advantage of the common techniques is runtime, which even for large datasets is now measured in microseconds compared with milliseconds for the more statistically robust techniques. This points to a tradeoff between bias, variance, and computational resources which in recent years has shifted heavily in favor of the more advanced methods, primarily driven by Moore's Law. Along these lines, we also propose a new algorithm which has better overall statistical properties than all techniques examined thus far, at the cost of significantly worse runtime, in addition to providing guidance on choosing the nonparametric regression technique most suitable to any specific problem. We then examine the more general problem of errors in both variables and provide a new algorithm which performs well in most cases and lacks the clear asymmetry of existing non-parametric methods, which fail to account for errors in both variables.

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128.07 – FRB121102: statistics of burst properties compared to the fast radio burst population

Fast Radio Bursts (FRBs) are millisecond-long radio events with dispersion measures that exceed that expected from our Galaxy. Therefore the FRB source is anticipated to be extragalactic and highly energetic. Until recently, these were only observed as one-off events. This was until multiple bursts were observed at the Arecibo Observatory from FRB 121102. I will present the most recent burst statistics from FRB 121102's follow-up observations. Understanding the distribution of all burst characteristics can eliminate some of the proposed mechanisms to FRB 121102’s burst events. Not only that, comparing these values to the rest of the FRB population can give insight as to whether FRB 121102 is distinct from the rest of the FRB population.

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Contributing team(s): PALFA Survey Team, VLA+AO FRB121102 Simultaneous Campaign Team, EVN FRB121102 Campaign Team

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129 – HAD III: History

129.01 – An Account of Stellar Spectroscopy and John S. Plaskett's Leadership within Early 20th-Century Astrophysics in Canada

From the perspective of the science of astronomy, the interpretation of the light spectrum was a fundamental development in the chemical analysis of celestial starlight. The breakthrough discovery with the application of spectroscopy in 1859, inaugurated a new period in astronomy that evolved into astrophysics. It launched a continuing episode of new astronomy that was later embraced in early 20th-century Canada where it was spearheaded by Canadian physicist and scientist, John S. Plaskett (1865-1941). The research work of John Plaskett at the Dominion Observatory in Ottawa, Ontario, from 1903 and, later, the Dominion Astrophysical Observatory in Victoria, British Columbia, from 1918, brought international recognition to Canada's early efforts in astrophysics. Plaskett's determination and personal boldness led to the establishment of a small cadre of Canadian astronomers who worked on their astrophysical research programs under Plaskett as their supervisor. Despite its small population at the time and a relatively infinitesimal number of professional astronomers, Canada did become recognized for its early spectrographic work in astrophysics, which was due to developing a professional status equal to its international colleagues. Plaskett improved the techniques of celestial spectroscopy during his scientific work at the Dominion Observatory and, again later, at its newly-built sister facility, the Dominion Astrophysical Observatory. Historically, Plaskett found himself to be the right person, in the right place, at the right time, and with the right temperament during the review period spanning 1903 to 1935.

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129.02 – *Under Connecticut Skies*: Exploring 100 Years of Astronomy at Van Vleck Observatory in Middletown, Connecticut

Under Connecticut Skies examines the history of astronomy at Van Vleck Observatory, located on the campus of Wesleyan University in Middletown, Connecticut. Since its dedication in June of 1916, Van Vleck has been an important site of astronomical research, teaching, and public outreach. Over a thousand visitors pass through the observatory each year, and regular public observing nights happen year-round in cooperation with the Astronomical Society of Greater Hartford. Our project explores the place-based nature of astronomical research, the scientific instruments, labor, and individuals that have connected places around the world in networks of observation, and the broader history of how observational astronomy has linked local people, amateur observers, professional astronomers, and the tools and objects that have facilitated their work under Connecticut's skies over the past 100 years.

Our research team has produced a historical exhibition to help commemorate the observatory's centennial that opened to the public in May of 2016. Our work included collecting, documenting, and interpretting this history through objects, archival documents, oral histories, photographs, and more. The result is both a museum and a working history "laboratory" for use by student and professional researchers. In addition to the exhibit itself, we have engaged in new interpretive programs to help bring the history of astronomy to life. Future work will include digitization of documents and teaching slides, further collection of oral histories, and expanding the collection to the web for use by off-site researches.

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Institution(s): *1. Wesleyan Univ.*

129.03 – Building the Green Bank Telescope

In a previous presentation, I reported on how the freak collapse of the NRAO 300-ft transit radio telescope led to the inclusion of $75 million for a new radio telescope in the 1989 Congressional Emergency Supplemental Appropriations Act. But, this was only the beginning. NRAO was faced with challenging specifications and an unworkable schedule, but there was no design and no project team. Only one bid was even close to the Congressional appropriation. In an attempt to meet the unrealistic antenna delivery date, the contractor started construction of the foundation and fabrication of antenna members before the design was finished, leading to retrofits, redesign, and multiple delays. The antenna contractor was twice sold to other companies leading to further delays and cost escalation. In order to recoup their mounting losses, the new owners sued NRAO for $29 million for claimed design changes, and NRAO countersued demanding to be reimbursed for added project management costs and lost scientific data resulting from the seven-year delay in the completion of the telescope. Legal fees and a small net award in favor of the contractor left NRAO and the NSF with a nine million dollar bill which NSF handled by an innovative accounting adjustment.

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129.04 – The 2017 Eclipse: Centenary of the Einstein Light Deflection Experiment

August 21st, 2017 will see a total eclipse of the Sun visible in many parts of the United States. Coincidentally this date marks the centenary of the first observational attempt to test Einstein's General Theory of Relativity by measuring gravitational deflection of light by the Sun. This was attempted by the Kodaikanal Observatory in India during the conjunction of Regulus with the Sun in daylight on August 21st, 1917. The observation was attempted at the urging of the amateur German-British astronomer A. F. Lindemann, with his son, F. A. Lindemann, a well-known physicist, who later played a significant role as Churchill's science advisor during World War II. A century later Regulus will once again be in conjunction with the Sun, but by a remarkable coincidence, this will occur during a solar eclipse! Efforts will be made to measure the star deflection during the eclipse and the experiment is contrasted with the famous expeditions of 1919 which were the first to actually measure the light deflection, since the 1917 effort did not meet with success. Although in recent decades there have been efforts made to suggest that the 1919 eclipse team, led by Arthur Stanley Eddington and Sir Frank Watson Dyson, over-interpreted their results in favor of Einstein this talk will argue that such claims are wrong-headed. A close study of their data analysis reveals that they had good grounds for the decisions they made and this conclusion is reinforced by comparison with a modern re-analysis of the plates by the Greenwich Observatory conducted in 1977.

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129.06 – The Unlikely Origins of NASA's "Search for Origins" Program

NASA's Origins Program for many years was by far one of the most important scientific initiatives in NASA's history, linking together priority research campaigns in planetary science, astrophysics, and the biological sciences. It served also as an overarching description to the agency stakeholders of a new generation of major space missions and technology investments. Moreover, the Program, although no longer formally in existence, significantly influences multiple major science priorities for NASA even today. Remarkably, inception of NASA's Origins Program — The Search for Our Cosmic Roots — two decades ago was initiated by the country's political leadership, not by the scientific community, the National Academy of Sciences, or by an advisory panel of experts. Instead, it was an initiative by the White House in response to the stunning announcement of 'evidence' for life found on a Martian meteorite not long after the discovery of the first extrasolar planet orbiting a sun-like star. A White House memo dated in September 1996, written by John H. Gibbons, Assistant to the President for Science and Technology to Dan Goldin, NASA Administrator at that time, called for a "Space Summit" that would include experts on three broad topics: the universe, planets, and life.

The summit was jointly organized by NASA and the National Research Council, and was chaired by Vice-President Al Gore in late October 1996. Three dozen biologists, planetary scientists, astronomers, and cosmologists participated. The outcome was the Origins Program, which has been a prominent part of NASA's science program ever since, theme which is captured by the simple and profound questions: How Did We Get Here? and Are We Alone?

This particular initiative and its genesis demonstrates that science discoveries, followed by political activism and then executive orders can impact and shape for decades the paths to major science priorities, practices, and implementation. In this presentation, we summarize the inception of the Search for Origins initiative, especially its beginnings outside the scientific community, and its early justification and activities.

Author(s): Mario R. Perez[2], Harley A. Thronson[1]
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129.07 – Recording of Supernovae in Rock Art, A Case Study at the Paint Rock Pictograph Site

The Paint Rock pictographs in central Texas and their use as solar markers were formally reported for the first time by Dr. R. Robert Robbins at the 1999 AAS meeting #193 in Austin, Texas. He reported the operations of the winter solstice marker and suggested the possibility of more, including a summer solstice solar marker. Since this first report, there have been many informal studies of the Paint Rock site. In 1955, William C. Miller made the first interpretation of rock art as depicting images of the Crab supernova of AD 1054, which has produced many reports at other rock art sites in the American Southwest, including one at Paint Rock. All of these claims have a star and crescent configuration. Recently, these claims have been dismissed. We propose that the second panel at Paint Rock is representative of Tycho Brahe's supernovae SN1572. Miller set up a set of restrictions and criteria to evaluate these potential claims. We discuss Miller's criteria and two additional sets of criteria to evaluate representations of historical records of supernovae sightings. Two sets of characteristics of supernovae are provided, the first being galactic location and the second observational characteristics of naked eye supernovae. Employing astronomical software, we show that the panel at Paint Rock meets the restrictions and criteria discussed, that leads to high confidence in stating it records Tycho Brahe's supernova SN1572.

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Contributing team(s): NA

129.08 – Thirty Years After Jack Eddy at the Big Horn Medicine Wheel

In the thirty years since John (Jack) Eddy's work on the Big Horn Medicine Wheel, attention to the astronomy of medicine wheels went from high to low, with the lowest moment occurring during the "welcome" talk of the Oxford IX International Archaeoastronomy (ISAAC) conference in Lima, Peru in 2011 when the wall-size projected image of the Big Horn Wheel carried a thick black "X" across its face.

The alignments proposed by Eddy in 1974 and by Robinson in the 1980s have been reviewed and analyzed at the Wheel on Medicine Mountain in situ under bitter cold, clear dark nights at 10,000 feet altitude. Research was conducted using naked eye skywatching, transit surveying, and a Meade Cassegraine 8" electronic telescope. Along with this "review" of 20th century research, new research was conducted Wheel causing the second decade of the 21st century to bring new physical evidence and historical information for consideration.

New research at the Big Horn Medicine Wheel gives evidence that the Wheel "mirrors" the night and daytime sky by creating a sky "grid" by its design made of basement and surface stones. The Wheel's stone design mirrors the precession of the equinoxes by showing positions of all major pole stars over the full precessional cycle. Its twenty-eight sections are useful in the same way the twenty-eight sectioned Stations of the Moon star charts were useful in ancient and historical times.

This manner of dividing the sky for tracking celestial objects holds celestial markers in constant position over millennia. This occurs because the Wheel's center represents the Sun' ecliptic north pole. Star charts that use the ecliptic pole do not need constant mathematical computation to keep up with current declinations and right ascensions. The Wheel's twenty-eight sectioned sky chart keeps the same Dec and RA for celestial positions for thousands of years and will more quickly alert the observer to changes due to proper motion than will our current Polaris-dependant Dec-RA system in use.

Author(s): Ivy Merriot[1]
Institution(s): *1. Montana State University*

129.09 – The Astronomy Genealogy Project: It's more than just tracing your ancestry

The Astronomy Genealogy Project ("AstroGen"), a project of the Historical Astronomy Division (HAD), will soon appear on the AAS website (https://astrogen.aas.org/). Ultimately, it will list the world's astronomers with their highest degrees, titles of theses for those who wrote them, academic advisors, universities, and links to the astronomers or their obituaries, their theses when online, and more. At present the AstroGen team is working on those who earned doctorates with astronomy-related theses. We show what can be learned already, with twelve countries essentially complete and about 19,000 theses recorded. For the twelve countries —Australia, Canada, Chile, Ireland, the Netherlands, New Zealand, Norway, South Africa, Spain, Sweden, the United Kingdom, and the United States—half of the theses have been submitted since 1999, and more than 60% are online. We will present information comparing countries, universities, and eras. Nearly all information has been gathered online, and there is much more available. We are seeking people with knowledge of the languages and academic cultures of other countries to join us.

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Contributing team(s): AstroGen Team

130 – Variable Stars, Asteroseismology

130.01 – Studying RR Lyrae Stars in M4 with K2

Observations by Kepler/K2 have revolutionized the study of RR Lyrae stars by allowing the detection of new phenomena, such as low amplitude additional modes and period doubling, which had not previously been seen from the ground. During its campaign 2, K2 observed the globular cluster M4, providing the first opportunity to study a sizeable group of RR Lyrae stars that belong to a single population; the other RR Lyrae stars that have been observed from space are field stars in the galactic halo and thus belong to an assortment of populations. We present the results of our study of the RR Lyrae variables in M4 from K2 photometry. We have identified additional, low amplitude pulsation modes in the two observed RRc stars. In three RRab stars we have found the Blazhko effect with periods of 16.6 days, 22.4 days, and 44.5 days.

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130.02D – RR Lyrae variable stars in M31-M33 super-halo

RR Lyrae variable stars can serve as powerful probes of their host stellar populations. Information such as distance, metallicity, reddening, and age can be gleaned from their pulsation properties. Therefore, studying them in the nearest spiral galaxies M31 and M33 will yield important information about the early history of these galaxies. The main goals of this study are: 1) To investigate the Oosterhoff type of RR Lyrae stars in M31 and M33 and compare them with the Milky Way to better understand the formation of these galaxies. 2) To investigate the early formation history of these two galaxies through knowledge of their RR Lyrae stars. In order to achieve these goals, we have analyzed 10 fields in M31 and M33 (6 fields in M31 and 4 fields in M33) using archival imaging from the Hubble Space Telescope. Published data for M31, M33, and several M31 dwarf spheroidal galaxies are also used to study the global properties of RR Lyrae in these systems. The results are then compared with those in the Milky Way galaxy.

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Institution(s): *1. University of Florida*

130.03D – Probing the Histories of Local Group Dwarf Galaxies with Pulsating Variable Stars

I have identified and characterized the Cepheid and RR Lyrae variables in several Local Group dwarf galaxies using archival Hubble Space Telescope imaging. Template light curve fitting routines have been applied to the observations in order to accurately characterize the properties of these variable stars. The pulsation properties of these stars help to constrain their masses and ages, which in turn shed light on the evolution of their respective host systems. I will summarize what this work has yielded in the context of dwarf galaxy evolution and the accretion history of the Milky Way halo. I will also discuss simulated observations on artificial light curves which we have used to characterize different observing strategies and analysis techniques for studies of pulsating variable stars.

Author(s): Antonio J Ordoñez[1], Ata Sarajedini[1]
Institution(s): *1. University of Florida*

130.04 – The connection between period spectra and constraints in white dwarf asteroseismology

White dwarfs are the end product of evolution for around 98% of the stars in our Galaxy. Buried in their interiors are the records of physical processes that take place during earlier stages in the life of the star. Not long after the discovery of the first pulsating white dwarf, the promise of asteroseismology to unveil the interior structure of white dwarfs and therefore help us constrain their prior evolution became apparent. In recent years, a well-established theory of non-radial oscillations, improved white dwarf models, year of expertise built up in the field of white dwarf asteroseismic fitting, and computing power have culminated in the asteroseismology finally delivering what it promised: a detailed map of the interior structure of white dwarfs. As always in science, new results raise new questions. We perform a number of numerical experiments to better understand the connection between a given set of periods varying in the number of periods and in the set of radial overtones and the quality of the constraints on interior structure one obtains from fitting these periods.

Author(s): Agnes Kim[1]
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130.05 – Asteroseismology with Kepler and K2 data: Exploring horizontal branch cores using subdwarf B stars

Through the first seven K2 fields, 16 pulsating subdwarf B (sdBV) stars have been discovered. From the original mission, we found 19 sdBV stars. We continue to analyze these stars and
I will review the current status of our work. To date, we have applied asteroseismology tools to identify pulsations, measure rotation rates, including both differential and solid-body rotation; and identify asymptotic sequences. With K2 we have discovered several new short-period pulsators, which were lacking in K1; an ellipsoidal variable with no indications of frequency multiplets, even though its orientation and short binary period are well-suited for their detection; and pulsators which are filling in evolutionary parameter space.

Author(s): Michael Reed[1], Joshua Kern[1], Laura Ketzer[1]
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130.06 – Mid-Infrared Studies of the Variability of the Dustiest, Most Extreme Asymptotic Giant Branch Stars in the Magellanic Clouds

The asymptotic giant branch (AGB) phase is one of the last phases of a star's life. AGB stars lose mass in an outflow in which dust condenses and is pushed away from the star. Extreme AGB stars are so named because their very red colors suggest very large amounts of dust, which in turn suggests extremely high mass-loss rates. AGB stars also vary in their brightness, and studies show that extreme AGB stars tend to have longer periods than other AGB stars and are more likely to be fundamental mode pulsators. The variability of extreme AGB stars must be explored at infrared wavelengths, as the copious amounts of circumstellar dust renders them invisible in the optical. Using the *Spitzer Space Telescope*, we have observed a sample of extreme AGB stars in the Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC) over Cycles 9 through 12 during the Warm *Spitzer* mission. For each cycle, we typically observed a set of extreme AGB stars at both 3.6 and 4.5 microns wavelength approximately monthly for most of a year. These observations reveal a wide range of variability properties. Though we targeted a certain number of extreme AGB stars, our observations also monitored other stars in the fields. We present results from our analysis of the data obtained from these *Spitzer* variability programs.

Author(s): Benjamin A. Sargent[1], Margaret Meixner[1], Olivia Jones[1]
Institution(s): *1. Space Telescope Science Institute*

130.07 – An LBC view of Andromeda's dwarf spheroidal satellites

Results will be presented from deep time series observations of four dwarf spheroidal galaxies (dSphs)
in the Andromeda (M31) complex, namely, And XIX, And XXI, And XXV and And XXVII, that we have resolved in stars using the Large Binocular Cameras of the Large Binocular Telescope (LBT). Thanks to the LBT observations we discovered a total of over 200 RR Lyrae stars and 20 Anomalous Cepheids in these M31 satellite galaxies. We have characterised the stellar populations and the spatial distributions of their resolved stars and found evidence for different stellar generations and processes of merging and disruption occurring in these M31 dSphs.
We have also identified a candidate globular cluster in the center of And XXV, thus further increasing the observational evidence that globular clusters sitting in the core of dwarf galaxies are not an unusual feature both among the Milky Way and Andromeda's satellites.

Author(s): Felice Cusano[2], Gisella Clementini[2], Alessia Garofalo[1]
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131 – Cool Stars I

131.01D – Calibrating the Age-Rotation-Activity Relation in Low-Mass Stars: Chromospheric and Coronal Activity in the 500 Myr-old M37 Open Cluster

In low-mass stars, the strength of the magnetic dynamo decreases over time as stars spin down through the loss of angular momentum via magnetized winds. Both coronal X-ray emission and chromospheric Hα emission trace the strength of the changing dynamo and, when combined with rotation periods in a single-aged population, can therefore be used to examine the dependence of magnetic activity on rotation across a range of masses. We observed the 500-Myr-old open cluster M37 with *Chandra* and Hectospec on the MMT to obtain X-ray and Hα measurements for its low-mass stars. We obtained a sample of ≈280 cluster members with X-ray detections, ≈290 with Hα measurements, and ≈80 with both. This is the largest sample available for analyzing the dependence of coronal and chromospheric emission on rotation for a single-aged population. We used published rotation periods ($P_{\rm rot}$) to calculate Rossby numbers, $R_0 = P_{\rm rot} / \tau$, where τ is the convective turnover time, for all of the known rotators. We also determined the ratios of X-ray and Hα luminosities to bolometric luminosities to minimize mass dependencies when characterizing the rotation-activity relation at 500 Myr. With these data we explored how X-ray and Hα luminosity depend on R_0, and whether the behavior in the unsaturated regime (i.e., when increasing or decreasing R_0 changes the measured activity) differ for these two tracers of magnetic activity. Finally, we examine the age-activity relation as measured in the X ray using seven open clusters spanning the age range 6–600 Myr.

Author(s): Alejandro Núñez[1], Marcel A. Agueros[1]
Institution(s): *1. Columbia University*

131.02D – Open clusters as laboratories for stellar spin-down and magnetic activity decay

The oldest open clusters within 250 pc of the Sun, the Hyades and Praesepe, are important benchmarks for calibrating stellar properties such as rotation and magnetic activity. As they have the same age and roughly solar metallicity, these clusters serve as an ideal laboratory for testing the agreement between theoretical and empirical rotation-activity relations at ~600 Myr. The repurposed Kepler mission, K2, has allowed us to measure rotation periods for dozens of Hyads and hundreds of Praesepe members, including the first periods measured for fully convective Hyads. These data have enabled new tests of models describing the evolution of stellar rotation; discrepancies with these models imply that we still do not fully understand how magnetic fields affect stellar spin-down. I will present rotation periods measured for 48 Hyads and 699 Praesepe members with K2, along with associated Halpha and X-ray fluxes. I will also show how we can compare the dependence of H-alpha and X-ray emission on rotation in order to test theories of magnetic field topology and stellar dynamos. These tests inform models of stellar wind-driven angular momentum loss and the age-rotation-activity relation.

Author(s): Stephanie Douglas[1], Marcel A. Agueros[1], Kevin R. Covey[2]
Institution(s): *1. Columbia University, 2. Western Washington University*

131.03 – The rotation-activity relation in M dwarfs

Main sequence stars with masses below approximately 0.35 solar masses are fully-convective, and are expected to have a different type of magnetic dynamo than solar-type stars. Observationally, the dynamo mechanism can be probed through the relationship between rotation and magnetic activity, and the evolution of these properties. Though M dwarfs are the most common type of star in the galaxy, a lack of observational constraints at ages beyond 1 Gyr has hampered studies of the rotation-activity relation. To address this, we have made new measurements of rotation and magnetic activity in nearby, field-age M dwarfs. Combining our 386 rotation period measurements and 247 new optical spectra with data from the literature, we are able to probe the rotation-activity in M dwarfs with masses from 0.1 to 0.6 solar masses. We observe a threshold in the mass--period plane that separates active and inactive M dwarfs. The threshold coincides with the fast-period edge of the slowly rotating population, at approximately the rotation period at which an era of rapid rotational evolution appears to cease. We confirm that the activity of rapidly rotating M dwarfs maintains a saturated value. We have measured rotation periods as long as 140 days, allowing us to probe the unsaturated regime in detail. Our data show a clear power-law decay in relative H-alpha luminosity as a function Rossby number. We discuss implications for the magnetic dynamo mechanism.

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Author(s): Elisabeth R. Newton[2], Jonathan Irwin[1], David Charbonneau[1], Perry L. Berlind[1], Michael L. Calkins[1], Jessica D. Mink[1]
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131.04 – Know the Planet, Know the Star: Precise Stellar Parameters with Kepler

The Kepler space telescope has revolutionized exoplanetary science with unprecedentedly precise photometric measurements of the light curves of transiting planets. In addition to information about the planet and its orbit, encoded in each Kepler transiting planet light curve are certain properties of the host star, including the stellar density and the limb darkening profile. For planets with strong prior constraints on orbital eccentricity (planets to which we refer as “stellar anchors”), we may measure these stellar properties directly from the light curve. This method promises to aid greatly in the characterization of transiting planet host stars targeted by the upcoming NASA TESS mission and any long-period, singly-transiting planets discovered in the same systems. Using Bayesian inference, we fit a transit model, including a nonlinear limb darkening law, to a large sample of transiting planet hosts to measure their stellar properties. We present the results of our analysis, including posterior stellar density distributions for each stellar host, and show how the method yields superior precision to literature stellar properties in the majority of cases studied.

Author(s): Emily Sandford[1], David M. Kipping[1]
Institution(s): *1. Columbia University*

131.05D – The Ages of A-Stars: Interferometric Observations of Our Brightest Neighbors

The age of a star is one of its most fundamental parameters. Accurate ages of disk and/or planet hosting systems are essential for understanding their evolution, and accurate ages of stars which host directly-imaged planets are necessary for estimating the masses of such companions. Furthermore, accurate ages can be used to distinguish between proposed explanations for certain chemical peculiarities such as whether λ Boötis stars are young stars accreting clean gas, or more evolved stars experiencing mass loss.

The rapid rotation of the vast majority of A-stars introduces two major difficulties to determining their ages. First, the gravity darkening induced by rapid rotation affects the observed properties of a star (e.g., flux, temperature, etc.) making them dependent on the star’s inclination. Secondly, it is predicted that this rotation changes how a star evolves both chemically and structurally relative to slowly rotating stellar models. Observations from optical interferometry can address the first concern and modern evolutionary models which account for rapid rotation can address and test the second. When used in conjunction, these can yield accurate age estimates for A-stars. Using observations from the CHARA Array interferometer and the MESA evolutionary models, we estimate the ages and masses of seven members of the coeval Ursa Major moving group leading to an age estimate for the group of 414 ± 23 Myr. We also estimate the age of the directly-imaged planet host star κ Andromedae finding it to be 47^{+27}_{-40} Myr implying that the companion is in fact a low-mass brown dwarf with a mass of 22^{+8}_{-9} M_{Jup}. Finally, we present new observations and preliminary age and mass estimates for five stars with the λ Boötis chemical peculiarity and for six members of the Hyades open cluster.

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Contributing team(s): The CHARA Team

132 – CO-HI Observations of Galaxies

132.01 – ALMA Reveals Large Molecular Gas Reservoirs in Ancestors of Milky Way-Mass Galaxies at *z*=1.2-1.3

The gas accretion and star-formation histories of galaxies like the Milky Way remain an outstanding problem in astrophysics. Observations show that 8 billion years ago, at redshifts $z > 1$, the progenitors to Milky Way-mass galaxies were forming stars 30 times faster than today and predicted to be rich in molecular gas, in contrast with low present-day gas fractions (<10%). Using ALMA Band 4 observations, we detected the molecular gas using the CO(J=3-2) emission (rest-frame 345.8 GHz) in a sample of galaxies at redshifts z=1.2-1.3, selected to have the stellar mass (Log $M_*/M_\odot$=10.2) and star-formation rate (SFR = 20 $M_\odot$ yr^{-1}) of the main progenitors of today's Milky Way-mass galaxies at this epoch. We show that with relatively short ALMA integrations, we now probe efficiently the CO luminosities of $z > 1$ star-forming galaxies a factor two lower than was possible previously. The CO emission from these galaxies reveals large molecular gas reservoirs, with a ratio of molecular-gas mass-to-stellar mass of ~100%, indicating most of the baryons are in cold gas, not stars. The ratio of the galaxies' total luminosity from star formation to CO luminosity corresponds to long gas-consumption timescales. Compared to local spiral galaxies, the star-formation efficiency, estimated from the ratio of total IR luminosity to CO emission, has remained nearly constant since redshift z=1.2, despite the order of magnitude decrease in gas fraction, consistent with results for more massive and more luminous galaxies at this epoch. This implies that the the physical processes that determine the rate at which gas cools to form stars in distant galaxies appear to be similar to that in local galaxies.

Author(s): Casey J. Papovich5, Ivo Labbe[1], Karl Glazebrook4, Ryan Quadri5, Georgios Bekiaris4, Mark Dickinson3, Steven L. Finkelstein[6], David B. Fisher4, Hanae Inami3, Rachael C. Livermore[6], Lee Spitler[2], Caroline Straatman[1], Kim-Vy Tran5
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132.02 – GBT CO observations of two ACT dusty star-forming galaxies

We report new observations of low-J CO emission lines in two dusty star-forming galaxies (DSFGs) originally detected in a 470 deg^2 survey with the Atacama Cosmology Telescope (ACT). Continuum and spectral line followup of the DSFG sample from which these two objects are drawn is allowing us to characterize the physical conditions and redshift distribution of this important population. The new observations, obtained with the Ka and Q-band receivers on the Robert C. Byrd Green Bank Telescope (GBT), complement higher-J CO observations with the Large Millimeter Telescope (LMT) and the IRAM 30m telescope, trace the galaxies' cold gas reservoirs, and enable estimates of lensing magnifications within modest uncerstainties.

This work has been supported by a Student Observing Support grant from the National Radio Astronomy Observatory.

Author(s): Jesus Rivera4, Andrew J. Baker4, Grant Wilson9, Min Su Yun9, David T. Frayer3, Andrew I. Harris[8], Tobias Marriage[2], Megan Gralla5, Ting Su[2], Itziar Aretxaga[1], Kirsten Hall[2], David Hughes[1], John Patrick Hughes4, Charles R. Keeton4, Felipe Menanteau[6], Alfredo Montana[1], Amitpal Tagore7, Yuping Tang9
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Contributing team(s): Atacama Cosmology Telescope team

132.03 – Initial HI results from the Arecibo Pisces-Perseus Supercluster Survey

The Arecibo Pisces-Perseus Supercluster Survey is a targeted HI survey of galaxies that began its second observing season in October 2016. The survey is conducted by members of the Undergraduate ALFALFA Team (UAT) and extensively involves undergraduates in observations, data reduction, and analysis. It aims to complement the HI sources identified by the ALFALFA extragalactic HI line survey by probing deeper in HI mass (to lower masses) than the legacy survey itself. Measurements of the HI line velocity widths will be combined with uniform processing of images obtained in the SDSS and GALEX public databases to localize the sample within the baryonic Tully Fisher relation, allowing estimates of their redshift-independent distances and thus their peculiar velocities.

The survey is designed to constrain Pisces-Perseus Supercluster infall models by producing 5-σ detections of infall velocities to a precision of about 500 km/s. By targeting galaxies based on SDSS and GALEX photometry, we have achieved detection rates of 68% of the galaxies in our sample. We will discuss the target selection process, HI velocities and mass estimates from the 2015 fall observing season, preliminary results from 2016 observations, and preliminary comparisons with inflow models predicted by numerical simulations.

This work has been supported by NSF grants AST-1211005, AST-1637339, AST-1637262.

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Contributing team(s): Undergraduate ALFALFA Team

132.04D – Using the Greenbank Telescope with Gravitational Lensing and the VLA to search for HI Beyond z=0.25

HI provides an important fuel for star formation, a good indicator of galactic environment, and more accurate information on mass, size, and velocity. Studies of Neutral Hydrogen (HI) in individual galaxies beyond z=0.25 have been limited by current technology. Most available telescopes do not have the frequency coverage, or sensitivity to detect the weak HI signal in a reasonable integration time. My thesis concentrates on pushing the limits on currently available telescopes to detect HI in individual sources out to higher redshifts. The COSMOS HI Large Extragalactic Survey (CHILES) team has pointed the JVLA toward the COSMOS field in a blind search of HI out to z=0.45. I am planning to use the data to study the HI properties of Luminous Compact Blue Galaxies, a heterogenous class of galaxies with high star formation rates, and metallicity amongst an older stellar population. These objects are numerous have a star formation rate density roughly equal to grand-design spiral galaxies at z~1, but become rare at z=0. A number of local LCBGs have been studied to determine HI, H2, and dynamical mass, and gas depletion timescales, and with the information provided from CHILES I can compare the properties of local LCBGs to intermediate redshift LCBGs. In preparation for final data products, I have generated a Luminosity function for LCBGs in the COSMOS field to track the evolution of their number density, star formation rate density, and how much they contribute to the overall luminosity function. I have also attempted to detect HI in gravitationally lensed galaxies using the Green Bank Telescope. The magnification provided by strong gravitational lensing should allow us to determine the HI mass of a small number of galaxies out to z~0.8 and beyond.

Author(s): Lucas Hunt[2], Daniel J. Pisano[2], Steve Crawford[1]
Institution(s): *1. South African Astronomical Observatory, 2. West Virginia University*
Contributing team(s): CHILES

132.05 – Mapping Diffuse HI Content in MHONGOOSE Galaxies NGC 1744 and NGC 7424

The universe contains an abundance of neutral atomic hydrogen, or HI. This HI holds the key to knowing how stars are born, how galaxies form and develop, and how dark matter halos accrete gas from the cosmic web. One of the most crucial questions regarding galaxy formation today is how galaxies accrete their gas and how accretion processes affect subsequent star formation. We are trying to answer these questions by mapping the HI content in a four square degree region around galaxies NGC 1744 and NGC 7424, galaxies to be observed as part of the MHONGOOSE survey. NGC 1744 has already been observed extensively with the VLA, so we will be able to quantify the differences in emission. To do this our GBT maps must be sensitive to column densities on the order of ~10^{18} cm^{-2}. With such low column densities, we will be able to search for features of the cosmic web in the form of tidal interactions and cosmic web filaments with its relation to star-forming galaxies.

Author(s): Amy Sardone[1], Daniel J. Pisano[1], Nickolas Pingel[1]
Institution(s): *1. West Virginia University*

132.06D – (Almost) Dark Galaxies in the ALFALFA Survey: HI-bearing Ultra-Diffuse Galaxies, and Beyond

Scaling relations between HI and stars in galaxies suggest strong ties between their atomic gas content and star formation laws. The Arecibo Legacy Fast ALFA (ALFALFA) blind extragalactic HI survey is well positioned to locate very low surface brightness sources that lie off these relations, the most extreme of which may fall below optical detection limits. Thus, the ALFALFA (Almost) Darks Project has been investigating extreme outliers from these relations by studying the ~1% of ALFALFA sources without apparent stellar counterparts in major optical surveys. We have obtained deep HI and optical imaging of 25 of these candidate "dark" sources. We find that most "dark" sources are not extreme "(almost) dark" galaxies. A few are rare OH Megamasers, redshifted into the ALFALFA bandpass, and many are part of large galactic plumes, stretching as far as 600 kpc from their host galaxy. However, a small handful of sources appear to be galaxies with extreme stellar systems. We find multiple systems with HI mass to stellar mass ratios an order of magnitude larger than typical gas rich dwarfs. Further, we find an isolated population of HI-bearing "ultra diffuse" galaxies (UDGs), with stellar masses of dwarfs, but HI and optical radii of L* galaxies. We suggest that these sources may be related to recently reported gas poor, quiescent UDGs.

Author(s): Luke Leisman[1], Martha P. Haynes[1], Riccardo Giovanelli[1]
Institution(s): *1. Cornell University*
Contributing team(s): The ALFALFA Almost Darks Team

132.07 – Characterizing source confusion in HI spectral line stacking experiments

Forthcoming studies like the Looking At the Distant Universe with the MeerKAT Array (LADUMA) deep HI survey will rely in part on stacking experiments to detect the mean level of HI emission from populations of galaxies that are too faint to be detected individually. Preparations for such experiments benefit from the use of synthetic data cubes built from mock galaxy catalogs and containing model galaxies with realistic spatial and spectral HI distributions over large cosmological volumes. I will present a new set of such synthetic data cubes and show the results of stacking experiments with them. Because the stacked spectra can be accurately decomposed into contributions from target and non-target galaxies, it is possible to characterize the large fractions of contaminant mass that are included in stacked totals due to source confusion. Consistent with estimates extrapolated from z = 0 observational data, we find that the amount of confused mass in a stacked spectrum grows almost linearly with the size of the observational beam, suggesting potential overestimates of the cosmic neutral gas density by some recent HI stacking experiments.

Author(s): Andrew J. Baker[1], Edward C Elson[2], Sarah Blyth[2]
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133 – Dust & Magnetic Fields

133.01D – Magnetic Fields in the Interstellar Medium

The Milky Way is magnetized. Invisible magnetic fields thread the Galaxy on all scales and play a vital but still poorly understood role in regulating flows of gas in the interstellar medium and the formation of stars. I will present highlights from my thesis work on magnetic fields in the diffuse interstellar gas and in accretion disks. At high Galactic latitudes, diffuse neutral hydrogen is organized into an intricate network of slender linear features. I will show that these neutral hydrogen "fibers" are extremely well aligned with the ambient magnetic field as traced by both starlight polarization (Clark et al. 2014) and *Planck* 353 GHz polarized dust emission (Clark et al. 2015). The structure of the neutral interstellar medium is more tightly coupled to the magnetic field than previously known. Because the orientation of neutral hydrogen is an independent predictor of the local dust polarization angle, our work provides a new tool in the search for inflationary gravitational wave B-mode polarization in the cosmic microwave background, which is currently limited by dust foreground contamination. Magnetic fields also drive accretion in astrophysical disks via the magnetorotational instability (MRI). I analytically derive the behavior of this instability in the weakly nonlinear regime and show that the saturated state of the instability depends on the geometry of the background magnetic field. The analytical model describes the behavior of the MRI in a Taylor-Couette flow, a set-up used by experimentalists in the ongoing quest to observe MRI in the laboratory (Clark & Oishi 2016a, 2016b).

Author(s): Susan Clark[1]
Institution(s): *1. Columbia University*

133.02 – Dust Grain Alignment and Magnetic Field Strength in the Wall of the Local Bubble

We use archival data on polarization (Berdyugin 2014) and extinction in the wall of the Local Bubble to study the grain alignment efficiency and the magnetic field strength. We find that the grain alignment efficiency variations can be directly tied to the location of the known OB-associations within 200pc from the Sun, strongly supporting modern, radiation-driven dust grain alignment. Based on the Davis-Chandrasekhar-Fermi method, we find a bimodal magnetic field-strength distribution, where the locations of the strongest fields correlate with the directions towards the near-by OB associations. We hypothesize that this strengthening is due to compression of the bubble wall by the opposing outflows in the Local Bubble and from the surrounding OB associations.

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133.03D – Characterizing Dust Attenuation in Local

Star Forming Galaxies

The dust attenuation for a sample of ~10000 local ($z \leq 0.1$) star forming galaxies is constrained as a function of their physical properties. We utilize aperture-matched multi-wavelength data from the UV-to-NIR, available from the *Galaxy Evolution Explorer*, the *Sloan Digital Sky Survey*, the *United Kingdom Infrared Telescope*, and the *Two Micron All-Sky Survey*, to ensure that regions of comparable size in each galaxy are being analyzed. We characterize the dust attenuation through the slope of the UV flux density and the Balmer decrement (Hα/Hβ). The observed relationship between these quantities is similar to the local starburst relation and is not seen to vary strongly with galactic properties. We derive the total attenuation curve over the range 1250 Å < λ < 28500 Å and find that a single attenuation curve is effective for characterizing the majority of galaxies in our sample. This attenuation curve is slightly lower in the far-UV than local starburst galaxies, by roughly 15%, but appears similar at longer wavelengths and has a normalization of $R_V = 3.7 \pm 0.4$ (*V*-band). This indicates that a single attenuation curve is reasonable for wide application in the local Universe.

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133.04 – PAH 8μm Emission as a Diagnostic of HII Region Optical Depth

PAHs are easily destroyed by Lyman continuum radiation and so in optically thick Strongren spheres, they tend to be found only on the periphery of HII regions, rather than in the central volume. We therefore expect that in HII regions that are optically thin to ionizing radiation, PAHs would be destroyed beyond the primary nebular structure. Using data from the Spitzer SAGE survey of the Magellanic Clouds, we test whether 8 μm emission can serve as a diagnostic of optical depth in HII regions. We find that 8 μm emission does provide valuable constraints in the Large Magellanic Cloud, where objects identified as optically thick by their atomic ionization structure have 6 times higher median 8 μm surface brightness than optically thin objects. However, in the Small Magellanic Cloud, this differentiation is not observed. This appears to be caused by extremely low PAH production in this low-metallicity environment, such that any differentiation between optically thick and thin objects is washed out by stochastic variations, likely driven by the interplay between dust production and UV destruction. Thus, PAH emission is sensitive to nebular optical depth only at higher metallicities.

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133.05D – The First Observation of the Submillimeter Polarization Spectrum in a Low-A_V Molecular Cloud

Polarized emission from aligned interstellar dust is both a crucial tool for studies of magnetism in the interstellar medium and a troublesome contaminant in studies of the polarized cosmic microwave background. In each case, an understanding of the significance of the dust polarization signal requires well-calibrated models that accurately describe dust grains' physical properties and interactions with their environment. Despite decades of progress in both theory and observation, polarized dust emission models remain largely underconstrained. During its 2012 flight, BLASTPol (the Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry) obtained simultaneous broad-band polarimetric maps at 250, 350, and 500 μm of a several degree-scale region containing several low-A_V molecular clouds. Combining these data with polarimetric observations from the Planck 850 μm band, we have produced a submillimeter polarization spectrum for one of these objects for the first time. We find the polarization degree to be largely constant across the four submillimeter bands. This result introduces a new observable with the potential to place strong empirical constraints on polarized dust models of the ISM in a density regime that has not been accessible to previous experiments. Comparing with the work of Draine & Fraisse (2009), our result is inconsistent with two of their four models. In particular, the two models for which all polarization arises from the aligned silicate component yield submillimeter polarization spectra that rise steeply with wavelength, in disagreement with our observations. This line of investigation will continue in the near future, as new experiments like The Next-Generation BLAST Polarimeter (BLAST-TNG) use their enhanced sensitivities to characterize polarized dust emission in even more diffuse environments.

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Contributing team(s): BLASTPol

133.06 – BLAST-TNG: A Next Generation Balloon-borne Large Aperture Submillimeter Polarimeter

Measurements of polarized thermal dust emission can be used to map magnetic fields in the interstellar medium. Recently, BLASTPol, the Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry, has published the most detailed map ever made of a giant molecular cloud forming high-mass stars. I will present an overview of The Next Generation BLAST polarimeter (BLAST-TNG), the successor telescope to BLASTPol, which maps linearly polarized dust emission at 250, 350 and 500 μm. BLAST-TNG utilizes a 2.5-meter carbon-fiber primary mirror that illuminates focal plane arrays containing over 3,000 microwave kinetic inductance detectors. This new polarimeter has an order of magnitude increase in mapping speed and resolution compared to BLASTPol and we expect to make over 500,000 measurements of magnetic field orientation per flight. BLAST-TNG will have the sensitivity to map entire molecular cloud complexes as well as regions of diffuse high Galactic latitude dust. It also has the resolution (FWHM = 25" at 250 μm) necessary to trace magnetic fields in prestellar cores and dense filaments. BLAST-TNG will thus provide a crucial link between the low resolution Planck all-sky maps and the detailed but narrow field of view polarimetry capabilities of ALMA. For our first Antarctic flight in December 2017 we are putting out a call for shared-risk proposals to fill 25% of the available science time. In addition, BLAST-TNG data will be publicly released within a year of the publication of our first look papers, leaving a large legacy data set for the study of the role played by magnetic fields in the star formation process and the properties of interstellar dust.

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134 – Structure of the Milky Way, & Stellar Astrometry

134.02D – Mapping Milky Way Halo Structure with Blue Horizontal Branch Stars

The use of blue horizontal brach (BHB) and red giant branch stars as tracers of stellar debris streams is a common practice and has been useful in the confirmation of kinematic properties of previously identified streams. This work explores less common ways of untangling the velocity signatures of streams traveling radially to our line of sight, and to peer toward the higher density region of the Galactic Center using data from the Sloan Digital Sky Survey (SDSS). Using spectra of BHB stars, we are able to kinematically distinguish moving groups in the Milky Way halo. The results of this thesis advance our knowledge of the following stellar halo substructures: the Pisces Stellar Stream, the Hercules-Aquila Cloud, the Hercules Halo Stream, and the Hermus Stream. A study of red giant stars led to the kinematic discovery of the Pisces Stellar Stream. Red giant stars were also examined to determine that the previously identified velocity signature that was suggested for the Hercules-Aquila Cloud was due to disk star contamination and errors in preliminary SDSS velocities. The Hercules Halo Stream is a previously unidentified structure that could be related to the Hercules-Aquila Cloud, and was discovered as a velocity excess of SDSS BHB stars. We identify a group of 10 stars with similar velocities that are spatially coincident with the Hermus Stream. An orbit is fit to the Hermus Stream that rules out a connection with the Phoenix Stream.

This work was supported by NSF grants AST 09-37523, 14-09421, 16-15688, the NASA/NY Space Grant fellowship, and contributions made by The Marvin Clan, Babette Josephs, Manit Limlamai, and the 2015 Crowd Funding Campaign to Support Milky Way Research.

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134.03 – The First Mass Function and Rise of Carbon in the Early Universe

We investigate the impact of the First Mass Function (FMF) of stars on the distribution of stellar carbon abundances in the early Universe. We propose a picture that includes primary carbon production by the massive first-generation stars, recorded in the atmospheres of CEMP-no stars (which show no over-abundances of neutron-capture elements), and secondary carbon production by subsequent generations of AGB stars, recorded in the subset of mass-transfer binaries now observed as CEMP-s stars (which exhibit strong over-abundances of neutron-capture elements).

Recently, CEMP-no stars have been found to comprise separable populations within this category, distinguished by their light-element and iron-peak element abundances (Yoon et al. 2016, Placco et al. 2016). The existence of these populations can also be used to indirectly infer information about the FMF. Additionally, we investigate the contrasting behavior of CEMP stars with their more metal-rich counterparts, focusing on their kinematics, spatial distribution, and elemental abundances, in order to constrain the chemical-enrichment history of the Galaxy, from the earliest stars to the present.

References:
Placco, V.~M., et al. (2016), ApJ, in press (arXiv:1609.02134)
Yoon, J., et al. (2016), ApJ, in press (arXiv:1607.06336)

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134.04D – Bayesian Mass Estimates of the Milky Way: Inferring the Mass Profile from Globular Cluster Kinematics

The mass and cumulative mass profile of the Milky Way's dark matter halo is a fundamental property of the Galaxy, and yet these quantities remain poorly constrained and span almost two orders of magnitude in the literature. There are a variety of methods to measure the mass of the Milky Way, and a common way to constrain the mass uses kinematic information of satellite objects (e.g. globular clusters) orbiting the Galaxy. One reason precise estimates of the mass and mass profile remain elusive is that the kinematic data of the globular clusters are incomplete; for some both line-of-sight and proper motion measurements are available (i.e. complete data), and for others there are only line-of-sight velocities (i.e. incomplete data). Furthermore, some proper motion measurements suffer from large measurement uncertainties, and these uncertainties can be difficult to take into account because they propagate in complicated ways. Past methods have dealt with incomplete data by using either only the line-of-sight measurements (and throwing away the proper motions), or only using the complete data. In either case, valuable information is not included in the analysis. During my PhD research, I have been developing a coherent hierarchical Bayesian method to estimate the mass and mass profile of the Galaxy that 1) includes both complete and incomplete kinematic data simultaneously in the analysis, and 2) includes measurement uncertainties in a meaningful way. In this presentation, I will introduce our approach in a way that is accessible and clear, and will also present our estimates of the Milky Way's total mass and mass profile using all available kinematic data from the globular cluster population of the Galaxy.

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134.06 – Estimating distances from parallaxes

In astrometric surveys such as *Gaia* and LSST, parallaxes will be measured for about a billion stars, but zero distances will be measured. Distances must be inferred from the parallaxes, and the common inference practice is by inverting the parallax. This, however, is only appropriate when there is no noise present. As noise will always be present and most stars in future surveys will have non-negligible fractional parallax uncertainties, we must treat distance estimation as an inference problem. The usage of prior assumptions become unavoidable. In this talk I will present a method on how to infer distances using Bayesian inference. Three minimalists, isotropic priors are used, as well an anisotropic prior derived from the observability of stars in a Milky Way model. The performance of these priors are investigated using a simulated *Gaia*-like catalogue. Recent results of distance estimation using the parallaxes of 2 million *Gaia* DR1 stars will also be discussed.

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134.07 – Beta Dips in the *Gaia* Era: Simulation Predictions of the Galactic Velocity Anisotropy Parameter (β)

Milky Way (MW) science has entered a new era with the advent of *Gaia*. Combined with spectroscopic survey data, we have newfound access to full 6D phase space information for halo stars. Such data provides an invaluable opportunity to assess kinematic trends as a function of radius and confront simulations with these observations to draw insight about our merger history. I will discuss predictions for the velocity anisotropy parameter, β, drawn from three suites of state-of-the-art cosmological N-body and N-body+SPH MW-like simulations. On average, all three suites predict a monotonically increasing value of β that is radially biased, and beyond 10 kpc, $\beta > 0.5$. I will also discuss β as a function of time for individual simulated galaxies. I will highlight when "dips" in β form, the severity (the rarity of $\beta < 0$), origin (*in situ* versus accreted halo), and persistence of these dips. Thereby, I present a cohesive set of predictions of β from simulations for comparison to forthcoming observations.

Author(s): Sarah Loebman[4], Monica Valluri[4], Kohei Hattori[4], Victor P. Debattista[2], Eric F. Bell[4], Greg Stinson[5], Charlotte Christensen[1], Alyson Brooks[3], Thomas R. Quinn[5], Fabio Governato[5]
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135 – Henry Norris Russell Lectureship: How Stars Form, Christopher McKee (University of California, Berkeley)

135.01 – How Stars Form

Stars are the atoms of the universe. The process by which stars form is at the nexus of astrophysics since they are believed to be responsible for the re-ionization of the universe, they created the heavy elements, they play a central role in the formation and evolution of galaxies, and their formation naturally leads to the formation of planets. Whereas early work on star formation was based on the assumption that it is a quiescent process, it is now believed that turbulence plays a dominant role. In this overview, I shall discuss the evolution of our understanding of how stars form and current ideas about the stellar initial mass function and the rate of star formation.

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137 – New, Fundamental, Cutting-Edge Science from Arecibo Observatory Poster Session

137.01 – Characterization of HI Filaments

We characterized the properties of dramatic interstellar HI filaments to learn more about the dynamics and structure of such features. Using Gauss fitting software, we searched the Effelsburg-Bonn HI Survey data for indications of a simple twisting (toroidal) motion across these filaments. Instead, we found that the structure was more complicated than expected. Apparent angular widths of several filaments were measured using the Galactic Arecibo L-band Feed Array HI (GALFA-HI), Bonn, and Leident/Argentine/Bonn (LAB) surveys. Based on filament widths and other parameters, we conclude that magnetism is the dominant force opposing internal motion and maintaining the structure of these filaments. The apparent width as a function of beam width closely follows a relationship reported in 1993 for HI features in general. They tend to subtend an angle two times the beam width, suggesting that the features remain unresolved.

The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation (AST-1100968), and in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association. The Arecibo Observatory REU is funded under grant AST-1559849 to Universidad Metropolitana.

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137.02 – The NANOGrav Eleven-Year Data Set: High-precision timing of 48 Millisecond Pulsars

Gravitational waves from sources such as supermassive black hole binary systems perturb times-of-flight of signals traveling from pulsars to the Earth. The NANOGrav collaboration aims to measure these perturbations in high precision millisecond pulsar timing data and thus to directly detect gravitational waves and characterize the gravitational wave sources. By observing pulsars over time spans of many years, we are most sensitive to gravitational waves at nanohertz frequencies. This work is complimentary to ground based detectors such as LIGO, which are sensitive to gravitational waves with frequencies 10 orders of magnitude higher.

In this presentation we describe the NANOGrav eleven-year data set. This includes pulsar time-of-arrival measurements from 48 millisecond pulsars made with the Arecibo Observatory (for pulsars with declinations between -1 and 39 degrees) and the Green Bank Telescope (for other pulsars, with two pulsars overlapping with Arecibo). The data set consists of more than 300,000 pulse time-of-arrival measurements made in nearly 7000 unique observations (a given pulsar observed with a given telescope receiver on a given day). In the best cases, measurement precision is better than 100 nanoseconds, and in nearly all cases it is better than 1 microsecond.

All pulsars in our program are observed at intervals of 3 to 4 weeks. Observations use wideband data acquisition systems and are made at two receivers at widely separated frequencies at each epoch, allowing for characterization and mitigation of the effects of interstellar medium on the signal propagation. Observation of a large number of pulsars allows for searches for correlated perturbations among the pulsar signals, which is crucial for achieving high-significance detection of gravitational waves in the face of uncorrelated noise (from gravitational waves and rotation noise) in the individual pulsars. In addition, seven pulsars are observed at weekly intervals. This increases our sensitivity to individual gravitational wave sources.

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137.03 – The NSF Undergraduate ALFALFA Team: Partnering with Arecibo Observatory to Offer Undergraduate and Faculty Extragalactic Radio Astronomy Research Opportunities

The NSF-sponsored Undergraduate ALFALFA (Arecibo Legacy Fast ALFA) Team (UAT) is a consortium of 20 institutions across the US and Puerto Rico, founded to promote undergraduate research and faculty development within the extragalactic ALFALFA HI blind survey project and follow-up programs. The objective of the UAT is to provide opportunities for its members to develop expertise in the technical aspects of observational radio spectroscopy, its associated data analysis, and the motivating science. Partnering with Arecibo Observatory, the UAT has worked with more than 280 undergraduates and 26 faculty to date, offering 8 workshops onsite at Arecibo (148 undergraduates), observing runs at Arecibo (69 undergraduates), remote observing runs on campus, undergraduate research projects based on Arecibo science (120 academic year and 185 summer projects), and presentation of results at national meetings such as the AAS (at AAS229: Ball et al., Collova et al., Davis et al., Miazzo et al., Ruvolo et al, Singer et al., Cannon et al., Craig et al., Koopmann et al., O'Donoghue et al.). 40% of the students and 45% of the faculty participants have been women and members of underrepresented groups. More than 90% of student alumni are attending graduate school and/or pursuing a career in STEM. 42% of those pursuing graduate degrees in Physics or Astronomy are women.

In this presentation, we summarize the UAT program and the current research efforts of UAT members based on Arecibo science, including multiwavelength followup observations of ALFALFA sources, the UAT Collaborative Groups Project, the Survey of HI in Extremely Low-mass Dwarfs (SHIELD), and the Arecibo Pisces-Perseus Supercluster Survey (APPSS). This work has been supported by NSF grants AST-0724918/0902211, AST-075267/0903394, AST-0725380, AST-121105, and AST-1637339.

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Contributing team(s): ALFALFA Team

137.04 – The Arecibo Environment Galaxy Survey: The NGC 2577/UGC 4375-galaxy pair

We searched for and catalogued galaxy candidates in an area of 5 square degrees around the NGC 2577/UGC 4375-galaxy pair via the 21-cm emission of the neutral hydrogen gas emitted by the candidates' interstellar media. The data were taken as a part of the Arecibo Galaxy Environment Survey (AGES) and consist of a data cube with the dimensions right ascension, declination, and the recessional velocity of the 21-cm line. We used the FITS viewer FRELLED to assist in visually extracting sources. We have cross identified the galaxy candidates with optical counterparts via the NASA Extragalactic Database and data from the Sloan Digital Sky Survey. We made a total of 49 HI detections in the vicinity of the galaxy pair. We did not detect the S0 galaxy, NGC 2577, but we did detect the SB galaxy, UGC 4375, and four galaxies in the region around the galaxy pair at ~2000 km/s. We detected another overdensity at 4000 km/s. Additionally, an HI detection appears in our local neighborhood at 426 km/s. The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation and in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association. The Arecibo Observatory REU program is funded under grant AST-1559849 to Universidad Metropolitana.

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137.05 – Improving Arecibo Observatory's Hardware

The Puerto-rican Ultimate Pulsar Processing Instrument (PUPPI) is a key backend for time-domain observations at Arecibo Observatory. PUPPI enables pulsar timing used for gravitational wave studies, single pulse studies of pulsars, searches for new pulsars, and allows in depth studies of Fast Radio Bursts (FRBs). Unfortunately, PUPPI is presently restricted to only certain Arecibo receivers due to its input frequency and bandwidth requirements. Here we present the design process, building, bench testing, and updates on the implementation of a one-channel breadboard of a new frequency mixer at the Arecibo Observatory. The function of the frequency mixer design is to translate a 1.1-1.9 GHz band to 0.8 – 1.6 GHz band, where PUPPI samples the data at the second Nyquist zone. When this seemingly simple device is fully implemented, it will allow for the further expansion of the abilities of PUPPI. Mainly it will expand PUPPI's frequency agility to higher frequencies from 4 to 10 GHz, by enabling it to work with many more of Arecibo's receivers. We hope this becomes particularly useful, now that a FRB has been detected at these higher frequencies. The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation (AST-1100968), and in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association. The Arecibo Observatory REU is funded under grant AST-1559849 to Universidad Metropolitana

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137.06 – Monitoring the Remarkable Radio Spectral-Line/Continuum Outburst in Galaxy NGC 660

A radio continuum and spectral-line outburst in galaxy NGC660 was serendipitously discovered by us at Arecibo in 2007/8. From Feb. 2013, roughly bi-monthly Arecibo spectral-line and continuum monitoring of this remarkable event has been performed, with 28 observing epochs completed to August 2016. Variability of the continuum spectrum, and of the detailed OH emission/absorption spectra at 4660, 4750, and 4765 MHz have been followed over this period. The rapid changes seen in the molecular emission from the nuclear region of this galaxy are unprecedented. To delineate the physical model of this complicated starburst system further, we have supplemented this Arecibo monitoring by two epochs of milliarcsecond-resolution HSA line and continuum imaging, (with Arecibo in this VLBI array). The VLBI images reveal jet structure consistent with a recent nuclear outburst. The OH features show association with the outburst hotspots. Both the continuum and OH maser intensities have been steadily declining since peaking at mid-2011.

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137.07 – Correcting the Redshift Measurement of 4C15.05 Using Neutral Hydrogen

4C15.05, (also known as PKS 0202+14 or J0204+15), is a quintessential blazar. It has a flat radio spectrum, a super-luminal jet and gamma-ray detections. Arecibo observations with the experimental 700-800 MHz receiver on the 305-m diameter William E. Gordon Telescope detected, serendipitously, HI in absorption against 4C15.05 while using it as a bandpass calibrator for another object in an HI absorption project. Although the redshift we derive is different to than that attributed to 4C15.05 by Perlman et al. (1998), it agrees very well with the value of z=0.833 determined by Stickel et al. (1996). We note that the erroneous value of z=0.405 has been extensively used in the literature.

Author(s): Kristen M. Jones[1], Tapasi Ghosh[1], Christopher J. Salter[1]
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137.08 – Detected Galaxies and Large Scale Structure in the Arecibo L-band Feed Array Zone of Avoidance

Survey (ALFAZOA)
While large, systematic redshift surveys of galaxies have been conducted for decades, lack of information behind the Milky Way (the Zone of Avoidance) contributes uncertainty to our picture of dynamics in the local universe. Controversy persists for the dipole calculated from galaxy and redshift surveys compared to the CMB. Depth in redshift space is an issue, as is incomplete sky mapping, even of supposed all sky redshifts surveys. For instance, the wide-angle 2MASS Redshift Survey retains a gap of 5-8 deg around the Galactic plane. Fortunately, there is no ZOA at 21cm, except for velocities occupied by the Galaxy. This long-wavelength spectral line passes unimpeded through dust, and is unaffected by stellar confusion. With immediate redshift determination, a 21-cm survey produces a 3-dimensional map of the distribution of obscured galaxies which contain HI. It traces large-scale structure right across the Galactic Plane, and identifies obscured mass overdensities relevant to flow-field studies.

ALFAZOA is a blind HI survey for galaxies behind the Milky Way covering more than 1000 square degrees of the Arecibo sky. It proceeds in two phases: shallow (completed) and deep (ongoing). The shallow survey (rms ~5-7 mJy) mapped the region within Galactic longitude l = 30 – 75 deg, and latitude b = -10 to +10 deg, detecting several hundred galaxies to about 12,000 km/s, tracing large-scale structure across the plane. The deep survey (rms ~1 mJy), in both the inner (Galactic longitude 30 – 75 deg and latitude plus/minus 2 deg) and outer (longitude 175 – 207 deg and latitude = +1 to -2 deg) Galaxy is ongoing, with detections reaching to 18,000 km/s. Analysis of detections to date, and large-scale structure mapped, will be presented.

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138 – Astrobiology Poster Session

138.01 – Glycolaldehyde and Ethylene Glycol on Nearly Isotropic Comets

The delivery of glycolaldehyde (GLA) and ethylene glycol (EG) could be could be important for understanding the origin of life. GLA, the simplest sugar, is a building block for ribose, the backbone of RNA; EG is a reduced alcohol variant of GLA, found to be created by the impact of GLA under simulated cometary impact conditions (McCaffrey et al. 2014). GLA and EG have been found in regions of the interstellar medium and recently on nearly isotropic comets (NICs), which originate in the Oort Cloud. NICs are long period comets (P > 200 years) and have orbits that are nearly randomly inclined to the ecliptic plane (Mumma & Charnley et al. 2011). Based on impact experiments that assess survivability of these molecules (McCaffrey et al. 2014), we aim to determine the mass of GLA and EG that could have been delivered on comets since the formation of the Solar System. The focus of the current study is to determine the abundances of GLA and EG on C/1995 O1 (Hale-Bopp), C/2012 F6 (Lemmon), C/2013 R1 (Lovejoy 2013), and C/2014 Q2 (Lovejoy 2014), all of which have been found to possess at least one of these molecules. Using published values of observed production rates of water, GLA, and EG (e.g., Biver et al. 2015), we have estimated a range of masses of these molecules of interest on their host comets. Even with a high degree of uncertainty in comet diameters and volumes, we estimate that 10^9 to 10^{17} kg of these molecules could be delivered by a single comet, and that 10^8 to 10^{17} kg could have survived the impact.

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Institution(s): *1. Albion College*

138.02 – Using Lunar Impact Glasses to Inform the Amount of Organic Material Delivered to the Early Earth

The delivery of organic material via comets and asteroids during the early history of Earth plays an important role in some theories about the origin of life on Earth. Given the close proximity of the Moon to the Earth, the Moon's impact history can be used to estimate the amount of organic material delivered to the early Earth. Analysis of lunar impact glasses, derived from energetic impacts on the Moon, provide valuable data that can be used to interpret the Moon's impact flux. Here we present the results of a study of the non-volatile lithophile element compositions of over 500 impact glass samples from the Apollo 14, 16, and 17 landing sites, along with associated ages of a subset of them. Our analyses show that many of the impact glasses possess compositions exotic to the local regolith in which they were found. Coupled with their ages, these glasses suggest material transport from distant regions of the Moon and may allow an estimate of the number of lunar (and terrestrial) impactors in a given time period. These results have important implications for constraining the Moon's impact flux and also the amount of organic material delivered to the early Earth. Results of our preliminary study, which investigates the amounts of organic material delivered by comets and asteroids to the Moon (and Earth), will be presented.

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138.04 – MISE: A Search for Organics on Europa

NASA's planned Europa Flyby Mission will try to assess the habitability of Jupiter's moon, Europa. One of the selected instruments on the mission is the Mapping Imaging Spectrometer for Europa (MISE). MISE is a near-infrared imaging spectrometer that takes spectra in the 0.8-5 micron range, and it will be capable of mapping Europa's surface chemical composition. A primary goal of the MISE instrument is to determine if Europa is capable of supporting life by searching for amino acid signatures in the infrared spectra. We present spectra of pure amino acid at MISE's resolution, and we analyze the effect of chirality on these spectra. Lastly, we present model spectra for diluted/mixed amino acids to simulate more realistic concentrations. We show MISE can distinguish between different types of amino acids, such as isoleucine, leucine, and their enantiomers.

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138.05 – How Mathematics Describes Life

The circle of life is something we have all heard of from somewhere, but we don't usually try to calculate it. For some time we have been working on analyzing a predator-prey model to better understand how mathematics can describe life, in particular the interaction between two different species. The model we are analyzing is called the Holling-Tanner model, and it cannot be solved analytically. The Holling-Tanner model is a very common model in population dynamics because it is a simple descriptor of how predators and prey interact. The model is a system of two differential equations. The model is not specific to any particular set of species and so it can describe predator-prey species ranging from lions and zebras to white blood cells and infections. One thing all these systems have in common are critical points. A critical point is a value for both populations that keeps both populations constant. It is important because at this point the differential equations are equal to zero. For this model there are two critical points, a predator free critical point and a coexistence critical point. Most of the analysis we did is on the coexistence critical point because the predator free critical point is always unstable and frankly less interesting than the coexistence critical point. What we did is consider two regimes for the differential equations, large B and small B. B, A, and C are parameters in the differential equations that control the system where B measures how responsive the predators are to change in the population, A represents predation of the prey, and C represents the satiation point of the prey population. For the large *B* case we were able to approximate the system of differential equations by a single scalar equation. For the small *B* case we were able to predict the limit cycle. The limit cycle is a process of the predator and prey populations growing and shrinking periodically. This model has a limit cycle in the regime of small *B*, that we solved for numerically. With some assumptions to reduce the differential equations we were able to create a system of equations and unknowns to predict the behavior of the limit cycle for small *B*.

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138.06 – Cosmogenic Secondary Radiation from a Nearby Supernova

Increasing evidence has been found for multiple supernovae within 100 pc of the solar system. Supernovae produce large amounts of cosmic rays which upon striking Earth's atmosphere, produce a cascade of secondary particles. Among these cosmic ray secondaries are neutrons and muons, which penetrate far within the atmosphere to sea level and even below sea level. Muons and neutrons are both forms of ionizing radiation which have been linked to increases in cancer, congenital malformations, and other maladies. This work focuses on the impact of muons, as they penetrate into ocean water to impact the lowest levels of the aquatic food chain. We have used monte carlo simulations (CORSIKA, MCNPx, and FLUKA) to determine the ionizing radiation dose due to cosmic ray secondaries. This information shows that although most astrophysical events do not supply the necessary radiation flux to prove dangerous; there may be other impacts such as an increase to mutation rate.

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139 – Laboratory Astrophysics Poster Session

139.01 – Improved Cr II log(gf)s and Cr Abundances in the Photospheres of the Sun and Metal-Poor Star HD 84937

New laser induced fluorescence (LIF) data for eight levels of singly ionized chromium (Cr) and emission branching fraction (BF) measurements for 183 lines of the second spectrum of chromium (Cr II) are reported. A goal of this study is to reconcile Solar and stellar Cr abundance values based on Cr I and Cr II lines. Analyses of eighteen spectra from three Fourier Transform Spectrometers supplemented with ultraviolet spectra from a high resolution echelle spectrometer yield the BF measurements. Radiative lifetimes from LIF measurements are used to convert the BFs to absolute transition probabilities. These new laboratory data are applied to determine the Cr abundance log eps in the Sun and metal-poor star HD 84937. The mean result in the Sun is <log eps(Cr II)> = 5.624 ± 0.009 compared to <log eps(Cr I)> = 5.644 ± 0.006 on a scale with the H abundance log eps(H) = 12. Similarly the photosphere of HD 84937 is found to be in Saha balance with <log eps(Cr II)> = 3.417 ± 0.006 and <log eps(Cr I, E.P. > 0 eV) > = 3.374 ± 0.011 for this dwarf star. The resonance (E.P. = 0 eV) lines of Cr I reveal overionization of the ground level of neutral Cr. We find a correlation of Cr with the iron-peak element Ti, suggesting an associated or related nucleosynthetic production. Four iron-peak elements (Cr along with Ti, V and Sc) appear to have a similar (or correlated) production history - other iron-peak elements appear not to be associated with Cr.
This work is supported in part by NASA grant NNX16AE96G (J.E.L.), by NSF grant AST-1516182 (J.E.L. & E.D.H.), by NASA interagency agreement NNH10AN381 (G.N.), and NSF grant AST-1211585 (C.S.). Postdoctoral research support for N. E. is from the Technological and Scientific Research Council of Turkey (TUBITAK).

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139.02 – Astrochemistry at the Cryogenic Storage Ring

Almost 200 different molecular species have been identified in space, and this number continues to grow steadily. This surprising molecular diversity bears witness to an active reaction network, in which molecular ions are the main drivers of chemistry in the gas phase. To study these reactions under controlled conditions in the laboratory is a major experimental challenge. The new Cryogenic Storage Ring (CSR) that has recently been commissioned at the Max Planck Institute for Nuclear Physics in Heidelberg will serve as an ideal testbed to study cold molecular ions in the gas phase. With residual gas densities of <140 cm^{-3} and temperatures below 10K, the CSR will allow for merged beams collision studies involving molecular ions, neutral atoms, free electrons and photons under true interstellar conditions.

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139.03 – Experimentally Determined Binding Energies of Astrophysically Relevant Hydrocarbons in Pure and H_2O-Layered Ices

Small hydrocarbons represent an important organic reservoir in a variety of interstellar environments. Constraints on desorption temperatures and binding energies of hydrocarbons are thus necessary for accurate predictions of where and in which phase these molecules exist. Through a series of temperature programmed desorption experiments, we determined binding energies of 1, 2, and 3-carbon interstellar hydrocarbons (CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_6, and C_3H_8) in pure ices and in relation to water ice, the dominant ice constituent during star and planet formation. These empirically determined values can be used to inform observations and models of the molecular spatial distribution in protoplanetary disks, thus providing insight into planetesimal composition. In addition, knowledge of hydrocarbon binding energies will refine simulations of grain surface chemistry, allowing for better predictions of the chemical conditions that lead to the production of complex organic molecules vital for life.

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139.04 – Investigating Cosmic Analog Dusts in the Lab at MM/Sub-MM Wavelength

Cosmic dust is abundant in many interesting astronomical environments such as active galactic nuclei (AGN) and protosteller systems. It also plays a key role in star formation and galactic evolution. In an effort to understand the thermal emission of dust in various environments, a dedicated instrument for measuring the emissivity of various cosmic analog dusts in the millimeter/sub-millimeter has been assembled and tested. In particular, novel design have adopted for the Fourier Transform Spectrometer (FTS) and the cold sample holder of the apparatus. We report here on the performance of the sample holder, FTS, and other parts of the complete experimental setup as found with our initial tests. Our next step will be to obtain science data on realistic cosmic analog dust samples synthesized by us such as amorphous silicate grains containing Mg/Fe.

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140 – Preparing for, & Engaging in, the 2017 Solar Eclipse Poster Session

140.01 – Celebrating the Eighth Annual International Observe the Moon Night and Supporting the 2017 Solar Eclipse

2017 marks the eighth International Observe the Moon Night (InOMN), which will be held on July 15, 2017. We will present findings from the first seven years, including the most recent figures from the October 2016 event, and provide an overview of the 2017 events which will support the Great American Eclipse which occurs about five weeks later, on August 21, 2017.

InOMN is an annual worldwide public event that encourages observation, appreciation, and understanding of our Moon and its connection to NASA planetary science and exploration. This year InOMN's event will support broad efforts to promote the eclipse by providing resources to help InOMN hosts highlight lunar science that will influence the eclipse, such as the topography of the Moon, which affects the edges of the eclipse path and the location and duration of Baily's beads. The InOMN team will host webinars to discuss the Moon, lunar science, and lunar and solar eclipses.

Each year, thousands of visitors take part in hundreds of events across the world. In the first seven years (2010 to 2016) over 3,700 events were registered worldwide and hosted by a variety of institutions including astronomy clubs, observatories, schools, and universities and held at a variety of public and private institutions all over the world including museums, planetaria, schools, universities, observatories, parks, and private businesses and homes. Evaluation of InOMN reveals that events are raising visitors' awareness of lunar science and exploration, providing audiences with information about lunar science and exploration, and inspiring visitors to want to learn more about the Moon and providing connections to opportunities to do so.

InOMN is sponsored by NASA's Lunar Reconnaissance Orbiter, NASA's Solar System Exploration Research Virtual Institute (SSERVI), and the Lunar and Planetary Institute. Learn more and register to host an event at http://observethemoonnight.org/.

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Contributing team(s): InOMN Coordinating Committee

140.02 – Update on the Citizen CATE Experiment: Indonesia to 2017

The Citizen *Continental-America Telescopic Eclipse* (CATE) Experiment is a team of students, citizen scientists and professional astronomers who will operate 60 identical telescopes distributed across the country in the path of totality from Oregon to South Carolina during the 21 August 2017 solar eclipse. The project goal is to produce a 90-minute time sequence of calibrated white light images of the solar corona. This unprecedented, continuous, temporal coverage during totality will allow us to address questions related to the dynamics in the inner 2.5 Rsun of the corona.

Field testing of the equipment began with one setup located on the Faroe Islands during the March 2015 total solar eclipse. Here we report on the more recent March 2016 eclipse where five CATE teams were sent to Indonesia. This group included university undergraduate students, their faculty mentors and other professional scientists. CATE completed a successful field testing of multiple sites near the equator that were distributed over 20 degrees in longitude. We conclude our discussion with how the experience gained over the past two years is being put to use as we prepare for the full implementation of the CATE Network in August 2017.

This work was supported in part by funding from NASA SMD grant NNX16AB92A and the NSF REU program through AST-1460743.

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Contributing team(s): The Citizen CATE Team

140.03 – There's An App For That: Planning Ahead for the Solar Eclipse in August 2017

With the total solar eclipse of 2017 August 21 over the continental United States approaching, the U.S. Naval Observatory (USNO) on-line Solar Eclipse Computer can now be accessed via an Android application, available on Google Play.
Over the course of the eclipse, as viewed from a specific site, several events may be visible: the beginning and ending of the eclipse (first and fourth contacts), the beginning and ending of totality (second and third contacts), the moment of maximum eclipse, sunrise, or sunset. For each of these events, the USNO Solar Eclipse 2017 Android application reports the time, Sun's altitude and azimuth, and the event's position and vertex angles. The app also lists the duration of the total phase, the duration of the eclipse, the magnitude of the eclipse, and the percent of the Sun obscured for a particular eclipse site.
All of the data available in the app comes from the flexible USNO Solar Eclipse Computer Application Programming Interface (API), which produces JavaScript Object Notation (JSON) that can be incorporated into third-party Web sites or custom applications. Additional information is available in the on-line documentation (http://aa.usno.navy.mil/data/docs/api.php).
For those who prefer using a traditional data input form, the local circumstances can still be requested at http://aa.usno.navy.mil /data/docs/SolarEclipses.php.
In addition the 2017 August 21 Solar Eclipse Resource page (http://aa.usno.navy.mil/data/docs/Eclipse2017.php) consolidates all of the USNO resources for this event, including a Google Map view of the eclipse track designed by Her Majesty's Nautical Almanac Office (HMNAO).
Looking further ahead, a 2024 April 8 Solar Eclipse Resource page (http://aa.usno.navy.mil/data/docs/Eclipse2024.php) is also available.

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140.04 – Eclipse '17 at Indiana University Bloomington

August 21, 2017, is the first day of fall classes at Indiana University Bloomington. On campus, we will host viewing stations to assist students, faculty, and community members to watch the eclipse safely. The Kirkwood Observatory solar telescope will provide an online view of the event. Science teachers of Indiana will be surveyed to understand their needs to be prepared for the first week of classes. Working this spring with K12 educators and other local organizations involved in science outreach, we will help to prepare Indiana classrooms to take advantage of the August event to meet the goals of Indiana's state science standards with eclipse-related activities at all grade levels. These activities are aimed at increasing the scientific literacy in rural Indiana.

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140.05 – Observing the 2017 Total Solar Eclipse from the Pisgah Astronomical Research Institute

The Pisgah Astronomical Research Institute (PARI) is located directly under the path of totality of next year's solar eclipse and possesses two 26m radio telescopes capable of interferometry at simultaneously at 2.3 GHz and 8.4 GHZ. PARI is preparing these radio telescopes for use by the astronomical community to observe solar eclipse. We will present the status of PARI's radio telescopes and information on access for the eclipse. We will also present the status and availability of several optical telescopes.

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Institution(s): *1. Pisgah Astronomical Research Institute*
Contributing team(s): Donald Cline, Mark Krochmal

140.06 – The 2017 solar eclipse and Majorana & Allais gravity anomalies

Two little known anomalies hint to phenomena beyond current theory. **Majorana effect:** around 1920 in a series of well-designed experiments with a chemical laboratory balance, Quirino Majorana found in Italy that mercury (Hg) and lead (Pb) might shield terrestrial gravity. Majorana experiments were never repeated by the international scientific community. Instead his results were dismissed on theoretical claims: a) unobserved heating of earth by absorption of gravity, and b) unobserved cyclic lunar perturbation of solar gravity at earth's surface. However, Majorana critics missed the crucial fact that shielding is not mere absorption, but also scattering, and that atomic number Z of matter in the moon is much lower than Z=80 (Hg) and Z=82 (Pb). From the June 30/1954 solar eclipse onwards, high-quality mechanical gravimeters were used to search for Majorana shielding by the moon. Results are positive, provided that shielding is interpreted as scattering rather than absorption of gravity by moon (H. A. Munera, Physics Essays 24, 428-434, 2011). **Allais effect**: during the same 1954 eclipse (partial in Paris) Maurice Allais had in operation a sensitive paraconical pendulum for a very different purpose. Surprisingly, the pendulum was perturbed by the eclipse, condition repeated once again in a 1959 solar eclipse, also partial in Paris. During the past sixty years, paraconical, torsion and Foucault pendula, and other mechanical devices, have been used to (dis)confirm Allais effect, but the results are not conclusive thus far. A book edited by this author (Should the laws of gravitation be revised? Apeiron 2011) describes some of those observations. Various unexpected effects, some of them torsional, appear both near the optical shadow, and far away. The Sun-Moon-Earth alignment in a solar eclipse allows detection on the terrestrial surface of the dark matter flow scattered on moon's surface (flow not hitting earth in other geometries). Rotation of moon may induce torsional effects on scattered dark matter. Scattered gravity may be detected with mechanical gravimeters and torsinds located inside and outside the optical shadow path in USA, Canada and Mexico.

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141 – Relativistic Astrophysics, Gravitational Lenses & Waves Poster Session

141.01 – Microlensing Events in Gaia and other Astrometric Surveys

The region within a kiloparsec of the Sun is a vast and mysterious place filled with uncharted planets, stars and compact objects, whose masses and properties are unknown. The Gaia space mission provides a unique opportunity to study of this region by measuring parallax distances and proper motions to millions of nearby stars, significantly advancing data available from previous astrometric surveys.
We are putting this new astrometric information from the first Gaia data release to a novel use, by searching for matches between the positions of known microlensing events and the positions of stars observed by both the Gaia and the Tycho-2 missions, as listed in the Tycho-Gaia Astrometric Solution (TGAS) Catalogue.
The existence of a gravitational microlensing event near a TGAS-listed star may provide information about the nature of either the source star lensed in the event, or the lens itself. For example, the source star lensed in the 'TAGO' event lies nearby, and is listed in the TGAS Catalogue. Other events may also have been caused by nearby TGAS-listed stars, or by their dim companions. In such cases, we can determine the lens mass and acquire information about any compact objects or planets which may exist around the lens.
We report on the process of matching the positions of over 20,000 candidate microlensing events discovered by either OGLE and/or MOA, with the positions of 2 million stars from the TGAS Catalogue and stars from a range of other surveys, including Lepine's SUPERBLINK survey, and discuss the implications of the matches obtained.

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141.02 – Exploring Parameter Space Coverage of Various LISA Configurations

With the success of LISA Pathfinder, the measurement of gravitational waves in space has taken an important step forward. We conduct an analysis of the measurement abilities of distinctive LISA detector designs, examining how the low-frequency band-edge behavior of the detector sensitivity curve affects measurement capabilities. We are particularly interested in LISA's ability to measure massive black holes that are merging near the band-edge, with masses in the range of $\sim 10^6-10^{10}M_\odot$. We examine the ringdown and insprial detectability over a wide range of Massive Black Hole (MBH) binaries along with a broad palette of possible LISA design parameters.

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Institution(s): *1. Northwestern University*

141.03 – Gravitational Wave Detection of Compact Binaries Through Multivariate Analysis

The first detection of gravitational waves (GW), GW150914, as produced by a binary black hole merger, has ushered in the era of GW astronomy. The detection technique used to find GW150914 considered only a fraction of the information available describing the candidate event: mainly the detector signal to noise ratios and chi-squared values. In hopes of greatly increasing detection rates, we want to take advantage of all the information available about candidate events. We employ a technique called Multivariate Analysis (MVA) to improve LIGO sensitivity to GW signals. MVA techniques are efficient ways to scan high dimensional data spaces for signal/noise classification. Our goal is to use MVA to classify compact-object binary coalescence (CBC) events composed of any combination of black holes and neutron stars. CBC waveforms are modeled through numerical relativity. Templates of the modeled waveforms are used to search for CBCs and quantify candidate events. Different MVA pipelines are under investigation to look for CBC signals and un-modelled signals, with promising results. One such MVA pipeline used for the un-modelled search can theoretically analyze far more data than the MVA pipelines currently explored for CBCs, potentially making a more powerful classifier. In principle, this extra information could improve the sensitivity to GW signals. We will present the results from our efforts to adapt an MVA pipeline used in the un-modelled search to classify candidate events from the CBC search.

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141.04 – A unified relativistic treatment of tidal disruption by a Schwarzschild black hole

Stars on orbits with pericenters sufficiently close to their galaxy's supermassive black hole can be ripped apart by tidal stresses due to the hole's gravitational field. Some of the resulting stellar debris becomes more tightly bound to the hole and can potentially produce an observable flare. We provide a self-consistent, unified treatment of tidal disruption events, investigating the effects of general relativity (for non-spinning holes) on loss-cone boundaries and find that although the rate of tidal disruption events decreases rapidly (due to direct stellar capture) as a function of black hole mass, the effect is slightly countered by the widening of the loss cone due to stronger tidal fields under relativity. We find also that relativity generally increases the peak accretion rate of stellar debris into the black hole and lowers the time delay between disruption and this peak rate and express the results as multiplicative correction factors. These correction factors have maximal values for both total (approximately 8.65) and partial (approximately 8.91) disruption events at black hole masses of 10^(7.27) solar masses and approximately 10^(8.03) solar masses, respectively, and help place an upper limit on the mass of a hole capable of producing an observable flare for the non-spinning case.

Author(s): Juan Edgardo Servin[1], Michael Kesden[1]
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141.05 – Multi-Messenger Astronomy: White Dwarf Binaries, LISA and GAIA

The discovery of gravitational waves has ushered in a new era in astronomy. The low-frequency band covered by the future LISA detector provides unprecedented opportunities for multi-messenger astronomy. With the Global Astrometric Interferometer for Astrophysics (GAIA) mission, we expect to discover about 1,000 eclipsing binary systems composed of a WD and a main sequence star - a sizeable increase from the approximately 34 currently known binaries of this type. In advance of the first GAIA data release and the launch of LISA within the next decade, we used the Binary Stellar Evolution (BSE) code simulate the evolution of White Dwarf Binaries (WDB) in a fixed galaxy population of about 196,000 sources. Our goal is to assess the detectability of a WDB by LISA and GAIA using the parameters from our population synthesis, we calculate GW strength h, and apparent GAIA magnitude G. We can then use a scale factor to make a prediction of how many multi- messenger sources we expect to be detectable by both LISA and GAIA in a galaxy the size of the Milky Way. We create binaries 10 times to ensure randomness in distance assignment and average our results. We then determined whether or not astronomical chirp is the difference between the total chirp and the GW chirp. With Astronomical chirp and simulations of mass transfer and tides, we can gather more information about the internal astrophysics of stars in ultra-compact binary systems.

Author(s): Michael Bueno[2], Katelyn Breivik[1], Shane L. Larson[1]
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141.06 – Studying Variance in the Galactic Ultra-compact Binary Population

In the years preceding LISA, Milky Way compact binary population simulations can be used to inform the science capabilities of the mission. Galactic population simulation efforts generally focus on high fidelity models that require extensive computational power to produce a single simulated population for each model. Each simulated population represents an incomplete sample of the functions governing compact binary evolution, thus introducing variance from one simulation to another. We present a rapid Monte Carlo population simulation technique that can simulate thousands of populations on week-long timescales, thus allowing a full exploration of the variance associated with a binary stellar evolution model.

Author(s): Shane L. Larson[1], Katelyn Breivik[1]
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141.07 – Geometry of Superluminal Light-Echo Pair Events

Light echoes, shadows, and ionization fronts can and do move faster than light, both in the lab and out in the cosmos. In general, though, a single observer cannot tell the speed of such echoes without distance information -- unless a very specific geometry arises: the radial component crosses c. The observer then sees this crossing location as the site where a pair of bright light echoes is created or annihilated. This pair event tells the observer that a precise speed occurs, a speed that does not scale with distance and so can potentially be leveraged to reveal geometry and distance information. A few simple scattering surface geometries are shown illuminated by a point flash, including linear and circular filaments. In practice, useful astronomical flash sources include novae and supernovae, although in theory any uniquely varying source of stellar variability could be sufficient.

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141.08 – The Effects of Physically Unrelated Near Neighbors on the Galaxy-Galaxy Lensing Signal

A suite of Monte Carlo simulations was used to investigate the effects of near neighbors on the galaxy-galaxy lensing signal. The simulated lenses were drawn from a set of observed galaxies with known spectroscopic redshifts and known luminosities. The relative locations of the lenses were obtained from the actual locations of the observed galaxies on the sky. The simulations take into account the weak lensing deflections of central lenses and their nearest neighbor galaxies on the sky. The relative depths of the gravitational potentials of the lenses were obtained from their rest-frame blue luminosities using a Faber-Jackson type of relationship, and they naturally incorporate the intrinsic clustering of galaxies. In the first set of simulations, all lenses were assigned a single, fixed redshift. In this case, as expected, the mean tangential shear about the central lenses, γ_T, was found to be identically equal to the excess surface mass density, $\Delta\Sigma$, divided by the critical surface mass density, Σ_c. In the second set of simulations, the lenses were assigned their actual, observed spectroscopic redshifts and Σ_c was taken to be the critical surface mass density of the central lens. In the second set of simulations, the relationship $\gamma_T = \Delta\Sigma/\Sigma_c$ was found to be violated on large scales because more than 90% of the near neighbors for a given central lens are located at redshifts that differ significantly from that of the central lens. That is, the simulations show the “two-halo” term in galaxy-galaxy lensing can have a significant contribution from galaxies that are not physically associated with the central lens. For a given central lens, physically unrelated near neighbors give rise to a ratio of γ_T to $\Delta\Sigma/\Sigma_c$ that spans a wide range from 0.5 to 1.5 at a projected distance ~1 Mpc. The magnitude and the sense of the discrepancy between γ_T and the ratio $\Delta\Sigma/\Sigma_c$ are functions of both the projected radius and the velocity dispersions of the central lens galaxies. On average, at large projected radii, the difference between γ_T and $\Delta\Sigma/\Sigma_c$ is greater for low velocity dispersion central lenses than it is for high velocity dispersion central lenses. This work was supported NASA ATP grant NNX13AH24G S04.

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141.09 – The UV Luminosity Function at 6 < z < 10 from the Hubble Frontier Fields

The Hubble Frontier Fields program has obtained deep optical and near-infrared Hubble Space Telescope imaging of six galaxy clusters and associated parallel fields. The depth of the imaging (m_AB ~ 29) means we can identify faint galaxies at z > 6, and those in the cluster fields also benefit from magnification due to strong gravitational lensing that allows us to reach intrinsic absolute magnitudes of M_UV ~ -12.5 at z ~ 6. Here, we present the UV luminosity functions at 6 < z < 10 from the complete Hubble Frontier Fields data, revealing a steep faint-end slope that extends to the limits of the data. The lack of any apparent turnover in the luminosity functions means that faint galaxies in the early Universe may have provided sufficient ionizing radiation to sustain reionization.

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142 – The Milky Way, The Galactic Center Poster Session

142.01 – An Enigmatic Variable Star in the Backyard of Sagittarius A*

We present updates on a search for stellar near-infrared (*K′*) variability in the Milky Way's galactic center (GC), using twelve years of Keck adaptive optics data. In particular, one late-type variable star within a few arcseconds of the central supermassive black hole, Sgr A*, features a long period (~6.5 years); a large near-infrared amplitude (~1.7 mag); and an apparently regular, non-sinusoidal profile in its light curve. Multiple interpretations are plausible for this signal: For instance, the source could be an AGB or post-AGB star experiencing rapid mass loss; it may then host molecular masers, with ramifications for precision astrometry in the GC. A second, more exotic possibility is that of a "V Hydrae" object—a mass-losing giant orbited eccentrically by a main-sequence companion. This second case may provide evidence for the action of the eccentric Kozai-Lidov mechanism in the GC due to third-body perturbations from Sgr A*.

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142.02 – Observable Priors: Limiting Biases in Estimated Parameters for Incomplete Orbits

Over twenty years of monitoring stellar orbits at the Galactic center has provided an unprecedented opportunity to study the physics and astrophysics of the supermassive black hole (SMBH) at the center of the Milky Way Galaxy. In order to constrain the mass of and distance to the black hole, and to evaluate its gravitational influence on orbiting bodies, we use Bayesian statistics to infer black hole and stellar orbital parameters from astrometric and radial velocity measurements of stars orbiting the central SMBH. Unfortunately, most of the short period stars in the Galactic center have periods much longer than our twenty year time baseline of observations, resulting in incomplete orbital phase coverage--potentially biasing fitted parameters. Using the Bayesian statistical framework, we evaluate biases in the black hole and orbital parameters of stars with varying phase coverage, using various prior models to fit the data. We present evidence that incomplete phase coverage of an orbit causes prior assumptions to bias statistical quantities, and propose a solution to reduce these biases for orbits with low phase coverage. The explored solution assumes uniformity in the observables rather than in the inferred model parameters, as is the current standard method of orbit fitting. Of the cases tested, priors that assume uniform astrometric and radial velocity observables reduce the biases in the estimated parameters. The proposed method will not only improve orbital estimates of stars orbiting the central SMBH, but can also be extended to other orbiting bodies with low phase coverage such as visual binaries and exoplanets.

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142.04 – HI Clouds Near the Galactic Center: Possible Tracers of the Nuclear Wind

We have used the Green Bank Telescope to discover more than one hundred neutral hydrogen clouds that appear to be embedded in the Fermi Bubble -- the Milky Way's nuclear wind. With the other members of this population that were previously found with the Australia Telescope Compact Array, we now have a sample of about 200 such clouds. They are identified by their peculiar velocities. The cloud kinematics show no trace of Galactic rotation or association with the Galactic bar. Near longitude zero the clouds can have values of VLSR = +-200 km/s. No clouds have been detected with |VLSR| > 350 km/s. The clouds are concentrated toward the Galactic plane, but some are still found to |b|=10 degrees, or z > 1 kpc at the Galactic Center, where the current surveys end. These clouds are important tracers of conditions in the nuclear wind of the Milky Way.

Author(s): Felix J. Lockman[2], Naomi McClure-Griffiths[1], Enrico DiTeodoro[1]
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142.05 – Probing Magnetized Turbulence in the Fermi Bubbles

Fermi-LAT observations have revealed giant, sharply defined gamma-ray structures emanating from the Galactic center known as the Fermi bubbles. They extend ~50 degrees (~8.5 kpc) above and below the plane of the Milky Way. Their origin is uncertain but thought to be related to an energetic event such as accretion onto Sgr A* or a burst of nuclear star formation. We analyzed archival radio measurements of Faraday rotation toward extragalactic sources and detected a signature of the bubbles at the shock boundary to the Galactic halo. To confirm these preliminary findings we performed new radio observations with the Karl G. Jansky Very Large Array (JVLA). We discuss the findings of our observations, the shock energetics of the bubbles and their implications for nuclear Galactic activity.

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142.06 – A Detailed Analysis of the Physical Conditions in the Infrared Dark Clouds in the Region IGGC 16/23

There is an ongoing debate about why the star formation rate is low in the Galactic Center and Galactic Bar region of the Milky Way. Clump 2 is located at a distance of ~400 pc from the Galactic Center in the Galactic Bar region near the edge of the Central Molecular Zone (CMZ). Molecular clouds in this region are too distant to be influenced by the central black hole. However, despite of its location, Clump 2 is comprised of molecular clouds that show the same low star formation rate as those in the Galactic Center. Using Herschel PACS and SPIRE and APEX dust continuum emission data, our measurements indicate that cores in the IGGC 16/23 region have dust masses and densities comparable to those of more typical star-forming molecular clouds in the solar neighborhood. In addition, we analyzed Herschel HIFI high-J 12CO emission line observations supplemented by MOPRA molecular line observations. We find that the IGGC 16/23 region is composed of many smaller cores with different systemic velocities in the same line of sight advocating that additional analysis should be done to provide better constraints on the core sizes and masses to confirm that the core masses are below their virial masses and, thus, are not collapsing.

The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. 1262851, and by the Smithsonian Institution.

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142.07 – On the claimed X-shaped structure in the Milky Way bulge

A number of recent studies have claimed that the double red clump observed in the Milky Way bulge is a consequence of an X-shaped structure. In particular, Ness & Lang (2016) report a direct detection of a faint X-shaped structure in the bulge from the residual map of the Wide-Field Infrared Survey Explorer (WISE) image. Here we show, however, that their result is seriously affected by a bulge model subtracted from the original image. When a boxy bulge model is subtracted, instead of a simple exponential bulge model as has been done by Ness & Lang, we find that most of the X-shaped structure in the residuals disappears. Furthermore, even if real, the stellar density in the claimed X-shaped structure is way too low to be observed as a strong double red clump at l=0°

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142.08 – The Dynamics of Molecular Clouds in the Galactic Bar Region on the Near-Side of the CMZ

The inner Galaxy, the area inside the 3-kpc arms, can be divided into two main regions, the Central Molecular Zone (CMZ; Morris and Serabyn 1996) and the Galactic Bar region. Gas and dust moves from the end points of the Galactic Bar on dust lanes towards the CMZ, where it merges with the gas and dust forming a 100-pc molecular ring or stream around the central black hole. The stream of gas and dust on the dust lanes is not continuous, but fragmented into irregularly separated clumps of varying sizes and clustering. On the near side of the CMZ the most prominent cloud clusters are the l=1.6^{0} complex, Clump 2, and the molecular clouds around l=5.5^{0}. We are analyzing Herschel, MOPRA, APEx, and other archival observations in order a) to identify molecular clouds that are part of the gas and dust stream in the Galactic Bar region near the CMZ, b) to determine the dynamics of the Galactic Bar clouds, and c) to derive a gas and dust mass flow rate to the CMZ. This poster will present our initial results.

Author(s): Volker Tolls[1], Howard Alan Smith[1]
Institution(s): *1. Harvard-Smithsonian, CfA*
Contributing team(s): HIGGS Team

142.09 – Hunting for accretors towards the bulge with the Chandra and Hubble Space Telescopes

We are undertaking a deep X-ray/optical observational campaign of a well-studied low-extinction region towards the Galactic Bulge. Crucially, we have chosen a field for which very high-quality proper motions already exist from Hubble Space Telescope (HST) observations (or can be produced from a combination of archival and new observations covering much of the large Chandra ACIS-I field of view), allowing kinematic population membership constraints for X-ray point sources. While the ultimate scientific goal is to provide a new constraint on bulge formation models by tracing the accreting binary population that can be kinematically identified with the bulge, a large number of science investigations will ultimately be enabled by this initiative.

Here we report on our search for accreting binaries within the Sagittarius Window. The deep Chandra observations provide a rich catalog of X-ray point sources, while the new HST observations allow a sensitive search for Hα emission-line objects including the accreting binaries we seek. We present the techniques used to uncover accretors, and outline progress towards a catalog of X-ray point sources with kinematic and Hα identifications.

Author(s): Brittany Howard[6], Emily Aufdemberge[6], JaeSub Hong[2], William I. Clarkson[6], Maureen Van Den Berg[2], Kailash C. Sahu[4], Jonanthan Grindlay[1], Robert Michael Rich[5], Annalisa Calamida[3]
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142.10 – Distance to the High-Latitude Molecular Cloud MBM 37 (LDN 183)

The molecular cloud MBM 37 and the corresponding dust cloud LDN 183 belong to a group of high-latitude clouds near the Serpens Caput and Libra border at b = +36 deg. We determined the distance to this cloud applying the extinction A_V vs. distance diagram based on two-dimensional photometric classification of about 800 stars down to V = 15 mag and about 200 stars down to V = 19 mag observed in the Vilnius seven-color system. Additionally, for the stars brighter than V = 12 mag MK types were determined spectroscopically. Distances for part of them, located nearer than 500 pc, were calculated from the Gaia parallaxes. The distance to MBM 37 is found to be at 90 pc placing it among the dust and molecular clouds closest to the Sun.

Author(s): Richard P. Boyle[4], Robert Janusz[3], Vytautas Straizys[5], Christopher J. Corbally[4], Ulisse Munari[1], B-G Andersson[2], Justas Zdanavicius[5], Marius Maskoliunas[5], Algirdas Kazlauskas[5]
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142.12 – Smith's Cloud: No chemistry but we did find some of the Milky Way's Missing Baryons

The Green Bank Observatory's 100 meter Green Bank Telescope (GBT) was used to search for OH emission from Smith's Cloud. Smith's Cloud is a large, few 10^{6} Solar Mass cloud which will impact the Milkay Way's disk in about 35 Million years. The origin of Smith's Cloud is uncertain but its environmental conditions should have allowed for the formation of molecules. The GBT OH observations did not detect any OH from Smith's Cloud and limits the metalicity to be below 3% solar. Sulpher has been observed in the Smith's Cloud with a metalicity of 0.5 solar. Since OH is the first molecule to form and should have been easily detected, the GBT observations indicate that there is currently no active chemistry occuring in Smith's Cloud.

The observations did turn up a substantial amount of OH emission from the Milky Way along the line of sight. The observed lines of sight do not have any detected CO emission and suggests "dark gas" (dense enough to form OH but not CO) is present. The column density of this "dark gas" could be as high as 10^{18-19} at a galactic latitude of 35^{0}. The "dark gas" could represent a significant fraction of the Milky Way's missing baryons.

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142.13 – Age-Metallicity Relationships Across the Milky Way Galaxy with APOGEE

The Apache Point Observatory Galactic Evolution Experiment (APOGEE) has measured the infrared spectrum of over 160,000 stars. The unique combination of high resolution (R~20,000) and infrared wavelength coverage allows APOGEE to determine precise abundances for ~15 elements in stars located across the Galactic midplane, from ~3 kpc to ~15 kpc. The observed metallicity gradient over this radial range is also accompanied by a change in the shape of the metallicity distribution function (MDF) as a function of galactocentric radius (Hayden et al. 2015). Here, we combine the APOGEE sample with stellar age determinations (Ness et al. 2016) to measure how the distribution of stellar metals changes as a function of both galactocentric radius and age. We determine the age-metallicity relationship (AMR) in several radial zones, allowing comparison with the AMR measured in the local solar neighborhood. In addition, our analysis shows the skewness of the MDF changes as a function of radius even for the youngest (age < 1 gigayear) stars. These stars are too young to have migrated far from their birth radii. Our results suggest that the changing skew of the MDF with radius does not require substantial radial migration in the disk as recent studies contend.

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Contributing team(s): APOGEE Team (Sloan Digital Sky Survey)

142.14 – Local Velocity Substructure in the Milky Way Disk

We confirm and measure coherent velocity substructure of the Milky Way disk within 2 kpc of the Sun towards the anticenter. This substructure is likely related to the wave-like density substructure recently identified in the Milky Way disk, which could be caused by perturbations from dwarf galaxy satellites. We use the radial velocities of ~430,000 F stars from the Guoshoujing Telescope (also known as the Large Sky Area Multi-Object Fiber Spectroscopic Telescope, LAMOST), and proper motions derived from the PPMXL catalog. The PPMXL proper motions have been corrected to remove systematic errors by subtracting the average proper motions of galaxies and QSOs within 2.5 degrees of the star's position that have been spectroscopically confirmed in the LAMOST spectroscopic survey. We create a correction table to account for systematic error in proper motion from the PPMXL catalog that can be used in other studies. We find statistically significant deviations in the bulk disk velocity of about 20 km s^{-1} in the three dimensional velocities of Galactic disk stars near the anticenter. We present figures of these findings along with all propagated random and systematic errors. This project was funded by NSF grants AST 14-09421 and AST 16-15688.

Author(s): Alan Pearl[2], Heidi Jo Newberg[2], Jeffrey L. Carlin[1], R. Fiona Smith[2]
Institution(s): *1. LSST and Steward Observatory, 2. Rensselaer Polytechnic Institute*

142.15 – Halo Substructure Towards the Galactic Center

We measure the velocity substructure of blue horizontal branch stars in Data Release 10 of the Sloan Digital Sky Survey, particularly in the regions of the Hermus Stream, the Hyllus Stream, and the Hercules-Aquila Cloud. These stars are concentrated at lower latitudes ($b < 50°$) in the first quadrant ($0°<l<90°$). We present orbits fit to the stars in each substructure, and N-body simulations that plausibly replicate the morphologies of the observed tidal debris. From comparison with N-body simulations, we estimate the mass of the stream progenitors. This project was funded by a Rensselaer Presidential Fellowship, NSF grants AST 14-09421 and AST 16-15688, the NASA/NY Space Grant fellowship, and contributions made by The Marvin Clan, Babette Josephs, Manit Limlamai, and the 2015 Crowd Funding Campaign to Support Milky Way Research.

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142.16 – Better Galactic mass models through chemistry

With the upcoming release of the Gaia catalog and the many multiplexed spectroscopic surveys on the horizon, we are rapidly moving into a new data-driven era in the study of the Milky Way's stellar halo. When combined, these data sets will give us a many-dimensional view of stars in accreted structures in the halo that includes both dynamical information about their orbits and chemical information about their formation histories. Using simulated data from the state-of-the-art Latte simulations of Milky-Way-like galaxies, which include hydrodynamics, feedback, and chemical evolution in a cosmological setting using the FIRE physics model, we demonstrate that while dynamical information alone can be used to constrain models of the Galactic mass distribution in the halo, including the extra dimensions provided by chemical abundances can improve these constraints as well as assist in untangling different accreted components.

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142.17 – Structures in the Milky Way's Halo System using the Age Distribution of Field Horizontal-Branch Stars

Twenty five years ago it was demonstrated that the colors of blue horizontal-branch (BHB) stars in the halo of the Milky Way correlate with age (Preston et al., 1991). More recently, this property of BHB stars has been used to construct chronographic (age) maps of the Galaxy (Santucci et al., 2015; Carollo et al., 2016), which revealed the presence of substructures on the basis of the age contrast between younger accreted satellites with respect to the diffuse halo field stars, and, for the first time, obtained an empirical estimate of the age gradient for the halo of the Galaxy based on field BHB stars. These maps also indicated the presence of an ancient chronographic sphere, including the oldest BHB stars, extending from close to the Galactic center out to some 10-15 kpc.

We extend these studies making use of deeper *u*-band photometry from the recent public data release of the SCUSS survey (Zou et al., 2016). We also describe application of a new grid of ages that takes into account both metallicity and colors for BHB stars.

By building deeper chronographic maps we can better explore the age structures that are revealed. Up- coming large surveys, including the public release of Pan-STARRS, as well as photometry from the Dark Energy Survey, will further add to these efforts.

This work received partial support from PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

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142.18 – Identifying CEMP-s and CEMP-no Stars within Milky Way Halo Structures

Carbon-enhanced metal-poor (CEMP) stars are ancient objects used to probe the star-formation history of the first generations of stars in the Galactic halo. CEMP stars may be further separated into sub-classes based on the presence or absence of heavy elements associated with different neutron-capture processes. Here we examine CEMP stars enriched with the nucleosynthesis products of the slow neutron-capture process (CEMP-s stars) and those that exhibit no strong neutron-capture element enrichments (CEMP-no stars), which are preferentially found in the Galaxy's inner and outer halo regions, respectively [1,2].

Recent structure-finding algorithms have been applied to samples of K giants from SDSS to identify groups of associated stars and classify them as members of known structures, such as the Sagittarius tidal debris stream [3]. Here we investigate whether CEMP-s and CEMP-no stars are associated in different proportion with such structures or with the diffuse halo. We distinguish CEMP-s stars from CEMP-no stars using metallicity ([Fe/H]) and carbonicity ([C/Fe]), a method that has been demonstrated to be as effective as separation based on the presence of Ba enhancements used in the past [4]. We discuss the impact of our results on our understanding of the nature of CEMP stars and their progenitor populations, as well as on the assembly history of the Milky Way.

This work received partial support from PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

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[1] Carollo, D. et al. 2007, Nature, 450, 1020
[2] Carollo, D. et al. 2010, ApJ, 712, 692
[3] Janesh, W. et al. 2016, ApJ, 816, 80

[4] Yoon, J. et al. 2016, ApJ, in press (arXiv:1607.06336)

Author(s): Sarah Eliana Dietz[1], Timothy C. Beers[1], Daniela Carollo[1], Jinmi Yoon[1], Vinicius M Placco[1]
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142.19 – Keck Spectroscopy of NGVS Sources: Milky Way Halo Star Kinematics

We present a study of the kinematics of main sequence turnoff stars in the halo of the Milky Way based on Next Generation Virgo Cluster Survey photometry and Keck/DEIMOS spectroscopic follow-up. Specifically, we investigate the properties of the Virgo overdensity and Sagittarius stream Milky Way halo substructures in the foreground of the Virgo Cluster of galaxies. We use an inverse concentration (iC) parameter that characterizes the angular size of a source, which is defined by the magnitude difference measured by two different apertures for the same object. After combining this information as well as redshift measured from spectra into a Z vs iC plot, all of the objects are separated clearly into three categories: foreground Milky Way stars, Virgo globular clusters, and background galaxies. Most objects located in unexpected regions in the V_iC plot are subsequently rejected through a rigorous examination due to low spectral quality or bad imaging quality, indicating that our sample selection approach gives a very clean classification. We then select Sagittarius stream stars and Virgo overdensity stars out of the foreground star sample to characterize their distributions of spatial position, radial velocity and metallicity, from which we can probe deeper into the history of structure formation in the Milky Way Galaxy.

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HZ has been sponsored by China Scholarship Council to carry out this research project at University of California, Santa Cruz.

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Contributing team(s): Next Generation Virgo Cluster Survey (NGVS) Collaboration

142.20 – The WFIRST view of the distant stellar halo

Only a handful of Milky Way (MW) stars are now known to exist beyond 100 kpc from the Galactic center. Though the distribution of these stars is believed to be sparse, they can be a valuable source of information on the accretion history of the galaxy, providing evidence of more recent accretion events than the inner halo, while kinematic data for these distant stars can help map out the MW's dark matter halo all the way to the virial radius. Currently, searches for distant M giants are opening this window into the distant galaxy for the first time; in the future, WFIRST's High-Latitude Survey (HLS) offers the prospect of extending proper motion measurements to the edge of the MW virial radius over several thousand square degrees of sky. RR Lyrae identified by LSST in the HLS field will have accurate distances as well, offering the tantalizing prospect of complete six-dimensional phase space coordinates for these tracers at large distances. Using synthetic surveys of cosmological mock stellar halos, we explore how WFIRST will shed new light on the contents of the distant stellar halo.

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143 – Elliptical Galaxies Poster Session

143.01 – The Origin of Isolated Early-Type Galaxies: A Multiwavelength Study of Three Systems

One major approach to understanding the zero-redshift galaxy population is to distinguish the processes driving passive (internal) evolution of stellar systems from interaction-induced changes. The study of the structure and star formation history of highly isolated systems defines the baseline for quiescent evolution. Isolated early-type galaxies (ETGs) are an especially interesting population, since most ETGs are found in cluster environments. Possible evolutionary paths for isolated ETGs are merged (formerly) compact groups or direct collapse early in cosmic time.

As part of our long-term program to identify and explore highly isolated ETGs, we present panchromatic observations of the stars, neutral gas and dust in three highly isolated systems: Mrk 150, KIG 824 and SDSS J235021+141343, a subset of our initial isolated ETG sample. Our goal is to understand the evolutionary paths for these systems, in terms of their merger history, gas fueling and star formation rates. Each system presents diverse properties: Mrk 150 is optically blue and currently forming stars, while KIG 824 is red with no evidence for ongoing star formation; all possess neutral gas. Mrk 150 fits the class of luminous blue compact galaxies [M(V) = -19.2, B-V = 0.47] and possibly represents a link in the evolutionary chain leading to isolated, red and dead systems.

We combine GALEX UV photometry, optical images and spectra from the Sloan Survey, IR photometry from 2MASS, WISE and IRAS along with neutral hydrogen observations from the GBT. These data permit us to describe their morphology, quantify the current high-mass star formation rate, and determine the gas and dust content. Derived properties help constrain the evolution of these particular systems in the larger context of ETGs evolving in void-like regions.

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143.02 – Early type galaxies, i.e. ellipticals and lenticulars, are generally considered to be largely devoid of cool gas and associated dust

In this REU project we employ the unsharp masking technique to study a large sample of relatively bright and extended early type galaxies with imaging from SDSS. While most galaxies behave as expected, showing only a smooth, feature-less light distribution, we find a small but significant population of, in particular, S0-type galaxies with detectable dust features, such as dust disks, rings, or clumps. Based on a cross-match of our dusty early-type galaxies with the catalog of infrared-bright galaxies detected by IRAS reveals that all galaxies in which we find dust are also detected by IRAS, allowing us to better describe the geometry and distribution of the IR-emitting dust to improve modeling of their UV-optical-IR spectral energy distributions. We also found a small subset of galaxies showing evidence for tidal shells and debris, indicating a recent interaction. Lastly, the methods developed as part of this project can easily be adopted for similar and/or larger studies, providing a lasting benefit beyond the science results of this project. This work was supported by the National Science Foundation's REU program through NSF award AST-1560016.

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143.03 – Examining the X-ray Properties of Lenticular Galaxies: Rollins S0 X-ray Sample (RS0X)

Lenticular galaxies represent a complex morphology in which many questions remain. The S0 morphology possesses spiral galaxy attributes, such as a disk, while also displaying the luminosity and old stellar population indicative of an elliptical galaxy. The proposed formation mechanisms for lenticulars are also varied, with the absence of gas suggesting a faded spiral and the high masses and luminosities implying a merger formation. The star formation and high-energy emission from a sample of S0s will be used to better understand the properties and formation mechanisms of this unique subset of galaxies.

We use the Chandra X-ray Observatory archives cycle 1 – 16 to identify a sample of seventeen lenticular galaxies residing in a variety of environments. Data was analyzed using the CIAO software to produce true color images, radial profiles of the halo gas, gas contours, as well as determine the X-ray luminosities of the point sources and gas.

The X-ray gas temperature of the sample S0s varied over a narrow range between 0.61 and 0.96 keV, with one outlier, NGC 4382 at 2.0 keV. The X-ray luminosity of the halo gas varies by four dex. The gas temperatures and X-ray luminosities do not vary by environment, with the majority of sample S0s displaying values of typical elliptical galaxies. The S0 sample is X-ray under-luminous relative to the optical luminosity as compared to the sample of early-type galaxies of Ellis & O'Sullivan (2006).

The halo gas exhibited some distinct morphological features, such as multiple X-ray peaks, which may indicate a merger event, and highly concentrated gas, suggesting limited gravitational disturbance. Isolated S0, NGC 4406, displays an asymmetric halo, which could be interpreted as gas stripping. An isolated lenticular experiencing gas redistribution due to gravitational perturbation or a cluster-like medium could be interpreted as NGC 4406 forming in a higher galactic density environment than the field.

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143.04 – HST Infrared Imaging of MASSIVE Survey Galaxies

We have recently obtained high-resolution *HST* WFC3/IR F110W (J-band) images of 34 early-type galaxies in the MASSIVE study sample. These galaxies are among the most massive in the local universe, and were chosen to study the connection between supermassive central black holes and their host galaxies. To determine accurate masses for the black holes, we are measuring high-precision surface brightness fluctuation (SBF) distances to the galaxies. The WFC3/IR data also allow us to measure high spatial resolution central surface brightness profiles to understand better the nuclear structure and dynamics of the galaxies. We present a first look at the IR images, profiles, and SBF magnitudes for 34 galaxies in the MASSIVE sample.

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143.05 – A New Distance Measurement to NGC 4874 in the Coma Cluster

By measuring distances to remote galaxies we can determine the size, expansion rate, and age of the Universe. One of the best ways to measure distance is known as surface brightness fluctuations (SBF). The purpose of this research is to improve the current distance to the Coma Cluster by making accurate SBF distance measurements to two galaxies, NGC 4874 and NGC 4921. We analyzed HST WFC3 images in the F110W and F160W bands for NGC 4874 and ACS F814W and F606W for NGC 4921. Although NGC 4921 has a Cepheid distance measurement, we were unable to make an SBF measurement to NGC 4921 due to the presence of dust and young stars. The results of the distance measurement to NGC 4874 will be compared with previous distance measurements for the Coma Cluster. We also present a comparison of the globular cluster luminosity function for NGC 4874 measured using Source Extractor and a modified version of Dophot to help determine the photometric accuracy of our measurements in the presence of the bright galaxy background.

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144 – Spiral Galaxies Poster Session

144.01 – Star Formation in MUSCEL Galaxies

We present preliminary star-formation histories for a subset of the low surface brightness (LSB) galaxies in the MUSCEL (MUltiwavelength observations of the Structure, Chemistry, and Evolution of LSB galaxies) program. These histories are fitted against ground-based IFU spectra in tandem with space-based UV and IR photometry. MUSCEL aims to use these histories along with kinematic analyses to determine the physical processes that have caused the evolution of LSB galaxies to diverge from their high surface brightness counterparts.

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144.02 – Kinematics of MUSCEL Galaxies

We have begun the MUSCEL (MUltiwavelength observations of the Structure, Chemistry and Evolution of LSB galaxies) program to explore the formation and evolution of low surface brightness galaxies. Using ground and space-based photometric and spectroscopic data, we are studying the spatially-resolved kinematics and star formation histories of our targets to determine why they have followed a different evolutionary path than their high surface brightness counterparts. Here we present kinematic data and modeling for a subset of our targets.

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Institution(s): *1. Carnegie DTM, 2. Georgia State University, 3. Mount Holyoke*

144.03 – New Photometric and Kinematic Evidence for a Bar in NGC 2841

We report finding a bar in the massive spiral NGC 2841 from both photometric and kinematic modeling. Visually, this galaxy possesses flocculent spiral structure and an inner hole devoid of dust and neutral HI gas, but no obvious indication of a stellar bar. While there has been some previous speculation of a bar based off of isophotal photometry of NGC 2841, there has been no recent follow-up work or confirmation, and this galaxy is considered unbarred in modern catalogues and surveys. We use the DiskFit code to model broadband B, V, R, I photometry from the ARCTIC imager on the APO 3.5m telescope and Halpha velocity field kinematics from data taken with the SparsePak IFU on the 3.5m WIYN telescope at KPNO. In both cases, we find that including a bar that is nearly aligned with the major axis of the galaxy significantly improves the fit of the DiskFit models. Here we report our results and discuss them in the context of previous work.

Author(s): Wesley Peters[1], Rachel Kuzio de Naray[1]
Institution(s): *1. Georgia State University*

144.04 – Improving Stellar Velocity Dispersion Measurements in Barred Spiral Galaxies With Supermassive Black Holes

For the past decade researchers have focused on accurately measuring the masses of supermassive black holes in different types of galaxies. Relatively less effort has been devoted to possible systematic errors in the measurement of the central velocity dispersion of stars, sigma_*, with which the masses of supermassive black holes are known to be well correlated. In barred galaxies the measurement of sigma_* depends quite sensitively on the method used to calculate it and the kind of spectroscopic data (long-slit or IFU) and the orientation of the bar to the line-of-sight and inclination of the disk. We used simulations of barred disk galaxies with adiabatically grown SMBHs to generate mock kinematical data from which sigma_* is derived and compared with the true 3D velocity dispersion of stars in the simulations. By comparing simulations with real IFU data we aim to correct the measured sigma_* for aperture size /shape, disk inclination and bar position angle, to obtain the intrinsic central velocity dispersion of stars.

Author(s): Benjamin Dittenber[1], Monica Valluri[1]
Institution(s): *1. University of Michigan*

144.05 – Gravitational Instability of Nuclear Rings in Barred Galaxies

Nuclear rings at centers of barred galaxies exhibit strong star formation activities. They are thought to undergo gravitational instability when sufficiently massive. We approximate them as rigidly-rotating isothermal objects and investigate their gravitational instability. Using a self-consistent field method, we first construct their equilibrium sequences specified by two parameters: alpha corresponding to the thermal energy relative to gravitational potential energy, and R_B measuring the ellipticity or ring thickness. The density distributions in the meridional plane are steeper for smaller alpha, and well approximated by those of infinite cylinders for slender rings. We also calculate the dispersion relations of nonaxisymmetric modes in rigidly-rotating slender rings with angular frequency Omega and central density rho_c. Rings with smaller are found more unstable with a larger unstable range of the azimuthal mode number. The instability is completely suppressed by rotation when Omega exceeds the critical value. The critical angular frequency is found to be almost constant at 0.7(G rho_c)^0.5 for alph > 0.01 and increases rapidly for smaller alpha . We apply our results to a sample of observed star-forming rings and confirm that rings without a noticeable azimuthal age gradient of young star clusters are indeed gravitationally unstable.

Author(s): Woong-Tae Kim[1], Sanghyuk Moon[1]
Institution(s): *1. Seoul National Univ.*

144.06 – EVN VLBI Imaging of the Jet in the Nucleus of the Barred Spiral Galaxy NGC 7479

The nearby (D = 32 Mpc) barred spiral galaxy NGC 7479 hosts a remarkable jet-like radio continuum feature: bright, 12-kpc long in projection, and hosting an S-shaped, aligned magnetic field. The bending of the jet in 3-D is most easily explained by precession, with a jet age less than a million years. We have imaged the nucleus with European VLBI Network (EVN) observations at 6 and 18 cm. Here we report our tentative results on the search for nuclear jet emission on sub-arcsecond scales, including its alignment with the outer kpc-scale jet. We also describe the nature of the nucleus with the help of spectral index determination, brightness temperature limit and variability of the nucleus.

Author(s): Seppo J. Laine[1], Emmanuel Momjian3, Thomas Krichbaum[2], Rainer Beck[2], S. Komossa[2]
Institution(s): *1. Caltech, 2. MPIfR, 3. NRAO*

144.07 – Determining the Co-Rotation Radius of Nearby Spiral Galaxies Using Spiral Arm Overlays

Density wave theory, originally proposed by C.C. Lin and Frank Shu (Lin & Shu 1964), views the spiral arm structures in spiral galaxies as density waves that propagates through the galactic disk. Resonances within orbits create standing wave patterns of density waves that we observe as spiral arms. The theory predicts the existence of a radius known as the co-rotation radius in which the spiral arm pattern speed matches the velocities of the stars within the disk. We introduce a novel way of determining the co-rotation radius, based on an image overlaying technique, which involves tracing the arms of spiral galaxies on images observed from different wavelengths. For the purpose of this study, 12 nearby galaxies were analyzed from four different wavelengths using pitch angle measurements from a previous study (Hamed et al. 2016). We used optical wavelength images (B-Band,440 nm), two infrared wavelength (Infrared; 3.6 μm and 8 μm) Spitzer Space Telescope images and ultraviolet images from GALEX. The results were verified by checking against results compiled from the literature.

Author(s): Mohamed Shameer Abdeen[1], Daniel Kennefick[1], Julia D. Kennefick[1], Hamed Pour Imani[1], Douglas W Shields[1], Rafael Eufrasio[1], Jazmin Berlanga Medina[1], Erik Monson[1]
Institution(s): *1. Department of Physics, University of Arkansas*

144.08 – The Spiral Arm Pattern Speed for Different Components of the Interstellar Medium in NGC 3184

We test for a rigidly rotating spiral pattern in NGC 3184 by applying different versions of the Tremaine-Weinberg method to CO, H-alpha, and HI intensity and velocity data sets. These data sets produce different results when using the original method, which assumes a single value for the pattern speed. The result for the CO data is the largest, and the result for the HI data is the smallest. This is explainable if the pattern speed decreases with increasing radius by noting that the extent of the CO data is the smallest in radius, whereas the extent of the HI data is the largest. This interpretation is supported by the results for the general method, which shows the same decreasing trend with increasing radius for all three data sets. All three data sets also show evidence for an approximately rigid pattern in the central region, extending to where the two-arm pattern transitions to multiple arms. It is unclear, however, if this is due to bias from the regularization used to obtain these results. We are unable to find evidence for rigid rotation of the pattern beyond this transition. The results for the outer region closely follow the speed of the material, consistent with a shearing pattern, or multiple overlapping modes. The results rule out the existence of a single, rigidly rotating spiral wave mode in NGC 3184. They also demonstrate the possibility for bias when applying the original method to different types of data. Our findings contribute to a growing body of evidence for the existence of galaxy spiral arm pattern speeds that decrease with increasing radius.

Author(s): Jacob Lichtenberg[1], Jason Speights[1]
Institution(s): *1. Frostburg State University*

144.09 – Time Variability and Luminosity of X-ray Sources of Face-on Spiral Galaxy NGC 1232

The ACIS detector (Advanced CCD Imaging Spectrometer) onboard the *Chandra X-ray Observatory* has imaged the face-on spiral NGC 1232 over six epochs for a total exposure of ~250 ksec. We describe each observation as well as the merged data set. Each exposure contains ~50 individual sources. We focus on the time variability and luminosity distributions of the sources. We also describe our search for diffuse emission as well as our search for evidence for a reported collision with a dwarf galaxy. Finally, we compare the merged data set and the detected sources with other wavebands.

Author(s): Oscar Cantua[1], Tyler Rucas[1], Pranjal Singh[1], Eric M. Schlegel[1]
Institution(s): *1. The University of Texas at San Antonio*

144.10 – Chandra ACIS Observations of the Nearby Spiral Galaxy NGC 300

The ACIS detector (Advanced CCD Imaging Spectrometer) onboard the Chandra X-ray Observatory has imaged the nearby spiral NGC 300 over three epochs for a total exposure of 1.885×10^{2} ksec. We describe each observation as well as the merged data set. Each exposure contains 132 individual sources. We focus on the time variability and luminosity distributions of the sources. Initial results show no diffuse emissions in the galaxy. Finally, we compare the merged data set and the detected sources with other wavebands.

Author(s): Dale Bobar[1], Kevin Turner[1], Eric M. Schlegel[1]
Institution(s): *1. University of Texas at San Antonio*

144.11 – The Extent of Hot Gaseous Galaxy Halos

There are several constraints on the hot gas distribution around the Milky Way and external galaxies, but they are confined to within about 50 kpc, approximately $0.2R_{200}$. Beyond $0.2R_{200}$, several density distributions have been proposed, some that contain all the missing baryons within R_{200} and others that have the baryons extending to 2-3R_{200} before reaching the cosmological baryon to dark matter ratio. These differences are determined by galaxy formation processes and by feedback from supernovae and AGN. We present the conflicting evidence for the different extended baryon distributions. A clearer picture of the properties of these hot galaxy halos would be provided by high resolution soft X-ray spectroscopy, such as of the O VII and O VIII resonance lines, and the proposed Arcus mission would enable these breakthrough observations.

Author(s): Joel N. Bregman[2], Michael E. Anderson[1], Edmund J. Hodges-Kluck[2], Matthew J. Miller[2], Xinyu Dai3
Institution(s): *1. Max Planck Institute of Astrophysics, 2. Univ. of Michigan, 3. University of Oklahoma*

144.12 – A Chandra Observation of the Face-on Spiral Galaxy NGC 3938

The ACIS detector (Advanced CCD Imaging Spectrometer) onboard the Chandra X-ray Observatory has imaged the face-on spiral NGC 3938 for 50 ksec. We will detect ~50 sources within the D25 radius. We will describe the luminosity distribution in comparison with distributions from other nearby spiral galaxies. We do not detect any diffuse emission. We will compare the X-ray data to observations at other wavebands.

Author(s): Kelsey Buhidar[1], Eric M. Schlegel[1]
Institution(s): *1. University of Texas at San Antonio*

144.13 – Properties of Extended X-ray Halos Around Spiral Galaxies

The presence of hot X-ray emitting gaseous halos within the dark matter halos of massive spiral galaxies is a fundamental prediction of all galaxy formation models. Although the first extended X-ray halos around massive spiral galaxies have been detected in the past few years, most X-ray halos around spirals remain undetected. Given so few detections due to the faint nature of these halos, their average properties are poorly understood. To explore the average characteristics of hot halos, we initiated a multi-wavelength program. We utilize optical, infrared, and X-ray data of a large sample of spiral galaxies located at redshift $z<0.3$. To improve the signal-to-noise ratios and derive the average halo properties we stack the Chandra X-ray observations of the sample galaxies. We compare the observed properties of hot halos with those obtained from a state-of-the-art galaxy formation model. These results can be used to constrain the physical processes that influence the evolution of galaxies.

Author(s): Florence Concepcion Mairey[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysis*

144.14 – Observational Confirmations of Spiral Density Wave Theory

Using two techniques to reliably and accurately measure the pitch angles of spiral arms in late-type galaxies, we have compared pitch angles to directly measured black hole masses in local galaxies and demonstrated a strong correlation between them. Using the relation thus established we have developed a pitch angle distribution function of a statistically complete volume limited sample of nearby galaxies and developed a central black hole mass function for nearby spiral galaxies.
We have further shown that density wave theory leads us to a three-way correlation between bulge mass, pitch angle, and disk gas density, and have used data from the Galaxy Disk Mass Survey to confirm this possible fundamental plane. Density wave theory also predicts that the pitch angle of spiral arms should change with observed waveband as each waveband is sampling a different stage in stellar population formation and evolution. We present evidence that this is indeed the case using a sample of galaxies from the Spitzer Infrared Nearby Galaxy Survey. Furthermore, the evolved spiral arms cross at the galaxy co-rotation radius. This gives a new method for determining the co-rotation radius of spiral galaxies that is found to agree with those found using previous methods.

Author(s): Julia D. Kennefick[2], Daniel Kennefick[2], Mohamed Shameer Abdeen[2], Joel Berrier3, Benjamin Davis[1], Michael Fusco[2], Hamed Pour Imani[2], Doug Shields[2]
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Contributing team(s): DMS, SINGS

144.15 – UGC 4599: Revealing the Extended Structure of a Hoag's Object Analog with HERON

The Halos and Environments of Nearby Galaxies (HERON) survey utilizes a specialized telescope for imaging low surface brightness halos and galaxy environments. One such galaxy is UGC 4599, whose HERON images show improvements in observing the extended low luminosity structure as compared to previous studies. UGC 4599 is a nearby Hoag-Type Ring Galaxy with an extremely extended HI disk. Hoag's Object is characterized by a blue star-forming ring surrounding an older yellow nucleus. In the case of UGC 4599, the nuclear region was previously revealed to closely follow a De Vaucouleurs luminosity profile, suggesting the object to be at least elliptical-like. While previous photometric studies of UGC 4599 were focused mainly on the bright core and star forming ring of the galaxy, the HERON survey is able to probe the fainter, extended halo.

With an eight hour integration time, we find spiral structure surrounding the core and ring of UGC 4599. The main ring of the galaxy is broken with an m=2 (180 degree) symmetry, suggesting a two armed spiral structure. However, once the core and ring of UGC 4599 are modeled with the software GALFIT, a well defined m=1 (single arm) spiral emerges, extending from the central region to several times the radius of the ring. Though the ring appears to break in two places, the spiral structure may be comprised of mainly one dominant arm.

In late type galaxies, the pitch angle of spiral arms has been shown to correlate well with the mass of the central Supermassive Black Hole (SMBH) in an M-P relation. The pitch angle of the one arm spiral of UGC 4599 is measured to be roughly P=9 degrees, corresponding to a SMBH mass for UGC 4599 of between 10^7 and 10^8 solar masses (further constrained pitch angle measurements forthcoming). The outermost edge of UGC 4599 as detected in our imaging may be modeled as an extension of this one armed spiral, or as yet another ring feature. Due to many bright foreground stars, there is difficulty in ascertaining whether this outermost feature completes the spiral or instead forms yet another, lower surface brightness, ring.

Author(s): Michael Fusco3, David A. Thilker[1], Fufang Wen4, Junjie Xia4, Stephen Storment3, Noah Brosch[2], Francis Longstaff4, Julia D. Kennefick3, Robert Michael Rich4
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Contributing team(s): The Halos and Environments of Nearby galaxies (HERON) team

144.16 – Updated Photometry for the SINGS/KINGFISH Samples of Nearby Galaxies

We present an update to the complete panchromatic database of global broadband photometry for the 79 nearby galaxies that comprise the union of the KINGFISH and SINGS samples. Improvements of note in the 33-band dataset include recalibrations of previously-published SINGS BVRI and KINGFISH far-infrared/submillimeter photometry. Similar to previous results in the literature, an excess of submillimeter emission above model predictions is seen primarily for low-metallicity dwarf/irregular galaxies.

Author(s): Daniel A. Dale[1]
Institution(s): *1. Univ. of Wyoming*
Contributing team(s): SINGS, KINGFISH

144.17 – Dust lanes in backlit galaxies: first results from the STARSMOG survey

STARSMOG is an HST WFC3 snapshot survey of dust attenuation in overlapping backlit galaxies, planned to span the range of morphological type and luminosity of dust-rich galaxies. The target list came from the Galaxy Zoo and GAMA catalogs, imposing a minimum redshift difference to guarantee large line-of-sight separations, virtually eliminating scattering corrections and avoiding potentially distorted interacting systems. These include the first flocculent spirals studied with the occulting-galaxy approach. We present results from the geometrically most favorable subset of 9 pairs from the 54 observed STARSMOG systems. The data quality and intensity of background light let us map dust features with attenuations of only a few per cent in the red F606W band. Organized dust lanes show sharp outer boundaries in disks, and are absent in galaxies of late Hubble type. Many Sb-Sc disks show a dusty web of criss-crossing lanes, some nearly at right angles to the overall spiral pattern. Particularly favorable cases constraint the scale height of starlight in the foreground disks, through comparison of the light loss in regions with and without background light. The covering fraction of dust at various attenuation levels is consistent between barred and nonbarred spirals, although dust features may be more concentrated in azimuth when a bar is present (and concentrated in an annulus when a stellar resonance ring is seen). Together with our previous data on much more limited samples or at lower resolution,these results add to a picture where galaxies of similar morphology may have quite different attenuation patterns with radius for both arm and interarm dust.

Author(s): William C. Keel[10], Sarah Bradford[4], Benne Holwerda[5], Christopher Conselice[8], Ivan Baldry[2], Jonathan Bland-Hawthorn[9], Simon P Driver[1], Loretta Dunne[6], Jochen Liske[7], Aaron Robotham[1], Richard Tuffs[3]
Institution(s): *1. ICRAR, 2. Liverpool John Moores U., 3. MPIA, 4. MTSI, Inc., 5. Sterrewacht Leiden, 6. U. Edinburgh, 7. U. Hamburg, 8. U. Nottingham, 9. U. Sydney, 10. University of Alabama - Tuscaloosa*

144.18 – Identifying Hidden Supernova Remnants in M83 with the VLA

We present results of our analysis of C and L band observations of the grand design spiral galaxy, M83 made with the Karl G. Jansky Very Large Array (VLA). With recent optical (HST) and X-ray (Chandra) observations and utilizing the newly expanded bandwidth of the VLA, we are exploring the radio spectral properties of the historical radio point sources in M83 and have discovered more than 250 discrete radio sources. These observations allow us to probe the evolution of supernova remnants (SNRs) and to find previously undiscovered SNRs. These observations represent the fourth epoch of deep VLA observations of M83. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities.

Author(s): Bradley Cole[6], Christopher Stockdale[6], William P. Blair[5], John J. Cowan[10], Leith Godfrey[1], K. D. Kuntz[5], Knox S. Long[8], Larry A. Maddox[2], Paul P. Plucinsky[4], Tyler A. Pritchard[9], Roberto Soria[3], Bradley C. Whitmore[5], P. Frank Winkler[7]
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144.19 – De-coding the Neutral Hydrogen (21cm) Line Profiles of Disk galaxies

Neutral hydrogen is the most abundant element in the interstellar medium, and it has long lent astronomers insight into galaxy structure, galactic interactions, and even dark matter prevalence. It is necessary to implement a detailed coding scheme that characterizes the 21-cm HI line profiles which exist in abundance throughout literature. We have utilized a new computer simulation program that exposes the internal architecture of a galaxy by way of mapping the one-dimensional line profile on to the three-dimensional parameters of a given galaxy. We have created a naming system to classify HI line profiles, which represents a kinematic description of the galaxy simply by considering its classification within the coding scheme.

Author(s): Sandy Moak[1], Barry Madore[1], David Khatami[1]
Institution(s): *1. Carnegie Observatories*

144.20 – Stellar Populations in the Outer Regions of M101

We have analyzed deep HST (ACS and WFC3) images of the resolved stellar populations in a pair of fields in the outermost disk and halo regions of the face-on spiral galaxy M101. The color-magnitude diagram (CMD) of our ACS field, located at a projected distance ~40 kpc from M101, exhibits multiple stellar populations including an old red-giant-branch (RGB), and younger sequences of AGB, main sequence and helium burning stars. The resolved stellar populations indicate a short, metal-poor ([Fe/H] ~ -1.0) burst of star formation peaking ~ 300 Myr ago, consistent with inferences from our previous deep surface photometry of M101's outer disk. Our WFC3 ‘control’ field is located ~50 kpc from M101, and has an RGB indicative of a single old stellar population with a metallicity of [Fe/H] = -1.5, similar to that of the Milky Way halo.

Author(s): Patrick R. Durrell[2], Chris Mihos[1], John J. Feldmeier[2], Paul Harding[1], Aaron Emery Watkins[1], Christopher P. Leach[2]
Institution(s): *1. Case Western Reserve Univ., 2. Youngstown State Univ.*

144.21 – ALMA CO Observations of Shocks and Star Formation in the Interacting Galaxies IC 2163 and NGC 2207

The spiral galaxies IC 2163 and NGC 2207 are a well-studied pair undergoing a grazing collision. ALMA CO observations of masses, column densities, and velocities are combined with HI, Hα, optical, and 24 micron data to study the star formation rates and efficiencies. The close encounter of the galaxies produced in-plane tidal forces in IC 2163, resulting in a large shock with high molecular velocity gradients and both radial and azimuthal streaming (100 km/s) that formed a pile-up of molecular gas in the resulting cuspy-oval or ``eyelid'' structure at mid-radius. The encounter also produced forces nearly orthogonal to the plane of NGC 2207, resulting in a warp. By comparing with the Kennicutt-Schmidt relation for star formation, we find that some regions of NGC 2207 with unusually high turbulent speeds (40-50 km/s) and high star formation rates (>0.01 $M_0/pc^2/Myr$) have gas that is predominantly atomic with high density cores. Half of the CO mass is in 300 clouds each more massive than 4.0x105 M_0. The mass distribution functions for the CO clouds and star complexes in the eyelid in IC 2163 both have a slope similar to what is observed in Milky Way clouds; the CO slope is steeper in NGC 2207. The CO distribution in NGC 2207 also includes a nuclear ring, a mini-bar, and a mini-starburst region that dominates the 24 micron, radio, and Hα emission in both galaxies. Dust extinction, molecular column densities, and slightly negative molecular velocities indicate the mini-starburst region has ejected a jet of molecular gas nearly perpendicular to the plane of NGC 2207 on the near side with a kinetic energy of 10^{52} ergs. The large scale star formation efficiency, measured as the ratio of the summed masses of the star complexes near molecular clouds to the combined star complex and cloud masses, is 7% overall; it is 23% in the mini-starburst. The maximum age of star complexes in the galactic-scale shock front at the eyelid is about the same as the time since closest approach of the galaxies, suggesting a triggering process related to tidal compression.

Author(s): Debra M. Elmegreen[7], Bruce Elmegreen[2], Michele Kaufman[4], Elias Brinks[6], Curtis Struck[3], Frederic Bournaud[1], Kartik Sheth[5], Stephanie Juneau[1]
Institution(s): *1. CEA Saclay, 2. IBM T.J. Watson Research Ctr., 3. Iowa State University, 4. N.A, 5. NASA Headquarters, 6. University of Hertfordshire, 7. Vassar College*

145 – Dwarf & Irregular Galaxies Poster Session

145.01 – Exploring Dwarf Galaxy Evolution

Dwarf galaxies are the most numerous galaxies in the universe, yet little is definitively understood about their formation and evolution. An evolutionary link has been proposed between dwarf irregular and dwarf elliptical galaxies by previous studies. The nature and existence of so-called dwarf spiral galaxies is still heavily debated. This project explores the properties of dwarf galaxies spanning a range in morphological type, luminosity, physical size, and surrounding environment (i.e. group / field galaxies). The goal of this project is to determine the range of exhibited properties for each type of dwarf galaxy using available ultraviolet, visible, and near-infrared imaging and spectra. Similarities in visible, broadband colors support the proposed evolutionary link dwarf irregular and dwarf elliptical galaxies when the range of brightness of the samples is constrained to the fainter galaxies. Here, comparisons amongst a sub-sample of 59 dwarf irregulars, 12 dwarf ellipticals, and 29 dwarf spirals will be presented using archival ultraviolet, visible, and near-infrared imaging. The effect of constraining the comparisons to the fainter sample members will be explored, as well as the effect of constraining the comparisons to the brighter sample members.

Author(s): Jacqueline M. Dunn[1]
Institution(s): *1. Midwestern State Univ.*

145.02 – Investigating Dwarf Spiral Galaxies

Several studies have proposed that dwarf elliptical / spheroidal galaxies form through the transformation of dwarf irregular galaxies. Early and late type dwarfs resemble each other in terms of their observed colors and light distributions (each can often be represented by exponential disks), providing reason to propose an evolutionary link between the two types. The existence of dwarf spirals has been largely debated. However, more and more recent studies are using the designation of dwarf spiral to describe their targets of interest. This project seeks to explore where dwarf spirals fit into the above mentioned evolutionary sequence, if at all. Optical colors will be compared between a sample of dwarf irregular, dwarf elliptical, and dwarf spiral galaxies. The dwarf irregular and dwarf elliptical samples have previously been found to overlap in both optical color and surface brightness profile shape when limiting the samples to their fainter members. A preliminary comparison including the dwarf spiral sample will be presented here, along with a comparison of available ultraviolet and near-infrared data. Initial results indicate a potential evolutionary link that merits further investigation.

Author(s): Sachithra Weerasooriya[1], Jacqueline M. Dunn[1]
Institution(s): *1. Midwestern State University*

145.03 – The Smallest Galaxies in the Universe: Investigating the Origins of Ultra-faint Galaxies

One outstanding question in cosmology is, what are the smallest galaxies that can form? The answer to this question can tell us much about galaxy formation, and even of the properties of dark matter itself. A candidate for the smallest galaxies that can form are the ultrafaint galaxies. The star formation of ultrafaints appears to have been shut off during the epoch of reionization, when radiation from the first stars ionized all the free hydrogen in the universe. This would imply ultrafaints should exist everywhere in the universe. However, we can only observe ultrafaints as satellites of the Milky Way, due to their low brightness. This will change with the next generation of telescopes such as the Large Synoptic Survey Telescope (LSST). The focus of this work is to predict the number of ultrafaints that should be seen with future surveys. To that end, we use the ELVIS suite, which contains 14 dark matter only simulations of Local Group like systems containing a Milky Way and Andromeda-like galaxy and the substructure out to around 1 Mpc of the barycenter. We mock observe the simulations in order to mimic current surveys such as the Sloan Digital Sky Survey (SDSS), and the Dark Energy Survey (DES), and use the population of galaxies found by those surveys to project the population of dwarf galaxies out beyond the virial radius of either galaxy. This number will depend sensitively on the formation mechanism of ultrafaint dwarfs, and comparisons of future surveys to this work could help rule out certain formation scenarios.

Author(s): Yuewen Qi[1], Andrew Graus[1], James Bullock[1]
Institution(s): *1. UC Irvine*

145.04 – The WHAM Hα Magellanic Stream Survey: Progress and Early Results

We present early analysis of the Hα survey of the Magellanic Stream using the Wisconsin H-Alpha Mapper (WHAM). The neutral component of the Stream extends some 200° across the sky (Nidever et al. 2010). However, the full extent of the ionized gas has not been mapped in detail. Previous studies (e.g., Putman et al. 2003; Weiner & Williams 1996) suggest that ionized gas is likely to be found all along the length of the Stream, and may extend beyond the current neutral boundaries as traced by 21 cm. Barger et al. (2013) used WHAM to map ionized gas throughout the Magellanic Bridge between the Magellanic Clouds. Although ionized emission tracks the neutral emission for the most part, it often spans a few degrees away from the H I at slightly offset velocities. Additionally, Fox et al. (2014) find evidence in an absorption line study that the tidal debris in the Magellanic System contains twice as much ionized gas as neutral material and may extend 30° away from 21-cm sensitivity boundaries. We are now compiling the first comprehensive picture of the ionized component of the Magellanic Stream using WHAM's unprecedented sensitivity to trace diffuse emission (~tens of mR), its velocity resolution (12 km/s) to separate the Stream from the Milky Way, and its multiwavelength capabilities (e.g., [S II] and [N II]) to examine the physical conditions of the gas. Much of the data along the primary axis of the Stream has been collected for the first phase of this extensive study, a complete kinematic Hα survey of the Stream. We present survey progress, challenges in extracting Stream emission, and first-look kinematic maps at select positions along the Stream.

Author(s): Brianna Smart[2], L. Matthew Haffner[2], Kat Barger[1], Dhanesh Krishnarao[2]
Institution(s): *1. Texas Christian Univeristy, 2. University of Wisconsin - Madison*

145.05 – The rise of ionized gas in the Magellanic Stream

The Small and Large Magellanic Clouds are a pair of interacting galaxies near the Milky Way. Tidal interactions have stripped gas from these galaxies, leaving behind gaseous debris such as the Magellanic Stream. We explore the morphology and kinematics of the neutral and ionized hydrogen gas in the trailing stream traveling toward the Milky Way. This comparison provides us with insight into the physical processes that are affecting the gas flowing through the Galactic halo. This is done using mapped H-alpha emission-line spectroscopy, obtained with the Wisconsin H-alpha Mapper (WHAM), and archival 21-cm HI observations of the Stream near the Magellanic Clouds. We found that the neutral and ionized gas spatially and kinematically trace each other. With a map of the ionized gas in hand, we will continue to study the survival of this tidal relic.

Author(s): Michael Hernandez[1], Kathleen Barger[1], Brianna Smart[2], L. Matthew Haffner[2]
Institution(s): *1. Texas Christian University, 2. University of Wisconsin-Madison*

145.06 – Probing ionization conditions of Galactic halo gas using H-alpha observations of the Magellanic Stream

Galaxy interactions have greatly disturbed and redistributed the gas in the Magellanic System throughout the halos of the Milky Way. Using the Wisconsin H-alpha Mapper (WHAM) telescope, we have completed the highest sensitivity and kinematically resolved emission-line survey of the entire Magellanic Stream. These observations enable us to determine how the ionization conditions change over 100-degrees across the sky, including the region below the South Galactic Pole. We explore the sources of that ionization and find that photoionization from the Milky Way and Magellanic Clouds is insufficient to explain the observed H-alpha emission. We further investigate whether energetic processes associated with the Milky Way's center or interactions with the halo could provide the remaining ionization. The gas in the Magellanic Steam could supply enough gas to maintain or even boost the star formation in the Milky Way, but only if it can survive the journey to the Galaxy's disk.

Author(s): Kat Barger[6], Gregory J Madsen[2], Andrew Fox4, Bart P. Wakker[8], Jonathan Bland-Hawthorn5, David L. Nidever3, Nicolas Lehner7, L. Matthew Haffner[8], Alex S. Hill[1]
Institution(s): *1. Haverford College, 2. Lockheed Martin, 3. National Optical Astronomy Observatory, 4. Space Telescope Science Center, 5. Sydney Institute for Astronomy, 6. Texas Christian University, 7. University of Notre Dame, 8. University of Wisconsin-Madison*

145.07 – Feeding the Milky Way: Properties of the Leading Arm of the Magellanic Stream

The Leading Arm is a tidally formed gaseous structure spearheading the Magellanic Cloud galaxies on their trajectory through the Milky Way's halo. Its morphology shows evidence of interaction with the Galactic disk. Thus, this gas stream presents a first-hand opportunity to study direct fueling of our Galaxy with star-forming material. Using HST/COS spectra of two QSO targets, we measure the column densities of UV metal lines in two directions with HI 21 cm detections, and use these to constrain the Leading Arm's metallicity. This allows us to put constraints on its origin and formation.

Author(s): Jacqueline Antwi-Danso[2], Andrew Fox[1]
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145.08 – Supernovae explosions in the Large Magellanic Cloud drive massive winds toward the Milky Way

We present H-alpha mapped observations of Large Magellanic Cloud (LMC) intermediate- and high-velocity clouds. The intermediate-velocity cloud represents a present-day galactic wind while the high-velocity cloud may trace a remnant of a past wind from 300 Myr ago. Previous absorption-line studies detected these winds in front of the LMC, but were unable to confirm that these clouds extend off the LMC. Using the Wisconsin H-alpha Mapper, we mapped the H-alpha emission of the near side LMC cloud population. This enabled us, for the first time, to determine the extent, morphology, and kinematics of these clouds. The previous work by Lehner et al. (2009) and Barger et al. (2016) find that these clouds are roughly 10 million solar masses each; our observations show that these clouds contain substantially more mass than previous estimates. This ejected material is falling toward the Milky Way and may aid in replenishing our star formation reservoir.

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145.09 – VLA+WSRT HI Imaging of Two "Almost Dark" Galaxies

We present sensitive HI imaging of the "Almost Dark" galaxies AGC229385 and AGC229101. Selected from the ALFALFA survey, "Almost Dark" galaxies have significant HI reservoirs but lack an obvious stellar counterpart in survey-depth ground-based optical imaging. Deeper ground- and space-based imaging reveals very low surface brightness optical counterparts in both systems. The resulting M_HI/L_B ratios are among the highest ever measured for individual galaxies. Here we combine VLA and WSRT imaging of these two systems, allowing us to preserve surface brightness sensitivity while working at high angular resolution. The resulting maps of HI mass surface density, velocity field, and velocity dispersion are compared to deep optical and ultraviolet imaging. In both systems the highest column density HI gas is clumpy and resolved into multiple components. In the case of AGC229385, the kinematics are inconsistent with a simple rotating disk and may be the result of either an infall episode or an interaction between two HI-rich disks.

Support for this work was provided by NSF grant 1211683 to JMC at Macalester College.

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145.10 – "Almost Darks": HI Mapping and Optical Analysis

We present VLA HI imaging of the "Almost Dark" galaxies AGC 227982, AGC 268363, and AGC 219533. Selected from the ALFALFA survey, "Almost Dark" galaxies have significant HI reservoirs but lack an obvious stellar counterpart in survey-depth ground-based optical imaging. These three HI-rich objects harbor some of the most extreme levels of suppressed star formation amongst the isolated sources in the ALFALFA catalog. Our new multi-configuration, high angular (~20") and spectral (1.7 km/s) resolution HI observations produce spatially resolved column density and velocity distribution moment maps. We compare these images to Sloan Digitized Sky Survey (SDSS) optical images. By localizing the HI gas, we identify previously unknown optical components (offset from the ALFALFA pointing center) for AGC 227982 and AGC 268363, and confirm the association with a very low surface brightness stellar counterpart for AGC 219533. Baryonic masses are derived from VLA flux integral values and ALFALFA distance estimates, giving answers consistent with those derived from ALFALFA fluxes. All three sources appear to have fairly regular HI morphologies and show evidence of ordered rotation.

Support for this work was provided by NSF grant 1211683 to JMC at Macalester College.

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145.11 – SHIELD: EVLA HI Spectral Line Observations of Low-mass Dwarfs

The "Survey of HI in Extremely Low-mass Dwarfs" (SHIELD) is a multiwavelength study of local volume low-mass galaxies. Using the now-complete *Arecibo Legacy Fast ALFA* (ALFALFA) source catalog, 82 systems are identified that meet distance, line width, and HI flux criteria for being gas-rich, low-mass galaxies. These systems harbor neutral gas reservoirs smaller than 3x10^7 M_sun, thus populating the faint end of the HI mass function with statistical confidence for the first time. Here we present new *Karl G. Jansky Very Large Array* D-configuration HI spectral line observations of 32 previously unobserved galaxies. These low angular resolution (~40" beam) images localize the HI gas; with a few exceptions, the HI gas is co-spatial with the optical centers of the galaxies. These images provide the first glimpse of the neutral interstellar medium in these systems.

Support for this work was provided by NSF grant 1211683 to JMC at Macalester College.

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145.12 – SHIELD: Observations of Three Candidate Interacting Systems

Abstract:
The “Survey of HI in Extremely Low-mass Dwarfs” (SHIELD) is a multiwavelength study of local volume low-mass galaxies. Using the now-complete Arecibo Legacy Fast ALFA (ALFALFA) source catalog, 82 systems are identified that meet distance, line width, and HI flux criteria for being gas-rich, low-mass galaxies. These systems harbor neutral gas reservoirs smaller than 3x10^7 M_sun, thus populating the faint end of the HI mass function with statistical confidence for the first time. In a companion poster, we present new Karl G. Jansky Very Large Array D-configuration HI spectral line observations of 32 previously unobserved galaxies. Three galaxies in that study have been discovered to lie in close angular proximity to more massive galaxies. Here we present VLA HI imaging of these candidate interacting systems. We compare the neutral gas morphology and kinematics with optical images from SDSS. We discuss the frequency of low-mass galaxies undergoing tidal interaction in the complete SHIELD sample.

Support for this work was provided by NSF grant 1211683 to JMC at Macalester College.

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145.13 – Rotational Dynamics and Star Formation in the Nearby Dwarf Galaxy NGC 5238

We present new HI spectral line images of the nearby low-mass galaxy NGC 5238, acquired with the Karl G. Jansky Very Large Array (VLA). Located at a distance of 4.51 +/- 0.04 Mpc, NGC 5238 is an actively star-forming galaxy with widespread H-alpha and UV continuum emission. The source is included in many ongoing and recent nearby galaxy surveys, but until this work the spatially resolved qualities of its neutral interstellar medium have remained unstudied. Our HI images resolve the disk on physical scales of ~400 pc, allowing us to undertake a detailed comparative study of the gaseous and stellar components. The HI disk is asymmetric in the outer regions, and the areas of high HI mass surface density display a crescent-shaped morphology that is slightly offset from the center of the stellar populations. The HI column density exceeds 10^21 cm^-2 in much of the disk. We quantify the degree of co-spatiality of dense HI gas and sites of ongoing star formation as traced by far-UV and H-alpha emission. The neutral gas kinematics are complex; using a spatially-resolved position-velocity analysis, we infer a rotational velocity of 31 +/- 5 km/s. We place NGC 5238 on the baryonic Tully-Fisher relation and contextualize the system amongst other low-mass galaxies.

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145.14 – The Frequency of Starbursts in Dwarf Galaxies

Starbursts are periods of intense star formation that can dramatically impact the evolution of a galaxy, particularly in the shallow potential well of dwarf galaxies. Starbursts in dwarf galaxies have been measured to last hundreds of Myr based on star formation histories derived from resolved stellar populations. Often, these temporally extended events do not have direct evidence of an external trigger mechanism; this suggests that it is possible starbursts in dwarfs may be internally driven. Using archival HST data, we probe for (post-)starburst signatures using SFHs of a wider sample of dwarfs. These results will help constrain the fraction of dwarf galaxies in the local volume that experience a starburst event and the likelihood of whether starbursts can be internally triggered.

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145.15 – Scaling Stellar Mass Estimates of Dwarf Galaxies

Hubble Space Telescope (HST) optical imaging of resolved stellar populations has been used to constrain the star formation history (SFH) and chemical evolution of many nearby dwarf galaxies. However, even for dwarf galaxies, the angle subtended by nearby systems can be greater than the HST field of view. Thus, estimates of stellar mass from the HST footprint do not accurately represent the total mass of the system, impacting how SFH results can be used in holistic comparisons of galaxy properties. Here, we use the SFHs of dwarfs combined with stellar population synthesis models to determine mass-to-light ratios for individual galaxies, and compare these values with measured infrared luminosities from Spitzer IRAC data. In this way, we determine what fraction of mass is not included in the HST field of view. To test our methodology, we focus on dwarfs whose stellar disks are contained within the HST observations. Then, we also apply this method to galaxies with larger angular sizes to scale the stellar masses accordingly.

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145.16 – Exploring the Metal Retention Fractions of Dwarf Galaxies

Using a novel technique that combines star formation and chemical evolution histories from resolved stellar populations, nebular abundances, and gas masses, McQuinn et al. 2015 measured that only 5% of the oxygen produced by stellar nucleosynthesis was retained in the gas and stars in the very low-mass (stellar mass = 6x10^5 Msun) galaxy Leo P. In contrast to expectations, metal production and metal loss for spirals in the mass range ~10^9 - 10^{11} Msun show that these galaxies retain 20-25% of their metals, independent of mass (Peeples et al. 2014).

This suggests there is only a factor of ~5 difference in the ability of galaxies to retain metals, despite a factor of 10^6 difference in mass. In this prototype study, we explore using the same technique from McQuinn et al. on a small sample of dwarfs with HST archival data, with particular attention to understanding the uncertainties in the approach. Our results will provide a measurement in the intervening mass range between Leo P and more massive spirals. This will allow us to test theoretical predictions of metal loss as a function of galaxy mass.

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145.17 – Photometric and spectroscopic study of the ultra-faint Milky Way satellite Pegasus III

Pegasus III (Peg III) is one of the few known ultra-faint dwarf (UFD) satellite galaxies in the outer halo (R >150 kpc) of the Milky Way (MW). We present results from a recent study of Peg III using Magellan/IMACS and Keck/DEIMOS. Our newly-measured structural parameters confirm that Peg III is large (r_h = 53±14pc), elongated ($\epsilon = 0.38^{+0.22}_{-0.38}$), and faint (M_V=-3.4±0.4 mag) — indicative of its nature as a dwarf rather than a globular cluster. In the color-magnitude diagram, Peg III is well described by an old (>12Gyr) and metal-poor ([Fe/H]<-2.0 dex) stellar population at a heliocentric distance of 215±12 kpc. Using spectroscopic measurements of individual stars, we identify seven kinematic members of Peg III. The Ca II triplet lines of the brightest members verify that Peg III indeed contains stars with metallicity as low as [Fe/H]=-2.55±0.15 dex. The systemic velocity and velocity dispersion of Peg III are -222.9±2.6 km/s and $5.4^{+3.0}_{-2.5}$ km/s, respectively. The inferred dynamical mass within the half-light radius of $1.4^{+3.0}_{-1.1}\times10^6 M_\odot$, and the mass-to-light ratio of $M/L_V = 1470^{+5660}_{-1240} M_\odot/L_\odot$ provide further evidence that Peg III is a bona fide UFD. Peg III and another distant UFD Pisces II lie relatively close to each other ($\triangle d_{spatial}$=43±19 kpc) and share similar systemic radial velocities ($\triangle v_{GSR}$=12.3±3.7 km/s), which suggests that they may share a common origin.

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145.18 – Gas Stripping in the Simulated Pegasus Galaxy

We utilize the hydrodynamic simulation code GIZMO to construct a non-cosmological idealized dwarf galaxy built to match the parameters of the observed Pegasus dwarf galaxy. This simulated galaxy will be used in a series of tests in which we will implement different methods of removing the dwarf's gas in order to emulate the ram pressure stripping mechanism encountered by dwarf galaxies as they fall into more massive companion galaxies. These scenarios will be analyzed in order to determine the role that the removal of gas plays in rotational vs. dispersion support (V_{rot}/σ) of our galaxy.

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145.19 – The Nonbarred Double-Ringed Galaxy, PGC 1000714

Hoag-type galaxies are rare peculiar systems which bear strong resemblance to Hoag's Object with an elliptical-like core, a detached outer ring, and no signs of a bar or stellar disk. They represent extreme cases and help us understand the formation of galaxies in general by providing clues on formation mechanisms. The nature of outer rings in Hoag-type galaxies is still debated and may be related either to slow secular evolution, such as dissolution of a barlike structure or to environmental processes, such as galaxy-galaxy interactions or gas infall. Due to a fairly superficial resemblance to Hoag's Object, PGC 1000714 is a good target for detailed study of the peculiar structure of this type. We present the first photometric study of PGC 1000714 that has not yet been described in the literature. Our aim is to evaluate its structure and properties as well as understand the origin of outer rings in such galaxies. Surface photometry of the central body is performed using near-UV, BVRI and JHK images. Based on the photometric data, the nearly round central body follows a de Vaucouleurs profile almost all the way to the center. The detailed photometry reveals a reddish inner ring-shaped structure that shares the same center as the central body. However, no sign of a bar or stellar disk is detected. The outer ring appears as a bump in the surface brightness profile with a peak brightness of 25.8 mag/arcsec^{2} in the B-band and shows no sharp outer boundary. By reconstructing the observed SED for the central body and the rings, we recover the stellar population properties of the galaxy components. Our work suggests different formation histories for the inner and outer rings. We rule out the secular evolution model as being a formation mechanism for the outer ring. The colors of the outer ring are consistent with a feature that may have experienced a burst of star formation due to a possible recent accretion event. In addition, our work supports that the central body may be formed by a relatively dry major merger or in a single, short and highly effective star formation burst, and the inner ring may be formed as a result of intergalactic medium accretion or secular evolution of a possible gaseous disk

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145.20 – A Study of Low-Metallicity Red Giant Stars in the Ursa Minor Dwarf Spheroidal Galaxy Using APOGEE Survey Data

Studying the chemical evolution of stars in the Milky Way's faint dwarf galaxy satellites can provide valuable insight into the formation of the Galaxy and its companions. Past chemical abundance studies of the Ursa Minor dwarf spheroidal galaxy contain a maximum of sixteen stars, but large surveys such as APOGEE (Apache Point Observatory Galactic Evolution Experiment), which perform high-resolution spectroscopy (R ~ 22,500) for hundreds of stars at a time, have the potential to vastly expand the amount of available stellar chemical abundance data and provide a more comprehensive view of the dSph's chemical evolution. However, the APOGEE reduction and analysis pipelines were designed for high S/N observations of bright stars, and have not been tested in the lower S/N regime of dSph stars. We evaluate the performance of the APOGEE pipeline for low S/N spectra taken from faint, low-metallicity stars in the galaxy. We compare APOGEE metallicities against those found in literature, and examine the spectra for elemental absorption lines. We also attempt to constrain the population of binary stars in the dSph.

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Contributing team(s): APOGEE-2

145.21 – *Spitzer* Merger History and Shape of the Galactic Halo: The Distance to the Core of the Sagittarius Dwarf Galaxy from the Mid-Infrared Period-Luminosity Relation for RR Lyrae Variable Stars

The Sagittarius dwarf galaxy (Sgr) is among the most massive satellites of the Milky Way and is unique due to its extensive tails of tidally stripped stars. These tails provide strong constraints on the orbital history of Sgr, which in turn lend insight into the structure of the Milky Way's dark matter halo. Utilizing the dynamics of Sgr for these studies, however, relies on a precise distance measurement to the core. Yet past measurements yield a wide range of values (22.0 - 28.4 kpc) with a variation of >25%. Through photometry of 3.6μm *Spitzer* data and GLOESS light curve fitting, we have measured the mean magnitudes of 45 RR Lyrae variables in the Sgr Core. Fitting the magnitudes to a Period-Luminosity relation with a slope of -2.332, we find the distance modulus to be 17.19 ± 0.02 (ran) ± 0.08 (sys) based on zero points derived from HST parallax measurements of five Galactic RR Lyrae. This yields a mean distance of 27.40 ± 0.21 (ran) ± 1.01 (sys) kpc to the core of Sgr.

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Contributing team(s): SMHASH Team

145.22 – Mass-to-Light versus Color Relations for Dwarf Irregular Galaxies

We have determined new relations between *UBV* colors and mass-to-light (*M/L*) ratios for dwarf irregular galaxies, as well as for transformed $g' - r'$. These *M/L* to color relations (MLCRs) are based on stellar mass density profiles determined for 34 LITTLE THINGS dwarfs from spectral energy distribution fitting to multi-wavelength surface photometry in passbands from the FUV to the NIR. These relations can be used to determine stellar masses in dwarf irregular galaxies for situations where other determinations of stellar mass are not possible. Our MLCRs are shallower than comparable MLCRs in the literature determined for spiral galaxies. We divided our dwarf data into four metallicity bins and found indications of a steepening of the MLCR with increased oxygen abundance, perhaps due to more line blanketing occurring at higher metallicity.

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Contributing team(s): LITTLE THINGS

145.23 – The Magellanic Analog Dwarf Companions and Stellar Halos (MADCASH) Survey: Near-Field Cosmology with Resolved Stellar Populations Around Local Volume LMC Stellar-Mass Galaxies

We discuss the first results of our observational program to comprehensively map nearly the entire virial volumes of roughly LMC stellar mass galaxies at distances of ~2-4 Mpc. The MADCASH (Magellanic Analog Dwarf Companions And Stellar Halos) survey will deliver the first census of the dwarf satellite populations and stellar halo properties within LMC-like environments in the Local Volume. These will inform our understanding of the recent DES discoveries of dwarf satellites tentatively affiliated with the LMC/SMC system. We will detail our discovery of the faintest known dwarf galaxy satellite of an LMC stellar-mass host beyond the Local Group, based on deep Subaru+HyperSuprimeCam imaging reaching ~2 magnitudes below its TRGB. We will summarize the survey results and status to date, highlighting some challenges encountered and lessons learned as we process the data for this program through a prototype LSST pipeline. Our program will examine whether LMC stellar mass dwarfs have extended stellar halos, allowing us to assess the relative contributions of in-situ stars vs. merger debris to their stellar populations and halo density profiles. We outline the constraints on galaxy formation models that will be provided by our observations of low-mass galaxy halos and their satellites.

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145.24 – Hubble Space Telescope observations of the optical counterpart to a ultra-compact high-velocity cloud

As part of a comprehensive archival search for optical counterparts to ultra-compact high-velocity clouds (UCHVCs), our team has uncovered five Local Volume dwarf galaxies, two of which were not previously known. Among these was AGC 226067, also known as ALFALFA-Dw1, which appeared to be made up of several HI and blue optical clumps based on ground-based data, with at least one HII region. Here we present Hubble Space Telescope Advanced Camera for Surveys data of AGC 226067. The data show that AGC 226067 is made up of a ~7-30 Myr old stellar population with a [Fe/H]~-0.6. Further, there is no evidence for an old stellar population associated with the system, down to a limit of M_V>-8. Based on this and the position of AGC 226067 in the outskirts of the M86 subgroup of the Virgo cluster we present various arguments for the origin of this strange stellar system.

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145.25 – Analyzing the Formation of Ultra-compact Dwarfs through Stellar Populations

Since their discovery in 1999, ultra-compact dwarfs (UCDs) have been the subjects of intense study. Their small size, yet tremendous mass, brings into question their place among celestial objects. Are they galaxies or globular clusters? The answer to this question could come from analyzing how they formed. Thus, the goal of this project is to test one of the theories for the formation of UCDs, the theory of tidal stripping.
This project approaches the issue by looking at dwarf galaxies currently in the process of stripping to understand formation history. Over twenty such dwarf galaxies were identified and their stellar populations analyzed. Using modeling techniques on spectroscopic and photometric data, the age, metallicity, and color of each object was identified. By objectively categorizing each object into a stage of evolution in the process of tidal stripping, a virtual timeline was built for the formation of UCDs. Data for each object were plotted vs. stage of formation, with pristine dwarfs and UCDs signifying the endpoints. Trends in the data revealed a natural progression over all stages of evolution, showing that tidally stripped dwarfs likely represent an intermediate stage in the formation of UCDs.
This research was supported by NSF Grant AST-1515084. Most of this work was carried out by high school students working under the auspices of the Science Internship Program at UC Santa Cruz.

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145.26 – Comparison between high and low star forming sides of dwarf irregular galaxies with asymmetrical distributions of star formation.

Dwarf irregular galaxies DDO 187 and NGC 3738, in the LITTLE THINGS sample of nearby dwarfs, share the similar characteristic of having more star formation on one side of the galaxy than the other. I compared characteristics of the galaxies, such as pressure, HI surface density, and stellar mass surface density, measured on the high star formation half with those measured on the low star formation half. Comparing the galaxies, we see that the ratios of galactic properties from the high star formation side to the low star formation side are similar in both galaxies. We also see that the high star formation halves of the galaxies have higher pressure, higher stellar mass density, and higher gas mass density. Both galaxies also have peculiar gas kinematics. Looking at the young star clusters in NGC 3738 from the LEGUS survey, we see that there are younger and more clusters in the high star formation region. The cause of having such an asymmetrical distribution of star formation in these galaxies remains unknown.

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Contributing team(s): The LEGUS team

145.27 – Characterizing the Bow Shock of the Large Magellanic Cloud

The Circumgalactic Medium (CGM) surrounding our Milky Way plays an essential role in supplying the fuel needed to drive and sustain star formation in our Galaxy. However, the CGM is extremely diffuse (~10^28 g/cm^3), and therefore difficult to probe. Consequently, we know little about the structure, mass profile or evolution of the CGM. Using hydrodynamic simulations, we study the impact of the supersonic motions (Mach ~ 3) of the Large Magellanic Cloud (LMC), the largest satellite galaxy of the Milky Way, on the structure of the CGM. We conclude that the LMC must induce a large bow shock in the CGM and use simulations to characterize its size, shape, temperature, and density structure. Using these properties, we propose possible observational signatures that could be used to confirm the existence of the shock, and illustrate how the shock may provide a tool to probe the CGM. These results illustrate that the CGM is a dynamic system, affected not only by outflows from the host galaxy, but also by the motions of the satellites that orbit within it.

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145.28 – Cold Gas in Quenched Dwarf Galaxies using HI-MaNGA

MaNGA (Mapping of Nearby Galaxies at Apache Point Observatory) is a 6-year Sloan Digital Sky Survey fourth generation (SDSS-IV) project that will obtain integral field spectroscopy of a catalogue of 10,000 nearby galaxies. In this study, we explore the properties of the passive dwarf galaxy sample presented in Penny et al. 2016, making use of MaNGA IFU (Integral Field Unit) data to plot gas emission, stellar velocity, and flux maps. In addition, HI-MaNGA, a legacy radio-survey of MaNGA, collects single dish HI data retrieved from the GBT (Green Bank Telescope), which we use to study the the 21cm emission lines present in HI detections. Studying the HI content of passive dwarves will help us reveal the processes that are preventing star formation, such as possible AGN feedback. This work was supported by the SDSS Research Experience for Undergraduates program, which is funded by a grant from the Sloan Foundation to the Astrophysical Research Consortium.

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146 – Extrasolar Planets: Detection Poster Session

146.01 – The Gemini Planet Imager Exoplanet Survey

The Gemini Planet Imager Exoplanet Survey (GPIES) is one of the largest most sensitive direct imaging searches for exoplanets conducted to date, and having observed more than 300 stars the survey is halfway complete. We present highlights from the first half of the survey, including the discovery and characterization of the young exoplanet 51 Eri b and the brown dwarf HR 2562 B, new imaging of multiple disks, and resolving the young stellar binary V343 Nor for the first time. GPI has also provided new spectra and orbits of previous known planets and brown dwarfs and polarization measurements of a wide range of disks. Finally, we discuss the constraints placed by the first half of the GPIES campaign on the population of giant planets at orbital separations beyond that of Jupiter. Supported by NSF grants AST-0909188 and AST-1313718, AST-1411868, AST 141378, NNX11AF74G, and DGE-1232825, and by NASA grants NNX15AD95G/NEXSS and NNX11AD21G.

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Contributing team(s): The GPIES Team

146.02 – Orbits for the Impatient: A Bayesian Rejection Sampling Method for Quickly Fitting the Orbits of Long-Period Exoplanets

Direct imaging planet-finders like the Gemini Planet Imager (GPI) allow for direct imaging of exoplanets with orbital periods beyond ~10 years that are still close enough to their host stars to undergo detectable orbital motion on year or multi-year timescales, creating a need for methods that rapidly characterize newly discovered planets using relative astrometry covering a short fraction of an orbital period. We address this problem with Orbits for the Impatient (OFTI), a statistically robust and computationally efficient Bayesian rejection sampling method for fitting orbits to astrometric datasets covering small orbital fractions from directly imaged exoplanets, brown dwarfs, and wide-orbit stellar binaries. We demonstrate that OFTI produces valid orbital solutions by directly comparing its outputs with those of two Markov Chain Monte Carlo (MCMC) implementations, and compare the computational speeds of OFTI and MCMC as a function of orbital fraction spanned by input astrometry. We find that for well-sampled orbits with astrometry covering less than 15% of the total orbital period, OFTI converges on the correct orbital solution in orders of magnitude less CPU time than MCMC. Exoplanet observations with space missions such as the WFIRST coronagraph present a similar problem of sparse sampling, and we show how these methods can efficiently constrain the orbital inclination, phase, and separation of a planet such as 47 Uma c. Finally, we present some of the first orbital fits to astrometry from directly imaged exoplanets and brown dwarfs in the literature, including GJ 504 b, CD-35 2722 B, kappa And b, and HR 3549 B.

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Contributing team(s): GPIES Collaboration

146.03 – Astrometric Calibration of the Gemini Planet Imager

The Gemini Planet Imager (GPI), housed on the 8-meter Gemini South telescope in Chile, is an instrument designed to detect Jupiter-like extrasolar planets by direct imaging. It relies on adaptive optics to correct the effects of atmospheric turbulence, along with an advanced coronagraph and calibration system. One of the scientific goals of GPI is to measure the orbital properties of the planets it discovers. Because these orbits have long periods, precise measurements of the relative position between the star and the planet (relative astrometry) are required. In this poster, I will present the astrometric calibration of GPI. We constrain the plate scale and orientation of the camera by observing different binary star systems with both GPI and another well-calibrated instrument, NIRC2, at the Keck telescope in Hawaii. We measure their separations with both instruments and use that information to calibrate the plate scale. By taking these calibration measurements over the course of one year, we have measured the plate scale to 0.05% and shown that it is stable across multiple epochs. We also examined the effects of the point spread function on the positions of the binaries as well as their separations, the results of which I will discuss.

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146.04 – Gemini Planet Imager Calibrations, Pipeline Updates, and Campaign Data Processing

In support of GPI imaging and spectroscopy of exoplanets, polarimetry of disks, and the ongoing Exoplanet Survey we continue to refine calibrations, improve data reduction methods, and develop other enhancements to the data pipeline. We summarize here the latest updates to the open-source GPI Data Reduction Pipeline, including recent improvements spectroscopic and photometric calibrations and polarimetric data processing. For the GPI Exoplanet Survey we have incorporated the GPI Data Pipeline into a larger campaign data system that provides automatic data processing including rapid PSF subtraction and contrast measurements in real time during observations and fully automated PSF subtractions using several state-of-the-art algorithms shortly after each observation completes.

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146.05 – The Gemini Planet Imager view of the HD 32297 debris disk system

The Gemini Planet Imager (GPI) is a near-infrared imaging instrument used with the Gemini South Telescope in Chile to provide direct imaging and integral field spectroscopy of exoplanetary systems. One of the central goals of the GPI mission is to gain an improved understanding of debris disks, which are remnants of the planet formation process. In this investigation, we present GPI polarimetric observations of the debris disk around the star HD 32297. Previous imaging of the system revealed a nearly edge-on disk that extends into a fan-shaped nebulosity on scales of hundreds of AU. The exquisite quality of total intensity GPI observations, which focus on the inner 150 AU of the disk system, allows us to precisely establish the disk geometry, including evidence for eccentricity in the parent body ring as seen in other such disks. Furthermore, taking advantage of the polarimetric capabilities of GPI, we measure the linear polarization fraction induced by dust scattering. We combine these observations with radiative transfer modeling based on the MCFOST code and using a Markov Chain Monte Carlo (MCMC) method for a thorough and efficient exploration of the parameter space. By simultaneously modeling the GPI scattered light total intensity image, the corresponding polarization fraction map, and the spectral energy distribution of the system, we place constraints on the composition and density structure of the disk. This case study will contribute to an improved understanding of debris disks for the purpose of characterizing planetary system formation and evolution.

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146.06 – Blind Source Separation Algorithms for PSF Subtraction from Direct Imaging

The principal difficulty with detecting planets via direct imaging is that the target signal is similar in magnitude, or fainter, than the noise sources in the image. To compensate for this, several methods exist to subtract the PSF of the host star and other confounding noise sources. One of the most effective methods is Karhunen-Loève Image Processing (KLIP). The core algorithm within KLIP is Principal Component Analysis, which is a member of a class of algorithms called Blind Source Separation (BSS).

We examine three other BSS algorithms that may potentially also be used for PSF subtraction: Independent Component Analysis, Stationary Subspace Analysis, and Common Spatial Pattern Filtering. The underlying principles of each of the algorithms is discussed, as well as the processing steps needed to achieve PSF subtraction. The algorithms are examined both as primary PSF subtraction techniques, as well as additional postprocessing steps used with KLIP.

These algorithms have been used on data from the Gemini Planet Imager, analyzing images of β Pic b. To build a reference library, both Angular Differential Imaging and Spectral Differential Imaging were used. To compare to KLIP, three major metrics are examined: computation time, signal-to-noise ratio, and astrometric and photometric biases in different image regimes (e.g., speckle-dominated compared to Poisson-noise dominated). Preliminary results indicate that these BSS algorithms improve performance when used as an enhancement for KLIP, and that they can achieve similar SNR when used as the primary method of PSF subtraction.

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146.07 – Reprocessing of Archival Direct Imaging Data of Herbig Ae/Be Stars

Herbig Ae/Be (HAeBe) stars are intermediate mass (2–10 solar mass) pre-main sequence stars with circumstellar disks. They are the higher mass analogs of the better-known T Tauri stars. Observing planets within these young disks would greatly aid in understanding planet formation processes and timescales, particularly around massive stars. So far, only one planet, HD 100546b, has been confirmed to orbit a HAeBe star. With over 250 HAeBe stars known, and several observed to have disks with structures thought to be related to planet formation, it seems likely that there are as yet undiscovered planetary companions within the circumstellar disks of some of these young stars.

Direct detection of a low-luminosity companion near a star requires high contrast imaging, often with the use of a coronagraph, and the subtraction of the central star's point spread function (PSF). Several processing algorithms have been developed in recent years to improve PSF subtraction and enhance the signal-to-noise of sources close to the central star. However, many HAeBe stars were observed via direct imaging before these algorithms came out. We present here current work with the PSF subtraction program PynPoint, which employs a method of principal component analysis, to reprocess archival images of HAeBe stars to increase the likelihood of detecting a planet in their disks.

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146.08 – Project MINERVA's Follow-up on Wide-Field,

Small Telescope Photometry to Identify Exoplanets

MINERVA is an array of four 0.7-m telescopes equipped for high precision photometry and spectroscopy dedicated to exoplanet observations. During the first 18 months of science operations, MINERVA engaged in a program of photometric follow-up of potential transiting exoplanet targets identified by the Kilodegree Extremely Little Telescope (KELT). Robotically-obtained observations are passed through our data reduction pipeline and we extract light curves via differential photometry. We seek transit signals via a Markov chain Monte Carlo fit using BATMAN. We discuss results for over 100 target stars analyzed to date.

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146.09 – MINERVA-Red: A telescope dedicated to the discovery of planets orbiting the nearest low-mass stars

Results from Kepler and ground-based exoplanet surveys suggest that M-dwarfs host numerous small sized planets. Additionally, the discovery of the Earth-sized exoplanets orbiting Proxima Centauri and Trappist 1 demonstrate that these stars can host terrestrial planets in their habitable zones. Since low-mass stars are intrinsically faint at optical wavelengths, obtaining 1 m/s Doppler resolution to detect their planetary companions remains a challenge for instruments designed for sun-like stars. We describe a novel, high-cadence approach aimed at detecting and characterizing planets orbiting the closest low-mass stars to the Sun. MINERVA-Red is an echelle spectrograph optimized for the 'deep red', between 800 nm and 900 nm, where M-dwarfs are brightest. The spectrograph will be temperature controlled at 20C +/- 10mk and in a vacuum chamber which maintains a pressure below 0.01 mbar while using a Fabry-Perot etalon and U/Ne lamp for wavelength calibration. The spectrometer will operate with a robotic, 0.7-meter telescope at Mt. Hopkins, Arizona. We expect first light in 2017.

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146.10 – Simulating a Radial Velocity Precurser Survey for Target Yield Optimization for a Future Direct Imaging Mission

Future direct imaging mission concepts such as HabEx and LUVOIR aim to directly image and characterize Earth-analogs around nearby stars. With the scope and expense of these missions, the exoplanet yield is strongly dependent on the frequency of Earth-like planets and the a priori knowledge of which stars specifically host suitable planetary systems. Ground-based radial velocity surveys can potentially perform the pre-selection of direct imaging missions at a fraction of the cost of a blind direct imaging survey. We present a simulation of such a survey. We consider both the WIYN and Large Binocular Telescope, including weather conditions and limitations in telescope time, fitted with spectrometers of varying sensitivities including iLocator and NEID. We recover simulated planets and their orbital parameters, estimating the effectiveness of a pre-cursor radial velocity survey.

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146.11 – A Search and Exploration of Multi-Exoplanet Systems Via Transit Timing Variation (TTV) Algorithms for the K2 Mission

We use the K2 mission to search for and analyze multi-planet systems with the goal of performing a scalable search for multi-planet systems using the transit timing variation (TTV) method. We developed an algorithm in Python to perform a search for synodic TTVs from multi-planet systems. The algorithm analyzes images taken by the K2 mission, creates light curves, and searches for TTVs on the order of a few minutes for every star in the images. We detected 4 potential TTV signals of which 3 are possible new discoveries. One of the systems has known multiple transiting planets and exhibits TTVs consistent with theoretical and previously published TTVs from n-body simulations. Another exoplanet system exhibits possible TTVs consistent with at least two giant planets. Our results demonstrate that a search for TTVs with the K2 mission is possible, though difficult.

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146.12 – Analytical Methods for Exoplanet Imaging Detection Metrics

When designing or simulating exoplanet-finding missions, a selection metric must be used to choose which target stars will be observed. For direct imaging missions, the metric is a function of the planet-star separation and flux ratio as constrained by the instrument's inner and outer working angles and contrast. We present analytical methods for the calculation of two detection metrics: completeness and depth of search. While Monte Carlo methods have typically been used for determining each of these detection metrics, implementing analytical methods in simulation or early stage design yields quicker, more accurate calculations.

Completeness is the probability of detecting a planet belonging to the planet population of interest. This metric requires assumptions to be made about the planet population. Probability density functions are assumed for the planetary parameters of semi-major axis, eccentricity, geometric albedo, and planetary radius. Planet-star separation and difference in brightness magnitude or contrast are written as functions of these parameters. A change of variables is performed to get a joint probability density function of planet-star separation and difference in brightness magnitude or contrast. This joint probability density function is marginalized subject to the constraints of the instrument to yield the probability of detecting a planet belonging to the population of interest.

Depth of search for direct imaging is the sum of the probability of detecting a planet of given semi-major axis and planetary radius by a given instrument for a target list. This metric does not depend on assumed planet population parameter distributions. A two-dimensional grid of probabilities is generated for each star in the target list. The probability at each point in the grid is found by marginalizing a probability density function of contrast given constant values of semi-major axis and planetary radius subject to the constraints of the instrument.

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146.13 – Finding Planets in K2: A New Method of Cleaning the Data

We present a new method of removing systematic flux variations from K2 light curves by employing a pixel-level principal component analysis (PCA). This method decomposes the light curves into its principal components (eigenvectors), each with an associated eigenvalue, the value of which is correlated to how much influence the basis vector has on the shape of the light curve. This method assumes that the most influential basis vectors will correspond to the unwanted systematic variations in the light curve produced by K2's constant motion. We correct the raw light curve by automatically fitting and removing the strongest principal components. The strongest principal components generally correspond to the flux variations that result from the motion of the star in the field of view. Our primary method of calculating the strongest principal components to correct for in the raw light curve estimates the noise by measuring the scatter in the light curve after using an algorithm for Savitsy-Golay detrending, which computes the combined photometric precision value (SG-CDPP value) used in classic Kepler. We calculate this value after correcting the raw light curve for each element in a list of cumulative sums of principal components so that we have as many noise estimate values as there are principal components. We then take the derivative of the list of SG-CDPP values and take the number of principal components that correlates to the point at which the derivative effectively goes to zero. This is the optimal number of principal components to exclude from the refitting of the light curve. We find that a pixel-level PCA is sufficient for cleaning unwanted systematic and natural noise from K2's light curves. We present preliminary results and a basic comparison to other methods of reducing the noise from the flux variations.

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146.14 – MICRONERVA: A Novel Approach to Large Aperture Astronomical Spectroscopy

MICRONERVA (MICRO Novel Exoplanet Radial Velocity Array) is a prototype observatory for measuring spectroscopic radial velocities. The primary goal of MICRONERVA is to demonstrate that an array of 8-inch CPC Celestron telescopes can be used at a lower cost in place of a single, larger telescope. The equivalent light gathering power of the larger telescope is achieved by sending the starlight from each of the eight-inch telescopes down single mode fibers and combining the fiber output at a single entrance slit to a multi-object high resolution spectrograph. All of the hardware from the system is automated using Python programs, ASCOM and MaximDL drivers. The detection of exoplanets using the techniques of MICRONERVA opens the door to reducing costs for astronomical spectroscopy.

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146.15 – Distribution-dependent total exoplanet yield for a large aperture space telescope

A major scientific goal for future large aperture space telescopes is the discovery and characterization of habitable earth-like planets around FGK+M stars out to 10-20 pc. Using the design and observing plan for such a mission, we calculated the total exoplanet yield of a direct imaging survey, with detections including but not limited to potential earth analogs. In light of uncertainty of exoplanet occurrence rates, we used several of the best available exoplanetary distribution functions and assumed architectures to produce a Monte Carlo simulation of nearby planetary systems and observational parameters, and assessed detectability across the sample. Our calculations show a range of yields depending on the assumed distribution functions. We also compare our predictions to those of other detection methods in order to identify areas of parameter space (e.g. radius, period) uniquely constrained by direct imaging. In general, our calculations suggest that a higher completeness can be achieved with direct imaging, which will allow for calculation of a more accurate occurrence rate in local space.

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146.16 – The NASA Exoplanet Archive

The NASA Exoplanet Archive supports research and mission planning by the exoplanet community by operating a service providing confirmed and candidate planets, numerous project and contributed data sets and integrated analysis tools. We present the current data contents and functionality of the archive including: interactive tables of confirmed and candidate planetary and stellar properties; Kepler planet candidates, threshold-crossing events, data validation and occurrence rate products; light curves from Kepler, CoRoT, SuperWASP, KELT and other ground-based projects; and spectra and radial velocity data from the literature. Tools provided include a transit ephemeris predictor, light curve viewing utilities, a periodogram service and user-configurable interactive tables. The NASA Exoplanet Archive is funded by NASA's Exoplanet Exploration Program.

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146.17 – Searching for Wide, Planetary-Mass Companions in Archival *Spitzer*/IRAC Data

Over the past decade, a growing population of planetary-mass companions (< 20 M_{Jup}; PMCs) orbiting young stars have been discovered. These objects are at wide separations (> 100 AU) from their host stars, challenging existing models of both star and planet formation. It is unclear whether these systems represent the low-mass extreme of stellar binary formation or the high-mass and wide-orbit extreme of planet formation theories, as various proposed formation pathways inadequately explain the physical and orbital aspects of these systems. Even so, determining which scenario best reproduces their observed characteristics will come once a statistically robust sample of directly-imaged PMCs are found and studied.

We are searching for wide-orbit PMCs to young stars in *Spitzer*/IRAC images with an automated pipeline. A Markov Chain Monte Carlo (MCMC) algorithm is the backbone of our novel point spread function (PSF) subtraction routine that efficiently creates and subtracts a χ^2-minimizing instrumental PSF, producing a residuals image that is also assessed to ascertain the presence of a potential companion. In this work, we present the preliminary results of a *Spitzer*/IRAC archival imaging study of 11 young, low-mass (0.044-0.88 $M_\odot$; K3.5-M7.5) stars known to have faint, low-mass companions in 3 nearby star-forming regions (Chameleon, Taurus, and Upper Scorpius). Initial runs of the pipeline have recovered 7 of the companions from the 11 systems. An additional binary companion PSF-fitting pipeline is being developed to simultaneously measure astrometry and infrared photometry of these systems across the four IRAC channels (3.6 μm, 4.5 μm, 5.8 μm, and 8 μm). We also find 3 of these systems to have low-mass companions with non-zero [I1] – [I4] colors, potentially signifying the presence of a circum(sub?)stellar disk. Plans for future pipeline improvements and paths forward will also be detailed. Once this computational foundation is optimized, the stage is set to quickly scour the nearby star-forming regions already imaged by *Spitzer*, identify potential candidates for further characterization with ground-based telescopes, and increase the number of faint, widely-separated PMCs known.

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146.18 – Planet Occurrence Rates for K2 M Dwarfs

M dwarfs comprise the vast majority of stars in the galaxy, and so their planet populations are of particular interest. Kepler observed a few thousand early M dwarfs and now K2 has observed more than 10,000 low mass cool stars ranging in spectral type from late K to mid M. The short orbital period of planets in the habitable zones for these low-mass, cool stars makes them prime targets for transit spectroscopy and detectable within an 80 day K2 campaign. To calculate the occurrence rate, we must identify all the M dwarfs K2 has observed, which is observationally expensive to do spectroscopically for all ~160,000 stars so far and the thousands to follow. Using photometry from the spectroscopically classified targets of the Kepler mission, we train a Random Forest classifier to categorize the K2 targets using only their available photometry. We determine the probability of each K2 target being an M dwarf such that we can calculate the planet occurrence rate using the entire sample while accounting for the uncertainty of our classification method. As surveys provide more spectroscopic and photometric information for these K2 targets, the Random Forest can be re-trained and improved. The classifier can be used for all subsequent K2 campaigns and potentially be modified for TESS targets, giving it long-term applicability. For 115 planet candidates detected orbiting 17612 cool dwarfs observed during K2 C0-8, we calculate a cool dwarf planet occurrence rate of 1.4 for $P < 80$ days, biased toward small ($< 3\ R_{Earth}$) planets with $P < 50$ days.

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146.19 – The Snapshot A-Star SurveY (SASSY)

We present the Snapshot A-Star SurveY (SASSY), an adaptive optics survey conducted using NIRC2 on the Keck II telescope to search for young, self-luminious planets and brown dwarfs ($M > 5M_{Jup}$) around high mass stars ($M > 1.5\ M_{\odot}$). We describe a custom data-reduction pipeline developed for the coronagraphic observations of our 200 target stars. Our data analysis method includes basic near infrared data processing (flat-field correction, bad pixel removal, distortion correction) as well as performing PSF subtraction through a Reference Differential Imaging algorithm based on a library of PSFs derived from the observations using the pyKLIP routine. We present early results from the survey including planet and brown dwarf candidates and the status of ongoing follow-up observations. Utilizing the high contrast of Keck NIRC2 coronagraphic observations, SASSY reaches sensitivity to brown dwarfs and planetary mass companions at separations between 0.6'' and 4''. With over 200 stars observed we are tripling the number of high-mass stars imaged at these contrasts and sensitivities compared to previous surveys. This work was supported by the NSF REU program at the SETI Institute and NASA grant NNX14AJ80G.

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146.20 – Results of Edge Scatter Testing for a Starshade Mission

In the field of exoplanet detection and characterization, the use of a starshade, an external occulter in front of a telescope at large separations, has been identified as one of the highly promising methods to achieve the necessary high contrast imagery. Control of scattered sunlight from the edges of the starshade into the telescope has been identified as one of the key technology development areas in order to make the starshade feasible. Modeling of the scattered light has resulted in very different results so a campaign of experimentation with edge samples was undertaken to attempt to understand the discrepancies.

Here, we present our results from the measurement of select samples of materials which would be suitable for manufacturing the starshade edge, and related models. We have focused on coating metallic samples for ease of fabrication: Titanium, Aluminum, and a Beryllium Copper alloy. Using standard machine shop methods, we fabricated samples which had sharp edges with radius of curvature (RoC) between 15 and 20 μm. We then had these samples coated by two suppliers to evaluate how well these coating types would conform to the edge and provide scatter suppression. The results of scatter measurements of these coated edge samples are presented. These scatter results have been incorporated into a new geometrical model in FRED which includes the details of the starshade mechanical model. This model predicts both the magnitude and distribution of the scattered sunlight in the image plane of a nominal telescope. We present these results, including a first effort at modeling the Solar System at 10 pc as seen by this mission architecture.

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146.21 – Testbed Demonstration of Low Order Wavefront Sensing and Control Technology for WFIRST Coronagraph

NASA's WFIRST-AFTA Coronagraph will be capable of directly imaging and spectrally characterizing giant exoplanets similar to Neptune and Jupiter, and possibly even super-Earths, around nearby stars. To maintain the required coronagraph performance in a realistic space environment, a Low Order Wavefront Sensing and Control (LOWFS/C) subsystem is necessary. The LOWFS/C will use the rejected stellar light to sense and suppress the telescope pointing drift and jitter as well as low order wavefront errors due to the changes in thermal loading of the telescope and the rest of the observatory. The LOWFS/C uses a Zernike phase contrast wavefront sensor with the phase shifting disk combined with the stellar light rejecting occulting mask, a key concept to minimize the non-common path error. Developed as a part of the Dynamic High Contrast Imaging Testbed (DHCIT), the LOWFS/C subsystem also consists of an Optical Telescope Assembly Simulator (OTA-S) to generate the realistic line-of-sight (LoS) drift and jitter as well as low order wavefront error from WFIRST-AFTA telescope's vibration and thermal drift. The entire LOWFS/C subsystem have been integrated, calibrated, and tested in the Dynamic High Contrast Imaging Testbed. In this presentation we will show the results of LOWFS/C performance during the dynamic coronagraph tests in which we have demonstrated that LOWFS/C is able to maintain the coronagraph contrast with the presence of WFIRST like line-of-sight drift and jitter as well as low order wavefront drifts.

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146.22 – Laboratory validation of model-based wavefront control for multi-star systems

The NASA Ames Coronagraph Experiment (ACE) testbed has been used to validate milestone demonstrations for novel wavefront control methods. For example, direct imaging instruments for both ground and space have used single-star target lists exclusively but a recent technique has been developed that enables high-contrast imaging for multi-star systems. This technique utilizes non-redundant deformable mirror modes to create regions of high contrast for both stars simultaneously and utilizes diffraction orders to replicate the point-spread function to extend the controllable region beyond the Nyquist limit. We present the laboratory implementation and performance of model-based wavefront control methods starting with a single-star and no coronagraph and continuing with increasing complexity including multi-star and super-nyquist configurations and a PIAA coronagraph.

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146.23 – The DeMi CubeSat: Wavefront Control with a MEMS Deformable Mirror in Space

High-contrast imaging instruments on future space telescopes will require precise wavefront correction to detect small exoplanets near their host stars. High-actuator count microelectromechanical system (MEMS) deformable mirrors provide a compact form of wavefront control. The 6U DeMi CubeSat will demonstrate wavefront control with a MEMS deformable mirror over a yearlong mission. The payload includes both an internal laser source and a small telescope, with both focal plane and pupil plane sensing, for deformable mirror characterization. We detail the DeMi payload design, and describe future astrophysics enabled by high-actuator count deformable mirrors and small satellites.

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146.24 – Experimental Verification of Sparse Aperture Mask for Low Order Wavefront Sensing

To directly image exoplanets, future space-based missions are equipped with coronagraphs which manipulate the diffraction of starlight and create regions of high contrast called dark holes. Theoretically, coronagraphs can be designed to achieve the high level of contrast required to image exoplanets, which are billions of times dimmer than their host stars, however the aberrations caused by optical imperfections and thermal fluctuations cause the degradation of contrast in the dark holes. Focal plane wavefront control (FPWC) algorithms using deformable mirrors (DMs) are used to mitigate the quasi-static aberrations caused by optical imperfections. Although the FPWC methods correct the quasi-static aberrations, they are blind to dynamic errors caused by telescope jitter and thermal fluctuations. At Princeton's High Contrast Imaging Lab we have developed a new technique that integrates a sparse aperture mask with the coronagraph to estimate these low-order dynamic wavefront errors. This poster shows the effectiveness of a SAM Low-Order Wavefront Sensor in estimating and correcting these errors via simulation and experiment and compares the results to other methods, such as the Zernike Wavefront Sensor planned for WFIRST.

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146.25 – Kernel-Phase Interferometry for Super-Resolution Detection of Faint Companions

Direct detection of close in companions (exoplanets or binary systems) is notoriously difficult. While coronagraphs and point spread function (PSF) subtraction can be used to reduce contrast and dig out signals of companions under the PSF, there are still significant limitations in separation and contrast. Non-redundant aperture masking (NRM) interferometry can be used to detect companions well inside the PSF of a diffraction limited image, though the mask discards ~95% of the light gathered by the telescope and thus the technique is *severely* flux limited. Kernel-phase analysis applies interferometric techniques similar to NRM to a diffraction limited image utilizing the full aperture. Instead of non-redundant closure-phases, kernel-phases are constructed from a grid of points on the full aperture, simulating a redundant interferometer. I have developed my own faint companion detection pipeline which utilizes an Bayesian analysis of kernel-phases. I have used this pipeline to search for new companions in archival images from HST/NICMOS in order to constrain planet and binary formation models at separations inaccessible to previous techniques. Using this method, it is possible to detect a companion well within the classical λ/D Rayleigh diffraction limit using a fraction of the telescope time as NRM. This technique can easily be applied to archival data as no mask is needed and will thus make the detection of close in companions cheap and simple as no additional observations are needed. Since the James Webb Space Telescope (JWST) will be able to perform NRM observations, further development and characterization of kernel-phase analysis will allow efficient use of highly competitive JWST telescope time.

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146.26 – Status of Technology Development to enable Large Stable UVOIR Space Telescopes

NASA MSFC has two funded Strategic Astrophysics Technology projects to develop technology for potential future large missions: AMTD and PTC. The Advanced Mirror Technology Development (AMTD) project is developing technology to make mechanically stable mirrors for a 4-meter or larger UVOIR space telescope. AMTD is demonstrating this technology by making a 1.5 meter diameter x 200 mm thick ULE(C) mirror that is 1/3rd scale of a full size 4-m mirror. AMTD is characterizing the mechanical and thermal performance of this mirror and of a 1.2-meter Zerodur(R) mirror to validate integrate modeling tools. Additionally, AMTD has developed integrated modeling tools which are being used to evaluate primary mirror systems for a potential Habitable Exoplanet Mission and analyzed the interaction between optical telescope wavefront stability and coronagraph contrast leakage. Predictive Thermal Control (PTC) project is developing technology to enable high stability thermal wavefront performance by using integrated modeling tools to predict and actively control the thermal environment of a 4-m or larger UVOIR space telescope.

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Contributing team(s): MSFC AMTD Team

146.27 – A Model for Astrometric Detection and Characterization of Multi-Exoplanet Systems

In this thesis, we develop an approximate linear model of stellar motion in multi- planet systems as an aid to observers using the astrometric method to detect and characterize exoplanets. Recent and near-term advances in satellite and ground-based instruments are on the threshold of achieving sufficient (~10 micro-arcsecond) angular accuracies to allow astronomers to measure and analyze the transverse mo- tion of stars about the common barycenter in single- and multi-planet systems due to the gravitational influence of companion planets. Given the emerging statistics of extrasolar planetary systems and the long observation periods required to assess exoplanet influences, astronomers should find an approximate technique for preliminary estimates of multiple planet numbers, masses and orbital parameters useful in determining the most likely stellar systems for follow-up studies. In this paper, we briefly review the history of astrometry and discuss its advantages and limitations in exoplanet research. In addition, we define the principal astrometric signature and describe the main variables affecting it, highlighting astrometry's complementary role to radial velocity and photometric transit exoplanet detection techniques. We develop and test a Python computer code using actual data and projections of the Sun's motion due to the influence of the four gas giants in the solar system. We then apply this model to over 50 hypothetical massive two- and three-exoplanet systems to discover useful general patterns by employing a heuristic examination of key aspects of the host star's motion over long observation intervals. Finally, we modify the code by incorporating an inverse least-squares fit program to assess its efficiency in identifying the main characteristics of multi-planet systems based on observational records over 5-, 10- and 20-year periods for a variety of actual and hypothetical exoplanetary systems. We also explore the method's sensitivity to measurement frequencies, intervals and errors.

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146.28 – First light of an external occulter testbed at flight Fresnel numbers

Many approaches have been suggested over the last couple of decades for imaging Earth-like planets. One of the main candidates for creating high-contrast for future Earth-like planets detection is an external occulter. The external occulter is a spacecraft flown along the line-of-sight of a space telescope to suppress starlight and enable high-contrast direct imaging of exoplanets. The occulter is typically tens of meters in diameter and the separation from the telescope is of the order of tens of thousands of kilometers. Optical testing of a full-scale external occulter on the ground is impossible because of the long separations. Therefore, laboratory verification of occulter designs is necessary to validate the optical models used to design and predict occulter performance. At Princeton, we have designed and built a testbed that allows verification of scaled occulter designs whose suppressed shadow is mathematically identical to that of space occulters. The goal of this experiment is to demonstrate a pupil plane suppression of better than 1e-9 with a corresponding image plane contrast of better than 1e-11. The occulter testbed uses a 77.2 m optical propagation distance to realize the flight Fresnel number of 14.5. The scaled mask is placed at 27.2 m from the artificial source and the camera is located 50.0 m from the scaled mask. We will use an etched silicon mask, manufactured by the Microdevices Lab(MDL) of the Jet Propulsion Laboratory(JPL), as the occulter. Based on conversations with MDL, we expect that 0.5 µm feature size is an achievable resolution in the mask manufacturing process and is therefore likely the indicator of the best possible performance. The occulter is illuminated by a diverging laser beam to reduce the aberrations from the optics before the occulter. Here, we present first light result of a sample design operating at a flight Fresnel number and the experimental setup of the testbed. We compare the experimental results with simulations that predict the ultimate contrast performance.

Author(s): Yunjong Kim[3], Dan Sirbu[2], Mia Hu[3], Jeremy Kasdin[3], Robert J. Vanderbei[3], Anthony Harness[4], Stuart Shaklan[1]
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146.29 – Techniques for Constraining the Population of Small Close-in Planets Around Subgiants

Intermediate mass stars (> 1.3 solar masses) have high occurrence rates of Jupiter mass planets in predominately long period orbits (a ~1.0 AU). However, there is a prominent gap in the planet occurrence rate for low mass planets (i.e.; super-Earths and Neptunes) < 0.5 AU from subgiants, the evolved counterpart to intermediate mass stars, known colloquially as the "Planet Desert. Thus far, using current radial velocity methods, we have not been able to detect low-mass, short period planets around subgiants due to noise from p-mode oscillations which may mimic radial velocity signals (~5 m/s) from planets in this close-in regime. Here we present our technique and preliminary results in our work towards finding elusive low-mass, short-period planets around subgiants and its implications for the Planet Desert.

Author(s): Amber Medina[1], John A. Johnson[1]
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146.30 – Examining the Flicker-Jitter Relation of K2 stars: the Dependence on Chromospheric Activity

Recently, Bastien et al. (2014) have shown that short timescale photometric variations from high-precision *Kepler* light curves, coined "flicker", can be linked to radial velocity (RV) noise, or "jitter", in chromospherically inactive stars. Observations of the sun show invariance in flicker over its 11-year activity cycle. Therefore, we seek to examine how well the relation holds for more active stars. Here we explore the relation between photometric flicker and RV jitter by extending the sample to stars observed by the recent K2 mission for which data have been released (Campaigns 0-8). The initial *Kepler* sample included 12 stars with surface gravities $3 < \log(g) < 4.5$, effective temperatures $4900 < T_{eff} < 5900$, and chromospheric activity $-5.3 < \log(R'_{HK}) < -5.0$. Our sample includes over 50 stars across a slightly wider range of surface gravities ($2.5 < \log(g) < 5$), effective temperatures ($4700 < T_{eff} < 6100$), and much larger range of chromospheric activity ($-5.4 < \log(R'_{HK}) < -4.1$). Additionally, we provide an empirical estimate for RV jitter based on the photometric flicker. Finally, we discuss the implications of this result on future RV follow-up for TESS and other future telescopes which will produce high-precision light curves.

Author(s): Jacob K. Luhn[1], Fabienne A. Bastien[1], Jason Wright[1]
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146.31 – Analysis of a Close Pair of Faint Sources Near a Massive Young Star

Directly imaged exoplanets are rare but important, because they provide a rare glimpse at how planet interiors and atmospheres evolve over time via direct measurement of planetary luminosities and spectra. The details of individual planetary system architectures directly inform our understanding of planet formation and evolution. We present our findings from a high-resolution imaging survey of a nearby star-forming region that indicate the presence of a close pair of faint sources near a massive, A-type young star. From multiple epochs of AO imaging obtained with NIRC2, we test for association of each faint source with the host star via measurement of common proper motion. We also assess whether the sources are two planetary mass objects, or a more massive object obscured by an edge on disk. In the case of two planetary mass objects, we estimate the component masses from their luminosities and colors.We conclude by discussing possible future observations to further determine the nature of this complicated system.

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146.32 – A Possible 5th Planet in the Kepler-89 System

Kepler-89 is a system with four known, transiting planets. We investigate a large discrepancy in the mass of the Jupiter-sized Kepler-89d between previous radial velocity (RV) and transit timing variation (TTV) measurements. We model the TTV data for the system and find evidence of a fifth planet, which we call Kepler-89f, inducing high amplitude TTVs on the outer transiting planet, Kepler-89e. We model the characteristics of this hypothetical planet and investigate how its presence may affect other system parameters, including the mass of Kepler-89d. We also analyze whether future transit observations of Kepler-89e could improve the characterization of Kepler-89f. Lastly, we explore how model results differ between fitting against TTV data versus fitting against raw transit times, and whether this could also be a contributing factor to the discrepancy between RV and TTV measurements of Kepler-89d.

Author(s): Andrew Mayo[2], Katherine Deck[1], Heather Knutson[1], Konstantin Batygin[1], Jessie Christiansen[1]
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146.33 – How many habitable planets can we detect around nearby M dwarfs, and are they really habitable?

M dwarfs offer the best prospects around which to detect and characterize habitable exoplanets because of their small size, abundance and cool surface temperature. We know from previous research that these stars have a large number of planets around them. However, M dwarfs are known to be magnetically active at young ages and they may remain active for billions of years. Because of this, these stars may not be able to host truly habitable planets. We simulated the existence of exoplanets around all known M dwarfs in the northern hemisphere within 20 parsecs of our Sun. We randomly select planet properties according to distributions from derived from the Kepler M dwarf sample. We consider the capabilities of current detection methods in order to predict the number of planets that will be discovered orbiting the habitable zone. We predict that only 1 such planet can be found using the transit method, but that 18 habitable zone exoplanets can be found using the radial velocity method. We then consider the effect of high-energy radiation on planets in the habitable zone. We use stellar rotation periods and rotation-activity relations to estimate the stellar x-ray and UV luminosities, and evaluate the amount of stellar radiation incident on the planets.

Author(s): Hope Pegues[2], Elisabeth R. Newton[1], Benjamin Montet[1], John A. Johnson[1]
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146.34 – A Search for Exoplanets in the Open Star Clusters Messier 35 and Koposov 62 Using A Photometric Algorithm for the K2 Mission

To date, over 5000 exoplanet candidates have been discovered orbiting around isolated stars. Many of these stars once formed or existed in open star clusters, yet the existence and prevalence of exoplanets in open clusters has not been well studied. In this project, we search for exoplanets in the regions surrounding two open clusters, Messier 35 and Koposov 62, using data from the K2 mission. We developed a K2-optimized photometric pipeline to search for exoplanets transiting host stars in the K2 "super stamps". We discovered four potential exoplanet candidates in a sample of 620 stars in these clusters. All four exoplanet candidates have very short periods (0.46-7.6 days) due to the short baseline of K2 photometry. Through our discovery of exoplanet candidates in open clusters, we hope to further the understanding of planetary formation in crowded regions.

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146.35 – A Search for Radio Emission from Nearby Exoplanets

Since the discovery of the first extrasolar planet orbiting a main sequence star more than 20 years ago, the study of exoplanets has become a burgeoning field with more than 3300 confirmed extrasolar planets now known. A variety of techniques has been used to discover exoplanets orbiting main sequence stars and to deduce their properties: timing, radial velocities, direct imaging, microlensing, and transits in the optical/IR bands. Absent from this list so far is the detection of exoplanets at radio wavelengths, but not for lack of trying. Searches for radio emission from exoplanets predate their discovery (Winglee et al. 1986) and have continued sporadically to this day. The majority of searches for radio emission from exoplanets has searched for coherent radio emission. It is indeed the case that in our own solar system, all magnetized planets are powerful radio emitters, the likely emission mechanism being the cyclotron maser instability. The outstanding example is Jupiter, which emits 10^{10}-10^{11} W at decameter wavelengths (frequencies <40 MHz). If there are Jupiter-like planets in other solar systems, many must surely emit CMI radiation. The emitted radiation could be orders of magnitude more intense than Jupiter's if the interaction between the magnetized planet and the wind from the primary star is stronger than the Sun/Jupiter interaction – due, for example, to a more powerful wind and/or the planet being closer to the star.

We have initiated a new search for radio emission from exoplanets, focusing on all known exoplanetary systems within 20 pc - more than 50 systems containing nearly 100 planets using the Jansky Very Large Array (JVLA) in three frequency bands: 1-2 GHz, 2-4 GHz, and 4-8 GHz with a target sensitivity of ~10 microJy. We have completed the 2-4 GHz survey and report our preliminary results, which include the detection of two systems. We discuss whether the emission is from a planet or from the star and the implications of our conclusions for habitability of exoplanets.

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146.36 – KELT-FUN and the discovery of KELT-18b

The Kilodegree Extremely Little Telescope (KELT) project is a ground-based, wide-field, synoptic sky survey whose primary goal is to discover exoplanets around bright (8 < V < 11) host stars. KELT photometric observations are carried out using two small robotic telescopes: KELT-North in Arizona, operating since 2005; and KELT-South in South Africa, operating since 2009. Once a transit candidate is identified by the survey telescopes, KELT relies on its Follow Up Network (KELT-FUN) of observatories to vet and characterize the systems by obtaining more precise light curves and radial-velocities. KELT-FUN now includes nearly 50 telescopes around the world and the photometric follow-up is carried out by a diverse set of partners at universities, small colleges, high schools, and private amateur facilities, often with the help of students. We describe KELT-FUN operations and announce the discovery of KELT-18b, a strongly-irradiated hot Jupiter orbiting a mid-F star.

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Contributing team(s): KELT Collaboration

146.37 – An astro-comb calibrated solar telescope to study solar activity and search for the radial velocity signature of Venus

We recently demonstrated sub-m/s sensitivity in measuring the radial velocity (RV) between the Earth and Sun using a simple solar telescope feeding the HARPS-N spectrograph at the Italian National Telescope, which is calibrated with a laser frequency comb calibrator optimized for calibrating high resolution spectrographs and referred to as an astro-comb. We are using the solar telescope to characterize the effects of stellar (solar) RV jitter due to activity on the solar surface over the course of many hours every clear day. With the help of solar satellites such as the Solar Dynamics Observatory (SDO), we are characterizing the correlation between observed RV and detailed imaging of the solar photosphere. We plan to use these tools to mitigate the effects of stellar jitter with the goal of the detection of Venus from its solar RV signature, thus showing the potential of the RV technique to detect true Earth-twins.

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Contributing team(s): HARPS-N Collaboration

146.38 – Planet Hunters, Undergraduate Research, and Detection of Extrasolar Planet Kepler-818 b

Detection of extrasolar planets provides an excellent research opportunity for undergraduate students. In Spring 2012, we searched for transiting extrasolar planets using Kepler spacecraft data in our *Research Experience in Physics* course at Austin College. Offered during the regular academic year, these *Research Experience* courses engage students in the scientific process, including proposal writing, paper submission, peer review, and oral presentations. Since 2004, over 190 undergraduate students have conducted authentic scientific research through *Research Experience* courses at Austin College.

Zooniverse's citizen science Planet Hunters web site offered an efficient method for rapid analysis of Kepler data. Light curves from over 5000 stars were analyzed, of which 2.3% showed planetary candidates already tagged by the Kepler team. Another 1.5% of the light curves suggested eclipsing binary stars, and 1.6% of the light curves had simulated planets for training purposes.

One of the stars with possible planetary transits had not yet been listed as a planetary candidate. We reported possible transits for Kepler ID 4282872, which later was promoted to planetary candidate KOI-1325 in 2012 and confirmed to host extrasolar planet Kepler-818 b in 2016 (Morton et al. 2016). Kepler-818 b is a "hot Neptune" with period 10.04 days, flux decrease during transit ~0.4%, planetary radius 4.69 Earth radii, and semi-major axis 0.089 au.

Author(s): David Baker[1], Graham Crannell[1], James Duncan[1], Aryn Hays[1], Landon Hendrix[1]
Institution(s): *1. Austin College*

147 – The Solar System Poster Session

147.01 – Understanding the Earth's Composition through Neutrino Oscillations

While our understanding of the cosmos has improved dramatically in the last decades, we still only have limited knowledge of the inside of our own planet. In particular, we only have indirect information regarding the composition or size of the Earth's core. We do, however, know neutrinos interact with electrons and therefore their oscillations change as they propagate through matter. We theoretically examine how solar neutrinos propagating through the Earth can offer a look into the composition of its layers. We investigate if neutrinos can detect the Earth's core by numerically calculating the probability of finding an electron-neutrino and adjusting parameters such as electron density and the radius of the core. It is determined that changing both of these parameters significantly affect the probability, such that neutrinos could be used experimentally to detect the size of a hard, dense core.

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Institution(s): *1. Northwestern University*

147.03 – Recovering Neptune 170 Years After its Initial Discovery

Recent work by Trujillo and Shephard (2014) and Batygin and Brown (2016) has shown an as-yet unexplained clustering of the periapse vectors of the most distant Kuiper Belt objects. This unusual clustering has motivated the search for an unseen perturbing planet that is responsible for maintaining the alignment. As a proof of concept of a technique for locating unseen solar system planets, we use dynamical N-body integrations to simulate the orbital dynamics of distant Kuiper Belt objects, with the aim of determining the orbital parameters of Neptune (which, for the sake of exercise, we assume is, as-yet, undiscovered). In this poster, we determine the accuracy with which the perturbing planet's orbital elements and sky location can be determined, and we show how the lessons learned can improve the search strategy for potentially undiscovered trans-Neptunian planets.

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147.04 – A Search for Planet 9 at the Thacher Observatory

The recent inference that there may be a massive planet in the outer solar system has sparked much excitement and debate. A dedicated program, at the newly renovated Thacher Observatory, is designed to cover approximately 36 square degrees of sky where it is most likely to be found during the 2016-2017 observing season. The depth of the survey will reach 23rd magnitude in V band, and we will use an observing cadence in accord with its expected proper motion. Here we present the detailed parameters and first images from the survey.

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Institution(s): *1. The Thacher School*

147.05 – Rotational Study of Ambiguous Taxonomic Classified Asteroids

The Sloan Digital Sky Survey (SDSS) moving object catalog (MOC4) provided the largest ever catalog of asteroid spectrophotometry observations. Carvano et al. (2010), while analyzing MOC4, discovered that individual observations of asteroids which were observed multiple times did not classify into the same photometric-based taxonomic class. A small subset of those asteroids were classified as having both the presence and absence of a 1um silicate absorption feature. If these variations are linked to differences in surface mineralogy, the prevailing assumption that an asteroid's surface composition is predominantly homogenous would need to be reexamined. Furthermore, our understanding of the evolution of the asteroid belt, as well as the linkage between certain asteroids and meteorite types may need to be modified.

This research is an investigation to determine the rotational rates of these taxonomically ambiguous asteroids. Initial questions to be answered:
Do these asteroids have unique or nonstandard rotational rates?
Is there any evidence in their light curve to suggest an abnormality?

Observations were taken using PROMPT6 a 0.41-m telescope apart of the SKYNET network at Cerro Tololo Inter-American Observatory (CTIO). Observations were calibrated and analyzed using Canopus software. Initial results will be presented at AAS.

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147.06 – Eight Potentially Hazardous Near Earth Asteroids: Characterization and Threat Assessment

We present the initial results of a study of eight potentially hazardous asteroids identified in conjunction with NASA's OSIRIS REX Mission and observed via the Target Asteroid Project. This study will include a characterization of these asteroids' orbits and physical characteristics as well as a threat assessment. Using images obtained by the target asteroid project, light curves for each asteroid were constructed and subsequent analysis of the light curves was used to determine the rotation period of the asteroid and its size. Knowledge of the size and composition of the asteroid are the two critical parameters used in assessing the severity of the threat an asteroid poses. Using the determined characteristics for each target asteroid, risk assessment and impact scenario modeling are undertaken to determine the effects of an impact event specific to each target.

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147.07 – Spectral Classification of NEOWISE Observed Near-Earth Asteroids

Near-Earth asteroids (NEAs) allow us to determine the properties of the smallest solar system bodies in the sub-kilometer size range. Large (>few km) NEAs have albedos which span a wide range from ~0.05 to ~0.3 and are known to correlate with asteroid composition, determined by analysing the shape of their optical reflectance spectra. It is, however, still unknown how this relationship extends into the sub-kilometer population.

NEOWISE has performed a thermal infrared survey that provides the largest inventory to date of well-determined sizes and albedos for NEAs, including many in the sub-km population. This provides an opportunity to test the albedo-surface composition correlation in a new size regime. If it is found to hold, then a simple optical spectrum can give a well-constrained albedo and size estimate without the need for thermal IR measurements.

The sizes and composition of many more sub-km sized NEAs are needed to aid in the understanding of the formation/evolution of the inner solar system and the characterisation of potentially hazardous objects, possible mission targets and even commercial mining operations.

We obtained optical spectra of sub-kilometer NEOWISE-observed NEAs using the 1.5m Tillinghast telescope and the FAST spectrograph at the Whipple Observatory on Mt Hopkins, Arizona. We performed a taxonomic classification to identify their likely composition and combined this with NEOWISE data to look for known correlations between main belt asteroid spectral types and their optical albedos. Additionally, we tested the robustness of current data reduction methods in order to increase our confidence in the spectral classifications of NEAs.

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147.08 – Density and Macroporosity Distribution of Near Earth Asteroids

The density of near earth asteroids is a fundamental property which can illuminate the structure of the asteroid, provide clues about it's collisional history and is key in assessing the hazard of an impact of an NEA with Earth. A low density can be indicative of a rubble pile structure whereas a higher density can imply a monolith and/or a higher metal content. Unfortunately, measuring the density of asteroids is extremely difficult, has only been attempted for a tiny fraction of NEAs and usually results in measurements with large uncertainties. In the absence of density measurements for a specific object, understanding the range and distribution of likely densities can allow for probabilistic assessments of the population and facilitate estimates of the range of reasonable masses for a specific object. We have developed a candidate macroporosity distribution for near earth asteroids based on measurements of meteorite densities and asteroid densities. The macroporosity of an asteroid can be used to aid extrapolation from meteorite physical properties to asteroid physical properties. In addition, we discuss estimating an asteroid density distribution from the macroporosity distribution.

Author(s): Jessie L. Dotson[1], Donovan Mathias[1]
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147.09 – Models of millimeter-wave emission from dust in the coma of Comet 67P

The spacecraft Rosetta ended its mission on September 30th, 2016 after spending more than 2 years studying Comet 67P/Churyumov-Gerasimenko. The comet is constantly emitting gas and ejecting dust as it moves through the inner solar system, and understanding the properties of the gas and dust can help us better understand the comet and its origins. We present the results of a Monte Carlo simulation of dust production developed for comparison with millimeter and submillimeter data obtained by the Microwave Instrument for the Rosetta Orbiter (MIRO). The MIRO instrument measures the millimeter-wave continuum emission from the comet at two wavelengths, 0.53 mm and 1.59 mm. During the months around the August 2015 perihelion of the comet, a small emission excess was observed above the sunlit limb of the comet. The excess emission extends many beam widths off the dayside limb and is a persistent feature for months of observations. No excess is observed above the nightside limb, and given the known strong day-night asymmetry of gas production from the nucleus, we interpret the observed continuum excess on the day side to result from thermal emission from dust. A full treatment of the millimeter-wave emission from the large dust particles observed by MIRO must include many effects, including acceleration of dust particles by outflowing gas and the integration of millimeter-wave emission from a broad range of particle sizes. Our model also incorporates an accurate cometary shape model to demonstrate how dust production might vary with solar illumination over the surface. We find that the complex shape of 67P can lead to asymmetric structures in the distribution of the coma dust, with significant enhancements occurring where large areas of the nucleus have similar orientations with respect to the Sun.

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148 – Planetary Nebulae, Supernova Remnants Poster Session

148.01 – 17 Years of Chandra Observations of SN1987A

We present the latest spectroscopy and light curves from 17 years of observations of SN1987A by the Chandra X-ray Observatory. The flux increased over this period until 2014, but has remained roughly constant over the past three years. This is consistent with optical observations showing that the shock front is now ionizing material outside the inner equatorial ring. X-ray observations will continue to be important as the remnant of SN1987A moves into a new evolutionary phase and begins to probe the pre-explosion wind of the red giant phase of the progenitor.

Author(s): David N. Burrows[1], Kari A. Frank[1]
Institution(s): *1. Penn State Univ.*

148.02 – Calculating the Flux Density Decay of Cas A with LWA1

The supernova remnant Cassiopeia A (Cas A) is one of the brightest objects on the low frequency radio sky in the Northern hemisphere. Due to the expansion of the cloud of material left from the supernova, its flux density keeps decreasing at a rate of ~0.7-0.8% per year. Deviations from this steady decay were noted and a systematic monitoring of Cas A is recommended in order to better trace these fluctuations. The first station of the Long Wavelength Array, co-located with the Very Large Array in New Mexico, has been performing a systematic monitoring of the flux density ratio between the radio galaxy Cygnus A and Cas A below 100 MHz since 2013. In combination with archival observations using the VLA 74 MHz system, this dataset covers a wide range of temporal scales from days to decades. This analysis is expected to lead to a better understanding of the reliability of Cas A for low frequency flux density calibration and provide insights into the physical interaction between the expanding supernova remnant shell and the interstellar medium through light curve analysis. I will present an update on the monitoring effort and preliminary light curves that reveal a non-linear decay of the flux density of Cas A.

Author(s): Jaquelin Erazo[1], Frank Schinzel[2]
Institution(s): *1. CUNY Hunter College, 2. NRAO*
Contributing team(s): LWA Collaboration

148.03 – Exploring Supernova Remnants with the SPIES Project

X-ray observations provide a key window into supernova remnants, providing measurements of a plethora of physical properties that are critical for understanding SNRs, their environments, their progenitors, and the SNe that created them. However, characterizing the entire volume of shocked plasma in a SNR is difficult, due to their complicated three dimensional morphologies and spectra. The SPIES project aims to address this problem by applying a novel X-ray analysis method, Smoothed Particle Inference (SPI), to XMM observations of 12 SNRs. SPI is a Bayesian modeling process that fits a population of gas blobs ("smoothed particles") such that their superposed emission reproduces the observed spatial and spectral distribution of photons. Emission-weighted distributions and maps of plasma properties, such as abundances and temperatures, are then extracted from the properties of the individual blobs. Additionally, because the collection of blobs is a multi-dimensional representation of the shocked plasma, we can carry out a more detailed exploration of plasma properties by extracting any subset of the blobs (e.g. those with the highest temperatures) and investigating its properties (e.g. map the abundances). Here we present preliminary results from SPI analyses of the first 6 remnants in the SPIES project.

Author(s): Kari A. Frank[1], David N. Burrows[1], Vikram Dwarkadas[2]
Institution(s): *1. Pennsylvania State University, 2. University of Chicago*

148.04 – A Survey of X-Ray Luminosity Limits for Unobserved Compact Stellar Remnants in Core-Collapse SNRs

Based on archival Chandra data, we revisit a number of supernova remnants (SNRs) in the Milky Way Galaxy and Large Magellanic Cloud. While the core-collapse explosion of a massive star (M > 8 M_sun) has been established or suggested for the origin of some of those SNRs, the compact stellar remnant has yet to be detected within their boundaries. We estimate upper limits on the X-ray luminosity for several of those putative compact remnants. We compare our results with previous estimates, where available, and briefly entertain physical implications of our estimates.

Author(s): Anthony Glenn Rich[1], Ashley Herbst[1], Nina Clark [1], Paul Thongkham[1], Eric Cooper[1], Alexandria Carino[1], Robert Mathews[1], Andrew Schenck[1], Jayant Bhalerao[1], Sangwook Park[1]
Institution(s): *1. University of Texas at Arlington*

148.05 – Revealing the Detailed Structure of the Galactic Core-Collapse Supernova Remnant G292.0+1.8 with X-Ray Mapping

We present our results on the adaptive-mesh mapping of the chemical composition and thermodynamic parameters of the Galactic core-collapse supernova remnant G292.0+1.8 using our deep Chandra observation. Our maps cover the entire supernova remnant and show the detailed spatial distributions of the metal-rich ejecta, circumstellar medium, and the X-ray pulsar wind nebula-dominated regions. Our results suggest radial and azimuthal variations in the ejecta composition and the thermodynamic parameters, underscoring the rich and complex nature of this text book type supernova remnant. Combining our results from this study and our previous work on the ejecta radial velocity distribution (derived from our Chandra HETG data), we discuss the three dimensional structure of the remnant. Some implications on the nature of the progenitor star and explosion scenarios are discussed.

Author(s): Jayant Bhalerao[1], Sangwook Park[1], Andrew Schenck[1]
Institution(s): *1. UT Arlington*

148.06 – Optical Observations of Galactic Supernova Remnant G64.5+0.9

We present optical observations of galactic supernova remnant G64.5+0.9. First found as a potential remnant by Tian & Leahy (2006), G64.5 was confirmed by Hurley-Walker et al. (2009). The remnant is ~8 arcmin in diameter with a radio source near the center of the remnant, though the source has a spectrum very unlike that of a normal pulsar wind nebula. G64.5 is estimated to be at a distance of ~11 kpc, giving it a diameter of ~26 pc, suggesting that it is moderately old. However, because we have detected it in Halpha (albeit faintly) as well as its near spherical morphology, G64.5 may be considerably closer, smaller, and younger than previously estimated. We present narrow-band images of G64.5 in Halpha, [O III], and [S II], as well as low-dispersion spectra of its optical emission.

Author(s): Jack Neustadt[1], Robert A. Fesen[1], Christine Black[1]
Institution(s): *1. Dartmouth College*

148.07 – Measuring the Symmetry of Supernova Remnants in the Radio

Nearly 300 supernova remnants (SNRs) are known in the MIlky Way galaxy, and they offer an important means to study the explosions and interactions of supernovae at sub-pc scales. In this poster, we present analysis of the morphology of Galactic SNRs at radio wavelengths. Specifically, we measure the symmetry of several tens of SNRs in 6- and 20-cm Very Large Array images using a multipole expansion technique, the power-ratio method. We explore how the SNRs' morphology changes as a function of their size and estimated dynamical ages, with the aim of probing how SNR shapes evolve with time.

Author(s): Jennifer Stafford[1], Laura A. Lopez[1]
Institution(s): *1. The Ohio State University*

148.08 – Behind the Curtain: Revealing the Nebular Influence on X-ray Emission from Planetary Nebulae

Planetary Nebulae (PNe), the ionized shells of gas surrounding dying low- to intermediate-mass stars, are interesting astrophysical plasma laboratories because of the range of plasma conditions that exist in close proximity. Early in the lifetime of PNe, a 10^6 K plasma---called a hot bubble---fills the 10^4 K nebular shell. The interaction of these two plasmas is the potential origin of cooler than expected hot bubble temperatures. Studying high-spatial resolution imaging by the Hubble Space Telescope and the Chandra X-ray Observatory offer an opportunity to study the interaction of these two plasmas. Yet the Chandra and HST observations of PN BD+30°3639 indicate distinct X-ray and optical morphologies that do not appear directly correlated. However, we have developed a method that uses Chandra imaging spectroscopy to study the spatial distribution of the hot bubble X-ray emission. Remarkably, applying this method to the X-ray observation reveals the influence of the surrounding nebula and mimics the optical morphology that is otherwise hidden in the X-ray images. We present the methodology, images derived using the method, and the distribution of the physical conditions that likely give rise to the observed effect. Further improvement of the method and establishing its limitations in the low-count regime will help establish the utility of this method for other low-count extended X-ray sources.

Author(s): Rodolfo Montez Jr.[1]
Institution(s): *1. Smithsonian Astrophysical Observatory*

148.09 – Spectroscopy of Planetary Nebulae at the Bright End of the Luminosity Function

We have obtained spectra of 8 luminous planetary nebulae (PNe) in M31 and 4 in the Large Magellanic Cloud with the goal of understanding their properties and those of their progenitor stars. These PNe are at or near the M* region (the most luminous PNe) in their respective galaxies. M31 PNe were observed at the Gran Telescopio Canarias using the OSIRIS spectrograph; LMC PNe were observed with the FORS2 spectrograph at the Very Large Telescope. Line intensities were measured in IRAF. Using our n-level atom program, ELSA (Johnson, et.al, 2006, Planetary Nebulae in our Galaxy and Beyond, 234, 439), we determined temperature, density, and elemental abundances for each nebula. We then modeled the nebulae and central stars with Cloudy (Ferland, et al. 1998, PASP, 110, 761). We plan to use these models of the central stars to estimate the masses and ages of the progenitor stars. We hope to discover whether the progenitor stars of M* PNe exhibit consistently different characteristics from those of other PNe progenitors.

Author(s): Anneliese Rilinger5, Karen B. Kwitter5, Bruce Balick4, R. L. M. Corradi[1], Rebeca Galera Rosillo[1], George H. Jacoby[2], Richard A. Shaw3
Institution(s): *1. Instituto de Astrofisica de Canarias, 2. Lowell Observatory, 3. NOAO, 4. University of Washington, 5. Williams College*

148.10 – The Eclipsing Central Stars of the Planetary Nebulae Lo 16 and PHR J1040-5417

Binary central stars of planetary nebula are a valuable tool in understanding common envelope evolution. In these cases both the resulting close binary system and the expanding envelope (the planetary nebula) can be studied directly. In order to compare observed systems with common envelope evolution models we need to determine precise physical parameters of the binaries and the nebulae. Eclipsing central stars provide us with the best opportunity to determine high precision values for mass, radius, and temperature of the component stars in these close binaries. We present photometry and spectroscopy for two of these eclipsing systems; the central stars of Lo 16 and PHR 1040-5417. Using light curves and radial velocity curves along with binary modeling we provide physical parameters for the stars in both of these systems.

Author(s): Todd C. Hillwig3, David Frew[2], David Jones[1], Danielle Crispo3
Institution(s): *1. Instituto de Astrofisica de Canarias, 2. University of Hong Kong, 3. Valparaiso University*

148.11 – Zeeman Effect observations toward 36 GHz methanol masers in the Galactic Center

We present observations of 36 GHz Class I methanol masers taken with the Karl G. Jansky Very Large Array (VLA) in the B configuration with the aim of detecting the Zeeman Effect. We targeted several 36 GHz Class I methanol masers associated with supernova remnants (SNRs) toward the Galactic Center. Each source was observed in dual circular polarizations for three hours. The observed spectral profiles of the masers are complex, with several components blended in velocity. In only one case was the Stokes V maser profile prominent enough to reveal a 2-sigma hint of a magnetic field of zBlos = 14.56 +/- 5.60 Hz; we have chosen to express our results in terms of zBlos since the Zeeman splitting factor (z) for 36 GHz methanol masers has not been measured. There are several hints that these spectra would reveal significant magnetic fields if they could be spatially and spectrally resolved.

Author(s): Justin A Potvin[1], Emmanuel Momjian[2], Anuj Pratim Sarma[1]
Institution(s): *1. DePaul, 2. NRAO*

149 – Gamma Ray Bursts Poster Session

149.01 – Long-Wavelength Demographics of GRB Host Galaxies

We present new VLA observations of 32 Swift and pre-Swift GRB host galaxies, supplemented by new ALMA and Herschel observations. Although our observations are quite deep, we securely detect only a few targets in the sample. Indeed, we rule out several claimed detections of ULIRG-like host galaxies in the previous literature, including every pre-Swift ULIRG-like host: these now appear to have been due to residual afterglow contamination or source confusion. Our results indicate that only a small minority of GRBs (~10%) occur in ULIRG-like galaxies and that intense star-formation does little to directly facilitate GRB production. This suggests in turn that dynamical interactions or ultra-massive stellar progenitors are not likely to be critical ingredients in GRB formation. Every GRB securely associated with a ULIRG is observed to significantly dust-obscured, consistent with the large dust optical depths and covering frations thought to be characteristic of these systems.

Author(s): Daniel A. Perley[1]
Institution(s): *1. Niels Bohr Institute, University of Copenhagen*

149.02 – A Study of the Gamma-Ray Burst Fundamental Plane

A class of long gamma-ray bursts (GRBs) with a plateau phase in their X-ray afterglows obeys a three-dimensional (3D) relation (Dainotti et al. 2016), between the rest-frame time at the end of the plateau, Ta, its corresponding X-ray luminosity, La, and the peak luminosity in the prompt emission, Lpeak. We extended the original analysis with X-ray data from July 2014 to July 2016 achieving a total sample of 183 Swift GRBs with afterglow plateaus and known redshifts. We added the most recent GRBs to the previous ‘gold sample’ (now including 45 GRBs) and obtained a relation plane with intrinsic scatter compatible within one σ with the previous result. We compared several GRB categories, such as short with extended emission, X-ray Flashes, GRBs associated with SNe, long-duration GRBs, and the gold sample, composed only by GRBs with light curves with good data coverage and relatively flat plateaus and evaluated their relation planes. We found that they are not statistically different from the fundamental plane derived from the gold sample and that the fundamental plane still has the smallest scatter. We compared the jet opening angles tabulated in literature with the angles derived using the Eiso–Egamma relation of the method in Pescalli et al. (2015) and calculated the relation plane for a sample of long GRBs accounting for the different jet opening angles. We observed that this correction does not significantly reduce the scatter. In an extended analysis, we found that the fundamental plane is independent from several prompt and afterglow parameters.

Author(s): Christian Gilbertson[5], Maria Dainotti[3], Sergey Postnikov[1], Shigehiro Nagataki[2], Richard Willingale[4]
Institution(s): *1. Indiana University, 2. RIKEN, 3. Stanford University, 4. University of Leicester, 5. Virginia Polytechnic Institute and State University*

149.03 – A Spatially - Resolved Study of the GRB 020903 Host Complex

The host complex of GRB 020903 is one of only a few long-duration gamma ray burst (GRB) environments where spatially-resolved observations are possible. It may also be the only known GRB host consisting of multiple interacting components, as well as an active galactic nucleus. We were granted 4.5 hours of observing time on the Gemini Multi-Object Spectrograph (South) to obtain spatially resolved spectra of the GRB 020903 host complex. Using long-slit observations at two different position angles we were able to obtain optical spectra of the four main regions of the GRB host, with a spectral range of 3600 - 9000 Å. From this data we discern the redshift of each region to confirm that they comprise a single interacting system at an approximate redshift of z ~ 0.251. We also measure the metallicity, star formation rate, and young stellar population age of each region to create a spatially-resolved map of these parameters for the larger host complex. Based on the distribution of these characteristics we determine whether the localized GRB explosion site is representative of the host complex as a whole, or localized in a metal-poor or strongly star-forming region. Lastly, we consider the dynamics and past interactions of the host complex, studying the strongest emission lines for signs of potential inflows or outflows through each region.

Author(s): Mallory Thorp[1], Emily M. Levesque[1]
Institution(s): *1. University of Washington*

150 – Intergalactic Medium, QSO Absorption Line Systems Poster Session

150.01 – Quasar Absorption Lines and SDSS Galaxies

We present the results of a study of the sightlines of 45 low redshift quasars (0.06 < z < 0.85) observed with HST/COS that lie within the footprint of the Sloan Digital Sky Survey. We use both the SDSS DR12 galaxy photometric data, including photometric redshifts, and the measured properties of the absorbers along with the known absorption characteristics of the intergalactic medium and the circumgalactic medium of galaxies to assign the most probable galaxy matches for each absorber in the sample, using estimated galaxy luminosities and virial radii as a discriminator. We show that the scheme can recover known galaxy-absorber matches found from spectroscopic data and thus provides a method for identifying likely pairs in photometric data sets as well as targets for spectroscopic follow up.

Author(s): Emileigh Suzanne Shoemaker[1], Jennifer E. Scott[1], Katarzyna Oldak[1]
Institution(s): *1. Towson University*

150.02 – Shock waves and particle acceleration in clusters of galaxies

During the formation of the large-scale structure of the universe, intracluster media (ICMs), which fills the volume of galaxy clusters and is composed of hot, high-beta plasma, are continuously disturbed by major and minor mergers of clumps as well as infall along filaments of the warm-hot intergalactic medium (WHIM). Such activities induce shock waves, which are observed in radio and X-ray mostly in cluster outskirts. These shocks are collisionless, as in other astrophysical environments, and are thought to accelerate cosmic rays (CRs) via diffusive shock acceleration (DSA) mechanism. Here, we present the properties of shocks in ICMs and their roles in the generation of nonthermal particles, studied with high-resolution simulations. We also discuss the implications on the observations of diffuse radio emission from galaxy clusters, such as radio relics.

Author(s): Dongsu Ryu[2], Hyesung Kang[1], Ji-Hoon Ha[2]
Institution(s): *1. Pusan National University, 2. UNIST*

150.03 – First light with Trident: multi-platform synthetic quasar spectra

Observational efforts to better understand the nature of the intergalactic and circumgalactic media have relied heavily on the information encoded in the absorption line systems of quasar spectra. Numerical simulations of large-scale structure and galaxy evolution are well-suited to explore the properties of those same media owing to the relative ease with which one can access physical quantities from complex, three-dimensional data. However, a difficulty arises when one tries to make direct “apple-to-apples” comparisons between observed spectra and simulated data. In an effort to provide a common language capable of linking theory and observation, we announce the release of Trident. Trident is a publicly available software tool that enables the creation of realistic synthetic absorption spectra from virtually all widely-used hydrodynamics simulation codes. Through user-controlled levels of spectral realism, direct comparisons between simulated and observed data become not only possible, but greatly simplified. We present the methods for extracting artificial quasar sightlines and generating spectra as well as early-stage applications of those spectra to intergalactic and circumgalactic absorption line studies.

Author(s): Devin W. Silvia3, Cameron B. Hummels[1], Britton Smith[2]
Institution(s): *1. California Institute of Technology, 2. Institute for Astronomy, 3. Michigan State University*

150.04 – A Measurement of the z=4 Ultraviolet Background from the Proximity Effect

We present measurements of the metagalactic HI ionization rate from the proximity effect in the spectra of 33 quasars, twelve observed with the 6.5 m Baade telescope at Las Campanas Observatory and supplemented with 21 additional previously published quasar spectra of similar resolution from LRIS on the 10m Keck 1 telescope at the W. M. Keck Observatory. We use a method based on flux statistics in the quasar spectra in order to mitigate sensitivity to spectral resolution. We consider uncertainties in quasar systemic redshifts and Lyman limit fluxes. We compare the measured background to previous measurements at this redshift and to models based on the contribution from quasars and star-forming galaxies.

Author(s): Jennifer E. Scott[1]
Institution(s): *1. Towson Univ.*

150.05 – Understanding the IGM Through the Use of a Lensed Quasar

Quasars are among the brightest objects in the universe. In rare gravitationally lensed quasars, their light is split and travels along multiple paths through an intervening lensing galaxy. The light that follows these different paths encounters various parts of the intergalactic medium (IGM) and may show different absorption features, indicating the varying composition of the IGM. By analyzing spectra from a gravitationally lensed quasar, B1422+231, observed by the Gemini North Telescope, we compare the absorption features identified in the lensed images to form a small-scale structure of the IGM.

Author(s): Teresa Panurach[1], Matthew O'Dowd[2]
Institution(s): *1. CUNY Hunter College, 2. CUNY Lehman College*

150.06 – Deeper Insights into the Circumgalactic Medium using Multivariate Analysis Methods

Drawing from a database of galaxies whose surrounding gas has absorption from MgII, called the MgII-Absorbing Galaxy Catalog (MAGIICAT, Neilsen et al 2013), we studied the circumgalactic medium (CGM) for a sample of 47 galaxies. Using multivariate analysis, in particular the k-means clustering algorithm, we determined that simultaneously examining column density (N), rest-frame B-K color, virial mass, and azimuthal angle (the projected angle between the galaxy major axis and the quasar line of sight) yields two distinct populations: (1) bluer, lower mass galaxies with higher column density along the minor axis, and (2) redder, higher mass galaxies with lower column density along the major axis. We support this grouping by running (i) two-sample, two-dimensional Kolmogorov-Smirnov (KS) tests on each of the six bivariate planes and (ii) two-sample KS tests on each of the four variables to show that the galaxies significantly cluster into two independent populations. To account for the fact that 16 of our 47 galaxies have upper limits on N, we performed Monte-Carlo tests whereby we replaced upper limits with random deviates drawn from a Schechter distribution fit, f(N). These tests strengthen the results of the KS tests. We examined the behavior of the MgII λ2796 absorption line equivalent width and velocity width for each galaxy population. We find that equivalent width and velocity width do not show similar characteristic distinctions between the two galaxy populations. We discuss the k-means clustering algorithm for optimizing the analysis of populations within datasets as opposed to using arbitrary bivariate subsample cuts. We also discuss the power of the k-means clustering algorithm in extracting deeper physical insight into the CGM in relationship to host galaxies.

Author(s): James Lewis[1], Christopher W. Churchill[1], Nikole M. Nielsen[2], Glenn Kacprzak[2]
Institution(s): *1. New Mexico State University, 2. Swinburne University of Technology*

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151 – Stellar Atmospheres, Winds, Be Stars, & Wolf-Rayet Phenomena Poster Session

151.01 – Circumstellar Dust Composition of M-type Mira Variables observed with phase with Spitzer

Our research concerns the detailed dust composition surrounding Mira variables. These regular pulsators are easily observed in the optical and infrared due to their changes in brightness. Data on 25 galactic Miras were obtained with the Spitzer Infrared Spectrograph (IRS) instrument in 2008-09 under a GO program led by Creech-Eakman. The stars were observed approximately once per month to track changes in their brightness and spectral features. This dataset is unique for both the number of observations of each star and the high SNR due to their intrinsic brightness.

The stars in this study span the range of oxygen- to carbon-rich, with each type exhibiting certain known solid state components (i.e dust). The current focus is on trying to reproduce dust spectral features in the short, high (*SH*) and long, high (*LH*) resolution wavelength range (~9.7 – 40 microns) of the oxygen-rich Miras (C/O < 1). These high resolution, reduced spectra reveal a wonderful “forest” of features that provide insight into the stellar atmospheres and circumstellar dust composition with phase.

Using the 1-D radiative transfer modeling code, DUSTY, we are attempting to identify several broad, and some sharp, dust features by including recently derived laboratory spectral indices for dust opacities. Prominent features seen in oxygen-rich Mira variables include potential identifications of water ice emission, as well as amorphous and crystalline silicates. We implement a greybody continuum obtained from MARCS, a 1-D hydrostatic spherical LTE model grid code, as the stellar continuum input for DUSTY. Using a greybody rather than a blackbody curve allows us to obtain a better agreement between the DUSTY spectrum and the Spitzer data. We will show these amended model fits that will improve the identification of the dust and other features in the spectra.

Author(s): Tina Güth[1], Michelle J. Creech-Eakman[1]
Institution(s): *1. New Mexico Institute of Mining and Technology*

151.02 – Bridging the Gap between Coronal and Non-Coronal Evolved Stars

The Hubble Space Telescope (HST) Treasury Program "Advanced Spectral Library (ASTRAL)" enables investigations of a broad range of problems including the character and dynamics of the wind and chromosphere of cool stars. This paper presents an investigation of the change in spectral characteristics when transitioning from the cool non-coronal objects with fluorescent emission spectra from the iron group elements, molecular hydrogen, and carbon monoxide to the warmer stars on the blue side of the Linsky-Haish dividing line in the HR diagram. These warmer objects exhibit chromospheric emission from significantly hotter environments in addition to coronal signatures, while the hybrid stars overlap in the HR-diagram with some of the non-coronal objects and share many spectral characteristics but show differences in the wind properties. We show how the wind, fluorescent features, and hot stellar signatures dramatically change with spectral class by comparing the already analyzed non-coronal objects (Alpha Ori, Gamma Cru) with the hybrid stars (Gamma Dra, Beta Gem and Alpha Aqr) and the coronal object Beta Dra. We aim to gain understanding of the physical processes in these objects' outer atmospheres and their evolutionary tracks.

Author(s): Kenneth G. Carpenter[2], Krister E. Nielsen[1], Gladys V. Kober[1]
Institution(s): *1. Catholic University of America, 2. NASA's GSFC*

151.03 – Stratification in Ap star atmospheres: Simulations

It is now well established that the atmospheres of Ap stars can be chemically stratified (cf. Babel, A\&A 258, 645, 1992; Ryabchikova et al. A\&A 384, 545, 2002). The most convincing cases have been made with the profiles of very strong lines, such as Ca II K. Weaker line profiles are less obvious indicators. The collective behavior of sets or groups of lines have also been used. For example, if higher abundances are derived for strong lines in an atmosphere with zero microturbulence, one may assume that the absorbing species has been pushed into the higher photospheres. An example are the medium-strong Mn II lines in HgMn stars. In this paper, we probe this assumption by calculating line strengths with various assumed stratification models, and then determining abundances from those lines using an {\bf unstratified} model with the same Teff and log(g). We use the model from Castelli, Kurucz \& and Hubrig (A\&A, 508, 401, 2009) for HR 6000, whose spectrum shows numerous indications of stratification. A variety of stratification models are considered, for example, ones where the majority of an absorbing species is concentrated above (or below) \$log(\tau_{5000}\$ = -2.0. Cloud models are also investigated, where a species is concentrated within a range of photospheric depths. Curves of growth are generated in unstratified atmospheres for lines by holding the abundance fixed, and increasing log(gf). Similar curves are made in stratified models, and the ratios of strong to weak lines
are compared with and without stratification. The effects of stratification on ionization are also investigated, as well as on the profiles of strong lines. We find, in agreement with previous work, that severe abundance jumps are sometimes required to account for some of the observed peculiarities.

Author(s): Charles R. Cowley[2], Fiorella Castelli[1]
Institution(s): *1. Instituto Nazionale di Astrofisica, Osservatorio Astronomico di Trieste, 2. Univ. of Michigan*

151.04 – Spectroscopic Parameters of B Stars in the Carina Nebula

As part of an ongoing program to study the massive stars in the Carina Nebula, we have analyzed the spectra of 97 B stars. Using the Tlusty BSTAR2006 grids of model spectra, we have measured the effective temperature, surface gravities, and the projected rotational velocities of our sample. We also compared our results to the evolutionary tracks and isochrones of Ekström et al. to measure the mass, radius, and age of these stars.

Author(s): Richard Hanes[1], M. Virginia McSwain[1]
Institution(s): *1. Lehigh University*

151.05 – The Fe Group Abundances in the B3 IV Standard ι Herculis Determined from ASTRAL II Observations

Iota Herculis is an ultrasharp-lined B3 IV star that historically has been considered as an abundance standard for the early B stars. This star was one of the targets in the HST Treasury Program Advanced Spectral Library II: Hot Stars (ASTRAL II) that produced uninterrupted spectra of high to medium resolution in the region 1150-3100 Å. The abundances for the Fe group elements (Ti, V, Cr, Mn, Fe, Co, & Ni) in ι Her were determined mostly from STIS E140H and E230H (resolving power of 114,000) observations. Measurable lines from the Fe group, except for a very few multiplets of Fe II, III are not found in optical spectra. Whereas the light elements are delivered to the ISM by core-collapse supernovae (CCSNe), the Fe group elements are believed to come mostly from low/intermediate mass binaries containing white dwarfs that undergo SNe Ia explosions. A single SNe Ia can deliver 0.5 solar masses of pure Fe (and maybe Mn) to the ISM compared with about 0.07 solar masses from a CCSNe. The HST/STIS data were supplemented with optical spectra obtained at the Dominion Astrophysical Observatory (resolving power about 60,000). The abundance analysis was carried through with the NLTE code TLUSTY/SYNSPEC (Hubeny & Lanz, ApJ, 439,875,1995). The model parameters adopted for the ι Her are T_{eff} = 17750 ± 250 K, log g = 3.75 ± 0.05 dex, V_{turb} = 0 km s^{-1}, and υ sin i = 5 km s^{-1}. Solar abundances appear to prevail for the lighter elements but the abundances of Fe group elements are 0.3 - 0.7 dex below solar values determined by Grevesse et al. (2010, Ap&SpSci, 328, 179). It appears that ι Her was formed in a region our Galaxy mostly enriched by CCSNe.

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151.06 – The Be Population in 10 Galactic Open Clusters From the Discovery Channel Telescope

As part of a multi-site, multi-epoch campaign to study the time-scales of disk growth and dissipation for classical Be stars, we have studied ten Galactic open clusters with multi-color photometry (Johnson BVRIJK and narrow band H-alpha and an adjacent continuum filter). We have created color-color diagrams to isolate the Be stars in the targeted clusters. These clusters have previously been determined to contain multiple Be stars. From our early analysis of the clusters we have found a number of new candidate Be stars, as well as a few stars in each cluster that appear to have lost their gaseous disks. Such studies of clusters will provide a statistical basis for understanding the evolution of the disks around these stars and may provide insights into the formation processes for the Be stars. We are grateful for support of the NSF REU program at the University of Toledo through NSF grant 1262810, as well as for support from NSF AST 1411563, 1412110, and 1412135.

Author(s): Pa Chia Thao[1], Noel Richardson3, Cody Gerhartz3, Karen S. Bjorkman3, Jon Eric Bjorkman3, John P. Wisniewski[2], Anthony Burrow[2], Jamie R Lomax4, Kevin R. Covey5
Institution(s): *1. Mount Holyoke College , 2. University of Oklahoma , 3. University of Toledo , 4. University of Washington , 5. Western Washington University*

151.07 – Variable Circumstellar Disks: Prevalence, Timescales, and Physical Mechanisms

Rapidly rotating B-type stars often experience mass ejection that leads to the formation of a circumstellar gas disk, as diagnosed by distinct emission lines present in their spectra. The mass ejection from these stars, known as classical Be stars, sometimes slows or stops, leading to the mass falling back onto the central star and the disk dissipating. The prevalence and time-scale of such disk-loss and disk-replenishment episodes, as well as the underlying physical processes that cause the underlying mass ejection, remain unknown. We are using multi-epoch broad- and narrow-band photometric observations of 12 young open clusters to characterize the prevalence and time-scale of disk-loss and disk-replenishment episodes. We use our observations to gauge which cluster objects exhibit H-alpha emission, which is a primary indicator of Be stars in our clusters. This program is supported by NSF-AST 1411563, 1412110, and 1412135.

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Institution(s): *1. Mount Holyoke, 2. University of Oklahoma, 3. University of Toledo, 4. Western Washington University*

151.08 – A spectroscopic orbit for the late-type Be star β CMi

The late-type Be star beta CMi is remarkably stable compared to other Be stars that have been studied. This has led to a realistic model of the outflowing Be disk by Klement et al. (2015) These results showed that the disk is likely truncated at a finite radius from the star, which is easily accomplished by a binary companion in orbit. We report on an analysis of the Ritter Observatory spectroscopic archive of beta CMi in hopes of discovering evidence of the elusive companion. We detect orbital motion caused by a companion from small shifts in the H-alpha emission line. We then compared the small changes in the violet-to-red peak height changes (V/R) with the orbital motion. While some V/R variability seems to be present in the H-alpha profile, there is only weak evidence that it follows the orbital motion, as suggested by recent Be binary models by Panoglou et al. (2016). We also analyze several epochs of near-infrared moderate resolution spectra from the InfraRed Telescope Facility with the SpeX spectrograph. Near-infrared spectra show variations of the Pa-beta and Br-gamma lines, suggesting structure could be present in the inner parts of the Be disk. These results suggest that beta CMi is similar to several other Be stars, and is a product of binary evolution where Roche lobe overflow has spun up the current Be star, likely leaving a hot subdwarf or white dwarf in orbit around the star. Unfortunately, no sign of this star is found in the very limited archive of International Ultraviolet Explorer spectra, so future UV studies of the system are necessary.

We are grateful for support of the NSF REU program at the University of Toledo through NSF grant 1262810 and addtional support from the NSF under grant AST-1412135.

Author(s): Nick Dulaney4, Noel Richardson4, Cody Gerhartz4, Jon Eric Bjorkman4, Karen S. Bjorkman4, Alex C. Carciofi3, Luqian Wang[2], Nancy D. Morrison4, Robert Klement[1]
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Contributing team(s): Ritter Observing Team

151.09 – Destruction of Be star disk by large scale magnetic fields

Classical Be stars are rapidly rotating stars with circumstellar disks that come and go on time scale of years. Recent observational data strongly suggests that these stars lack the ~10% incidence of global magnetic fields observed in other main-sequence B stars. Such an apparent lack of magnetic fields may indicate that Be disks are fundamentally incompatible with a significant large scale magnetic field. In this work, using numerical magnetohydrodynamics (MHD) simulations, we show that a dipole field of only 100G can lead to the quick disruption of a Be disk. Such a limit is in line with the observational upper limits for these objects.

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Institution(s): *1. Penn State Worthington Scranton, 2. University of Delaware, 3. University of Tübingen*

151.10 – Spectral Classification of Central Stars of Bowshock Nebulae

We present spectroscopic follow-up of bowshock-supporting stellar sources from our catalog of 709 bowshock nebula candidates using the 2.3m telescope at the Wyoming Infrared Observatory. We have collected optical spectra of 81 central stars of candidate nebulae which show that 71 of these nebulae are supported by massive early-type OB stars (88%). The remaining spectra may be explained as evolved descendants of massive stars, however our observations are unable to conclusively distinguish between dwarf and giant/supergiant evolutionary states. These results are in agreement with the accepted interpretation that bowshock nebulae are created by the interaction of strong stellar winds from massive stars with their surrounding interstellar medium where either the star is moving at a high peculiar velocity (estimated to be 77% of candidates in our catalog) or the star lies in an outflow of gas from a nearby photoevaporating molecular cloud (8%) or HII region (15%). This work is supported by the National Science Foundation under grants AST-1063146 (REU), AST-1411851 (RUI), and AST-1412845.

Author(s): William T. Chick[2], Henry A. Kobulnicky[2], Matthew S. Povich[1], Don Dixon[1], Daniel Lee[1]
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151.11 – Polarization signatures of bow shocks: A diagnostic tool to constrain the properties of stellar winds and ISM

When a stellar wind traveling at supersonic speed interacts with almost stationary ISM, a bow shock shape is formed. By studying a bow shock, we can obtain information about the properties of the stellar wind as well as the surrounding ISM. Bow shocks are asymmetric structures, and thus produce net polarization even if they are unresolved. Hence, polarization studies of bow shocks can provide complementary constraints on their properties.
We simulate the polarization signatures of circumstellar material with bow shock geometries using a Monte Carlo radiative transfer code called *SLIP*. We use the analytic solution from Wilkin (1996) to define the geometry and mass surface density of the bow shock in our models. We present results from our simulations showing how changing CSM optical depth, CSM albedo, photon source, and scattering particles (electrons or different types of dust particles) affects the observed polarization in both resolved and unresolved cases. In the optically thin regime of the unresolved electron-scattering case, the polarization peaks at an inclination angle of 90°, in agreement with analytical single-scattering models. In optically thick cases, a second polarization peak appears near 130°, which we propose is due to multiple scattering. Given these results, an observed polarization value can constrain the inclination of an unresolved bow shock to two possible angles, which in turn constrain the motion of the star. In case of resolved bow shocks, our simulations produce polarization maps which we compare with observations.
We also present results from our dust-scattering simulations, which show that multicolor broadband polarization observations can constrain the characteristics of the dust in a resolved or unresolved bow shock-shaped CSM configuration.

Author(s): Manisha Shrestha[2], Jennifer L. Hoffman[2], Hilding R. Nielson3, Richard Ignace[1]
Institution(s): *1. East Tennessee State University, 2. University of Denver, 3. University of Toronto*

151.12 – Exploring X-ray Emission from Winds in Two Early B-type Binary Systems

The winds of the most massive (O-type) stars have been well studied, but less is known about the winds of early-type B stars, especially in binaries. Extending O-star wind theory to these smaller stars, we would expect them to emit X-rays, and when in a B-star binary system, the wind collision should emit additional X-rays. This combined X-ray flux from nearby B-star binary systems should be detectable with current telescopes. Yet X-ray observations of two such systems with the Chandra Observatory not only show far less emission than predicted, but also vary significantly from each other despite having very similar observed characteristics. We will present these observations, and our work applying the classic Castor, Abbott, and Klein (CAK) wind theory, combined with more recent analytical wind-shock models, attempting to reproduce this unexpected range of observations.

Author(s): John P. Rotter[2], Tabetha Hole[2], Richard Ignace[1], Lida Oskinova[3]
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151.13 – The Variability of the BRITE-est Wolf-Rayet star gamma Velorum. Photometric and Spectroscopic Evidence of Colliding Winds.

We report on the first results of an intensive photometric and spectroscopic campaign on the bright WC+O binary, gamma Velorum. The system was observed with two-color photometry with the BRITE-Constellation nanosatellites for six months, while we collected ~500 optical spectra in parallel from ground-based observatories. We report on the spectroscopic orbit and the evidence of colliding winds, both spectroscopically and photometrically. We find evidence of an inverse relationship between the orbital separation and the observed flux. Through a comparison with multiple spectra and the red/blue filter responses, we find that the flux excess seen photometrically is caused by the excess line emission at periastron. We have begun to quantify these variations and will compare them with smoothed-particle hydrodynamics simulations. We will further constrain these processes using XMM-Newton X-ray spectroscopy that will be obtained in late-2016 in parallel with further optical photometric and spectroscopic observations.

Author(s): Noel Richardson[5], Lucas St-Jean[4], Anthony F. J. Moffat[4], Nicole St. Louis[4], Christopher Michael Post Russell[2], Tomer Shenar[3], Herbert Pablo[4], Grant M. Hill[1], Tahina Ramiaramanantsoa[4], Kenji Hamaguchi[2], Michael F. Corcoran[2]
Institution(s): *1. Keck Observatory, 2. NASA Goddard, 3. Universitat Potsdam, 4. Universite de Montreal, 5. University of Toledo*

151.14 – Stagnant Shells in the Vicinity of the Dusty Wolf-Rayet-O/B Binary WR 112

We present high spatial resolution mid-infrared images of the nebula around the late-type carbon-rich Wolf-Rayet (WC)-O/B binary system WR 112 taken by the recently upgraded VLT spectrometer and imager for the mid-infrared (VISIR) with the PAH1, NeII_2, and Q3 filters. The observations reveal a morphology resembling a series of arc-like filaments and broken shells. Dust temperatures and masses are derived for each of the identified filamentary structures, which exhibit temperatures ranging from 179 ± 8 K at the exterior W2 filament to 355 ± 37 K in the central 3''. The total dust mass summed over all the features is $2.6 \pm 0.4 \times 10^{-5}$ $M_{\odot}$. A multi-epoch analysis of previous mid-IR photometry of WR 112 over the past ~20 yr reveals no significant variability in the observed dust temperature and mass. The morphology of the mid-IR dust emission from WR 112 also exhibits no significant expansion between archival imaging data taken in 2007 May 7, which disputes the current interpretation of the nebula as a high expansion velocity (~1200 km s^{-1}) "pinwheel"-shaped outflow driven by the colliding winds of the central WC-O/B system. An upper limit of <120 km s^{-1} is derived for the expansion velocity assuming a distance of 4.15 kpc. The upper limit on the average mass-loss rate from the central 3" of WR 112 is estimated to be $< 8 \times 10^{-6}$ $M_{\odot}$ yr^{-1}. Based on these constraints, we suggest that the WR 112 nebula formed in the slow, dense outflow during a previous red supergiant (RSG) phase of the central Wolf-Rayet star.

Author(s): Ryan M. Lau[1], Matthew Hankins[2], R. Schoedel[3], Joel Sanchez-Bermudez[5], Anthony F. J. Moffat[6], Michael E. Ressler[4]
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151.15 – TRES Survey of Variable Diffuse Interstellar Bands

Diffuse interstellar bands (DIBs) are absorption features commonly observed in optical/near-infrared spectra of stars and thought to be associated with polyatomic molecules that comprise a significant reservoir of organic material in the universe. However, because the central wavelengths of DIBs do not correspond with electronic transitions of known atomic or molecular species, the specific physical nature of their carriers remains inconclusive despite decades of observational, theoretical, and experimental research. It is well established that DIB carriers must be located in the interstellar medium, but the recent discovery of time-varying DIBs in the spectra of the extragalactic supernova SN 2012ap suggests that some may be created in massive star environments. We report evidence of short time-scale (~1–60 days) variations in DIB absorption line substructure toward 3 of 17 massive stars observed as part of a pathfinder survey of variable DIBs. The detections are made in high-resolution optical spectra (R ~ 44000) from the Tillinghast Reflection Echelle Spectrograph on the 1.5m Tillinghast telescope at the Smithsonian Astrophysical Observatory's Fred L. Whipple Observatory on Mt. Hopkins in Arizona. Our detections have signal-to-noise ratios of 5-15 around the features of interest, and are thus considered significant but requiring further investigation. We find that these changes are potentially consistent with interactions between stellar winds and DIB carriers in close proximity. Our findings motivate a larger survey to further characterize these variations and may establish a powerful new method for probing the poorly understood physical characteristics of DIB carriers.

Author(s): Charles Law[1], Dan Milisavljevic[2], Kyle Crabtree[3], Sommer Johansen[3], Daniel Patnaude[2]
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152 – Pulsating & Variable Stars Poster Session

152.01 – Variable Stars in the Large Magellanic Cloud from Archival HST Observations

In this study, we present deep observations of a field in the Large Magellanic Cloud (LMC) taken by the Advanced Camera for Surveys onboard the Hubble Space Telescope (HST) in coordinated parallel mode. While HST was observing SN1987a with the primary instrument, it was able to collect 42 images of a nearby field in the LMC over a timespan of 3.92 hours in the F606W (~V) and F814W (~I) filters. These deep observations allow us to search for variable stars from the level of the horizontal branch (HB) down to several magnitudes below the main sequence turnoff. We make use of existing light-curve-template fitting software in order to derive periods and amplitudes for our candidate variable stars. This approach complements the existing LMC variable star surveys, which are primarily designed to identify these stars at or above the HB. This results in ~10 magnitudes of coverage in the search for variables in the LMC.

Author(s): Gabriel Alejandro Fuentes[1], Ata Sarajedini[1]
Institution(s): *1. University of Florida*

152.02 – The First Kepler Observations of the Pulsations of R Coronae Borealis Stars

K2 has opened a new avenue for the detailed study of the pulsations of the R Coronae Borealis (RCB) stars. These observations are key to understanding the evolution of the RCB stars because their masses cannot be accurately estimated by other means. The ~75 days of near continuous, high-precision observations are ideal for our planned analysis of the brightness variations of the RCB stars. We are observing about 15 RCB stars In K2 Fields 7, 9, and 11.

These observations will provide a better understanding of the pulsation mechanisms and modes in RCB stars. RCB stars are thought to be ~0.8-0.9 M(Sun) from previous stellar pulsation modeling. These estimated masses agree well with the predicted masses of the merger products of a CO- and a He-WD. Final-flash stars, since they are single white dwarfs, should typically have masses of 0.55-0.6 M(Sun). No cool RCB star, with T(eff) = 5000-7000 K, is known to be a binary so these mass estimates are of great importance to understanding the evolution of these enigmatic stars. RCB stars show periodic or semi-periodic light and radial velocity fluctuations due to both radial and non-radial pulsations. These stars show pulsation periods in the 40-100 d range. These variations are separate from the large declines in brightness caused by dust forming around the star. The pulsations in RCB stars are thought to arise through strange-mode instabilities. Strange modes occur in stars with high luminosity where radiation pressure dominates. RCB stars comprise a peculiar and rare class of stars that offers an excellent opportunity to reveal crucial insights into the advanced stages of stellar evolution.

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Institution(s): *1. Armagh Observatory, 2. Louisiana State Univ., 3. Tohoku University, 4. UC Davis*

152.03 – Multiband Fourier Analysis and Interstellar Reddening of Variable Stars in the Globular Cluster NGC 6584

Globular clusters are excellent objects to study to help us understand the ways in which stars evolve. Key to this understanding are RR Lyrae variable stars. This research focused on the RR Lyrae stars in the globular cluster NGC 6584 to gain a better knowledge of post main sequence stellar evolution, horizontal branch morphology, and interstellar reddening to cluster variables. Using the 0.6 m SARA telescope at CTIO, we obtained nearly 1000 images in B, V, and I bands from July 2014 through July 2015. In addition to our prior work in V-band, this research adds B and I bands. By using difference image analysis, we found 77 variable stars in our 13’ x 13’ field of view. These consisted of 66 RR Lyrae stars, 7 long period variables, and 4 eclipsing binaries. The RR Lyrae stars were divided into 50 RR0 type stars, of which 14 exhibit the Blazhko effect, and 16 RR1 type stars. We found an average period for the RR0 variables of 0.56465 days and 0.30610 for the RR1 variables. By applying Fourier decomposition and examining the light curves in B, V, and I bands for each RR Lyrae variable, we were able to determine an average $[Fe/H]_{JKZW}$ of -1.619 ± 0.090, an average E(*B-V*) of 0.100 ± 0.032, and a distance to the cluster of 13527 ± 939 pc. This is the first detailed study to use RR Lyrae variable stars to estimate these parameters and the results are consistent with those obtained by other methods.

Author(s): Nathan J. Villiger[1], Sedrick Weinschenk[1], Paul T Hettinger[1], Brian W. Murphy[1]
Institution(s): *1. Butler University*

152.05 – Monitoring Period and Amplitude Changes in Classical Cepheids

Cepheid Variable Stars, which are located on the Instability Strip of the Hertzsprung-Russel Diagram, can be used as “standard candle” distance markers (Fiorentino 2007). This came about after the discovery of the Period-Luminosity Relationship (the Leavitt Law), and they have since become a cornerstone of the Cosmic Distance Scale and are helping to further refine the Hubble Constant. Cepheids will cross the Instability Strip, either in a “redward” (cooler) or “blueward” (hotter) direction depending on the stage in which the Cepheid is evolving (Neilson 2012).
While Cepheids were originally believed to have regular periods, many are now known to have varying periods, dating back to Eddington (1919). Therefore, Cepheids must be closely monitored in order to deduce where these period variations are coming from – either from inside the star itself or from some outside source. Determining period changes in Cepheids can reveal important information (e.g. evolutionary states, potential companions, etc.). Photometric data were taken for two Cepheids from two different sources and analyzed. The Cepheids in question are AA Gem and BB Gem, both located in the Gemini constellation. Data for these two stars were taken from the All Sky Automated Survey (ASAS) and from the Robotically Controlled Telescope (RCT) at Kitt Peak National Observatory, on which Villanova has guaranteed access. ASAS observes automatically each clear night, and has done so for several years, making it an excellent source for obtaining Cepheid data. The RCT telescope also operates automatically, observing from a preset target list, and achieves a much higher precision than ASAS can. Multi-aperture photometry was performed on the AA Gem and BB Gem RCT images, in Astroimagej.
The data were then separated into different seasons, and Fourier fits were applied to the light curves in Kephem (written by Andrej Prša and collaborators). These results were then analyzed via the Hertzsprung Method to find changes in the Cepheids’ times of maximum light (and thus periods).

Author(s): Mary Erickson[1], Scott G. Engle[1]
Institution(s): *1. Villanova University*
Contributing team(s): Mark Wells (Penn State University)

152.06 – Discovering Cepheid and RR Lyrae Stars: Pan-STARRS Science Archive @ STScI and Robotically Controlled Telescopes

Cepheid and RR Lyrae stars are an integral part of the cosmic distance ladder and are also useful for studying galactic structure and stellar ages. This project aims to greatly expand the number of known periodic variables in our galaxy by identifying candidates in the PanSTARRS-1 3pi catalog, and carrying out systematically targeted characterization with robotically controlled telescopes. Candidate targets are selected from available detection tables based on color and variability indices and are then fully vetted using robotic telescopes: the RCT 1.3 meter (Kitt Peak National Observatory) and RATIR 1.5 meter (Mexico). Here we present work to develop a full, semi-automated prescription for candidate selection, targeted follow-up photometry, cataloging, and classification, which allows the review of approximately 25 variable candidates every two weeks. We make comparisons of our sample selection and purity from a similar study based on Pan-STARRS data (Hernitschek et al. 2016), as well as candidates identified in Gaia DR1. The goal, through continued observation and analysis, is to identify at least 10,000 new variables, hundreds of which will be new Cepheid and RR Lyrae stars.

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Institution(s): *1. Johns Hopkins University, 2. NOAO, 3. Space Telescope Science Institute , 4. Villanova University, 5. Western Kentucky University*

152.07 – The Search for RR Lyrae Variables in the Dark Energy Survey

RR Lyrae variables are stars with a characteristic relationship between magnitude and phase and whose distances can be easily determined, making them extremely valuable in mapping and analyzing galactic substructure. We present our method of searching for RR Lyrae variable stars using data extracted from the Dark Energy Survey (DES). The DES probes for stars as faint as i = 24.3. Finding such distant RR Lyrae allows for the discovery of objects such as dwarf spheroidal tidal streams and dwarf galaxies; in fact, at least one RR Lyrae has been discovered in each of the probed dwarf spheroidal galaxies orbiting the Milky Way (Baker & Willman 2015). In turn, these discoveries may ultimately resolve the well-known missing satellite problem, in which theoretical simulations predict many more dwarf satellites than are observed in the local Universe. Using the Lomb-Scargle periodogram to determine the period of the star being analyzed, we could display the relationship between magnitude and phase and visually determine if the star being analyzed was an RR Lyrae. We began the search in frequently observed regions of the DES footprint, known as the supernova fields. We then moved our search to known dwarf galaxies found during the second year of the DES. Unfortunately, we did not discover RR Lyrae in the probed dwarf galaxies; this method should be tried again once more observations are taken in the DES.

Author(s): Chandler Nielsen[1], Jennifer L. Marshall[2], James Long[2]
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152.08 – KELT RR Lyrae Variable Stars Observed by NKU Schneider and Michigan State Observatories

In this poster we will discuss our ongoing program to use extant light curves from the Kilodegree Extremely Little Telescope (KELT) survey to find and characterize RR Lyrae (RRL) stars in the disk and inner halo of the Milky Way. RRL stars are of particular interest because they are standard candles and can be used to map out structure in the galaxy. The periods and shape of RRL light curves also contain information about their Oosterhoff type, which can probe galactic formation history, and metallicity respectively. Although there have been several large photometric surveys for RR Lyrae in the nearby galaxy (OGLE, NSVS, ASAS, and MACHO to name a few), they have each been limited in either sky coverage or number of epochs. The KELT survey represents a new generation of surveys that has many epochs over a large portion of the sky. KELT samples over 70% of the entire sky, and has a long-time-baseline of up to 11 years with a very high cadence rate of less than 20 minutes. This translates to upwards of 11,000 epochs per light curve with completeness out to 3 kpc from the Sun. This poster will present follow-up multi-color photometry taken of RR Lyrae candidate stars found in the KELT survey. These stars were observed using an 11inch telescope at the NKU Schneider Observatory. We also have archival photometry of these stars from the Michigan State Observatory. We will discuss photometric accuracies, cadence, and initial analysis of these stars. We will also discuss the capabilities of our new observatory as well as future follow-up and analysis plans.

Author(s): Nathan M. De Lee5, Stacy Brueneman5, Logan Hicks5, Neil Russell5, Karen Kinemuchi[1], Joshua Pepper3, Joseph Rodriguez[2], Martin Paegert[2], Horace A. Smith4
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152.09 – Reddening determination of RR Lyrae from small scale observations

We present an update on our program to conduct research-quality observations from an urban site. The UM-Dearborn Observatory lies at sea level on a small campus within the Detroit metropolitan area, with a 0.4m-aperture main telescope. The observatory equipment and location (and therefore the observing challenges presented) are typical for many higher education establishments; however, with minor adjustments, research-quality datasets can be produced from a site like ours, as we demonstrate here. RR Lyrae stars have long been seen to be attractive targets for small to moderate aperture telescopes, and observing programs including these objects have yielded important information about their characteristics. We focus our work on RR Lyrae stars, using their lightcurves and colors at minimum light to estimate intrinsic properties of the objects and also the reddening towards them. We establish feasibility by observing the relatively well-studied objects RW Dra and VZ Her, and are extending the project to a number of less-studied RR Lyrae objects.

Author(s): Lucas Stahl[1], Donald J. Bord[1], William I. Clarkson[1]
Institution(s): *1. University of Michigan - Dearborn*

152.10 – Evidence for Binarity in Kepler Observations of the Pulsating RV Tau Variable DF Cygni

We present a detailed study of the RV Tau variable star, DF Cygni, using high-precision light curve observations from Kepler. Kepler's light curve of DF Cyg is unparalleled in precision and cadence for any RV Tau star to date. The Kepler light curve spans a baseline of ~4 years and clearly displays the signature pulsational behavior of alternating deep and shallow minima as well as the long-term trend indicative of an RVb-type variable. We measure DF Cyg's formal period (the time interval between two successive deep minima) to be 49.84 +/- 0.02 days. Using the consistency of the pulsations from DF Cyg, we study the arrival times of each minimum throughout the light curve. A trend in the arrival times emulates that of the long-term period. There appear to be precisely 16 deep+shallow minima cycles in one long-term cycle, suggesting a long-term cycle period of ~797 days. We argue that binarity may naturally explain the long-term variability in DF Cyg. The spectral energy distribution of DF Cyg features an infrared excess indicative of a disk possibly linked to a binary companion. From kinematics and geometric arguments we consider whether the decrease in flux from the long-term maximum to long-term minimum, as well as the reduction of the short-term pulsation amplitude, could be caused by an occulting body such as a disk passing across DF Cyg.

Author(s): Laura D. Vega3, Rodolfo Montez Jr.[2], Keivan G. Stassun3, Patricia T. Boyd[1]
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152.11 – O-C analysis of the pulsating subdwarf B star PG 1219 + 534

PG 1219 + 534 (KY Uma) is a subdwarf B pulsating star with multiple periodicities between 120 – 175 s. So far, the most promising theory for the origin of subdwarf B (sdB) stars is that they result from binary mass transfer near the Helium Flash stage of evolution. The observations of PG 1219 +534 reported here are part of our program to constrain this evolutional theory by searching for companions and determining orbital separations around sdB pulsators using the Observed-minus-Calculated (O-C) method. A star's position in space will wobble due to the gravitational forces of any companion or planet. If the star emits a periodic signal like pulsations, its orbital motion around the system's center of mass causes periodic changes in the light pulse arrival times. PG 1219 + 534 was monitored for 90 hours during 2010-1 and 2016 using the 0.9m SARA-KP telescope at Kitt Peak National Observatory (KPNO), Arizona, and the 0.8 m Ortega telescope at Florida Institute of Technology in Melbourne. In this poster we present our time-series photometry and O-C analysis of this data.

Author(s): Tomomi Otani[1], Alexander Stone-Martinez[1], Terry D. Oswalt[1], Claudia Morello[1], Adam Moss[1], Dana Singh[1], Kenneth Sampson[1], Caila DeAbreu[1], Aliyah Khan[1], Austin Seepersad[1], Mehvesh Shaikh[1], Linda Wilson[1]
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152.12 – Radiative Transfer Modeling of the Mid-IR/Far-IR Dust Emissions of the Symbiotic Mira, V* R Aqr

We present RADMC-3D models of the symbiotic system V* R Aqr, which consists of a Mira variable and white dwarf. Thermal radiative transfer modeling is performed using RADMC-3D to characterize the mid-IR/far-IR Spectral Energy Distributions (SEDs) of the system at two different phases of the visible light curve. Near maximum visible light (Mira phase of 1.0), we utilize the Infrared Space Observatory (ISO) Short Wave Spectrometer/Long Wave Spectrometer observations (2.3 - 197 mu-m) and contrast them to the recently obtained near minimum visible light (~0.4 Mira phase) observations from the Stratospheric Observatory for Infrared Astronomy (SOFIA)/Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST) (6.4 - 37.1 mu-m). Initial spectra and photometry from the SOFIA/FORCAST observations of the central Mira indicate that flux values are about 50% of that measured by the ISO SWS/LWS observations. Dust models utilizing a spherical shell and amorphous silicates are used to generate synthetic SEDs, which are compared with the ISO and FORCAST observations in order to constrain the properties of the shell (such as its dust mass and temperature) at different phases of the Mira variability. Our proposed monitoring of the V* R Aqr system will establish a characterization baseline of the SEDs as the system approaches its upcoming eclipse and periastron passage.

Author(s): Eric B. Omelian3, Ravi Sankrit4, L. Andrew Helton4, Uma Gorti[2], R. Mark Wagner[1]
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152.13 – Period Analysis of Three SRS: Stars in the Kepler Field

As a portion of a larger project to observe SemiRegular Variable Stars in the original Kepler field, our research group is analyzing the light curve of three objects currently classified as SRS: stars in the GCVS, meaning that they possible members of the newer classification of Semi Regular variables of Short periods. We will present our analysis of the Kepler data to date. In particular these targets presented some interesting challenges to the standard analysis pipeline and we will present the steps taken to work around these challenges.

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Author(s): Wesley Red[1], Gabrielle Jones[1], Jennifer Cash[1], Donald K. Walter[1]
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152.14 – A Testing Ground for Polarized Maser Transport: Multi-Epoch Analysis of a π/2 Electric Vector Rotation

The near circumstellar environment (NCSE) around Asymptotic Giant Branch (AGB) stars is chaotic, exhibiting shocks, turbulence, velocity gradients, and a potentially dynamically significant magnetic field (Vlemmings et al. 2005). Very Long Baseline Interferometry (VLBI) of masers emanating from these environments can provide sub-milliarcsecond angular resolution of the NCSE (Kemball 2002). Solidifying the origin of the polarization in these masers may be the key to understanding the magnitude and behavior of these stars' magnetic fields (eg. Goldreich et al. 1973; Elitzur 1996). However, other theories of polarized maser transport do not rely heavily on the magnetic field; some are more dependent on anisotropic pumping (Elitzur 1996; Watson 2009) or anisotropic resonant scattering (Asensio Ramos et al. 2005; Houde 2014). One optimal test of these theories is their ability to account for a π/2 rotation of the Electric Vector Position Angle (EVPA) observed in some maser features. The profile of linear polarization across such a feature varies with the generating mechanism. In this study, we utilize multi-epoch observations of $v=1$, $J=1\text{-}0$ SiO maser emission around TX Cam (Diamond & Kemball 2003; Kemball et al. 2009; Gonidakis et al. 2010) to analyze a single feature with a π/2 rotation that persisted for five epochs and compare it to the behavior expected according to various theories of maser polarization. In addition, we analyze the low levels of circular polarization - now achievable due to recent improvements in millimeter-wavelength circular polarization reduction (Kemball & Richter 2011) - and compare their correlation with other parameters to further test these polarization generation theories.

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153 – Star Formation Poster Session

153.01 – Probing turbulent, magnetized star formation with ALMA observations and next-generation AREPO simulations

The first polarization data from ALMA have been delivered, and are both expanding and confounding our understanding of the role of magnetic fields in low-mass star formation. Here I will show the highest resolution and highest sensitivity polarization images ever made of a Class 0 protostellar source. These new ALMA observations of the source, known as Ser-emb 8, achieve 140 AU resolution, allowing us to probe polarization -- and thus magnetic field orientation -- in the innermost regions surrounding the protostar. The collapse of strongly magnetized dense gas is predicted to pinch the magnetic field into an hourglass shape that persists down to scales <100 AU. However, in contrast with more than 50 years of theory, the ALMA data definitively rule out an hourglass morphology and instead reveal a chaotic magnetic field that has not been inherited from the field in the interstellar medium surrounding the source. We have simulated the star formation process with cutting-edge, moving-mesh AREPO simulations on scales from a million AU (5 pc) down to 60 AU. We find that only in the case of a very strong magnetic field (~100 microgauss on 5 pc scales) is the field direction preserved from cloud to disk scales. When the field is weak, turbulence in the interstellar gas shapes the field on large scales, and the forming star system re-shapes the field again on small scales, divorcing the field from its history on larger scales. We conclude that this is what has happened in Ser-emb 8. The main distinction from the strong-field star formation model is that in the weak-field case it is turbulence -- not the magnetic field -- that shapes the material that forms the protostar.

Author(s): Charles L. H. Hull[2], Philip Mocz[2], Blakesley K. Burkhart[2], Josep Miquel Girart[1], Alyssa A. Goodman[2], Paulo Cortes5, Zhi-Yun Li[6], Shih-Ping Lai4, Lars Hernquist[2], Volker Springel3
Institution(s): *1. CSIC-IEEC, 2. Harvard-CfA, 3. HITS, 4. National Tsing Hua University, 5. NRAO, 6. University of Virginia*

153.02 – Simulating Stellar Cluster Formation and Early Evolution

We present our current development of a model of stellar cluster formation and evolution in the presence of stellar feedback. We have integrated the MHD code Flash into the Astrophysical Multi-Use Software Environment (AMUSE) and coupled the gas dynamics to an N-body code using a Fujii gravity bridge. Further we have integrated feedback from radiation using the FERVENT module for Flash, supernovae by thermal and kinetic energy injection, and winds by kinetic energy injection. Finally we have developed a method of implementing star formation using the Jeans criterion of the gas. We present initial results from our cluster formation model in a cloud using self-consistent boundary conditions drawn from a model of supernova-driven interstellar turbulence.

Author(s): Joshua Wall[2], Stephen L. W. McMillan[2], Mordecai-Mark Mac Low[1], Juan Ibañez-Mejia4, Simon Portegies Zwart3, Andrew Pellegrino[2]
Institution(s): *1. American Museum of Natural History, 2. Drexel University, 3. Leiden Observatory, 4. University of Cologne*

153.03 – Is Episodic Accretion Necessary to Resolve the Luminosity Problem in Low-Mass Protostars?

In this contribution, we compare the results of protostellar accretion simulations for scenarios both containing and lacking episodic accretion activity. We determine synthetic observational signatures for collapsing protostars by taking hydrodynamical simulations predicting highly variable episodic accretion events, filtering out the stochastic behavior by applying power law fits to the mass accretion rates onto the disk and central star, and using the filtered rates as inputs to two-dimensional radiative transfer calculations. The spectral energy distributions generated by these calculations are used to calculate standard observational signatures of L_{bol} and T_{bol}, and compared directly to a sample of 230 embedded protostars. We explore the degree to which these continually declining accretion models successfully reproduce the observed spread of protostellar luminosities, and examine their consistency with the prior variable models to investigate the degree to which episodic accretion bursts are necessary in protostellar formation theories to match observations of field protostars.

The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. 1262851, and by the Smithsonian Institution.

Author(s): Raymond Andrew Sevrinsky[1], Michael Dunham[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

153.04 – Predicting Complex Organic Molecule Emission from TW Hya

The Atacama Large Millimeter/submillimeter Array (ALMA) has significantly increased our ability to observe the rich chemical inventory of star and planet formation. ALMA has recently been used to detect CH_3OH (methanol) and CH_3CN (methyl cyanide) in protoplanetary disks; these molecules may be vital indicators of the complex organic ice reservoir in the comet-forming zone. We have constructed a physiochemical model of TW Hya, a well-studied protoplanetary disk, to explore the different formation mechanisms of complex ices. By running our model through a radiative transfer code and convolving with beam sizes appropriate for ALMA, we have obtained synthetic observations of methanol and methyl cyanide. Here, we compare and comment on these synthetic observations, and provide astrochemical justification for their spatial distributions.

Author(s): Shreyas Vissapragada[1], Catherine Walsh[2]
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153.05 – Modeling Protostar Envelopes and Disks Seen With ALMA

Thermal continuum emission from protostars comes from both the envelope and circumstellar disk. The dust emits on a variety of spatial scales, ranging from sub-arcseconds for disks to roughly 10 arcseconds for envelopes for nearby protostars. We present models of what ALMA should detect that incorporate a self-consistent collapse solution, radiative transfer, and realistic dust properties.

Author(s): Susan Terebey[1], Lizxandra Flores-Rivera[1], Karen Willacy[2]
Institution(s): *1. Cal. State Univ. at Los Angeles, 2. Jet Propulsion Lab*

153.06 – 3-D MHD disk wind simulations of jets and outflows from high-mass protostars

We present the results of a series of nested, large scale, three-dimensional magnetohydrodynamics simulations of disk winds with a Blandford-Payne like magnetic field configuration, resolving scales from the stellar surface to beyond the core. The goal is to understand the structure of massive protostellar cores at various stages of their formation as the protostellar mass grows from a massive core. At each stage of a given protostellar mass, first, we study how jets and winds develop from the inner accretion disk to ~100 AU scales. We use the results from these simulations to dictate the inner boundary condition of a set of simulation extending to the core boundary at ~10,000 AU of an initially 60 solar mass core. We run separate simulations where the protostellar mass is 1, 2, 4, 8, 12, 16, and 24 Msun, and we are working on making a small grid of models in the context of the Turbulent Core Model with three different core masses and three different core surface densities. The wind is blown into the simulation box with properties derived from the previous jet simulations. We examine the opening angle of the outflow cavity and thus the star formation efficiency from the core due to outflow feedback. We find that the opening angle increases as the protostellar mass grows, but it is always less than 10 degrees, which is surprisingly small compared with previous analytic models. This is caused by the core which confines the outflow. Finally, we use our simulation results as input to a radiative transfer calculation, to compare with observations made by the SOMA survey.

Author(s): Jan E. Staff3, Kei Tanaka[2], Jonathan C. Tan[2], Yichen Zhang[1], Mengyao Liu[2]
Institution(s): *1. RIKEN, 2. University of Florida, 3. University of the Virgin Islands*

153.07 – Argus: a new 16-pixel millimeter-wave spectroscopic instrument for star formation studies at the Green Bank Telescope

Argus is a new 16-pixel W-band focal plane array for millimeter spectroscopy at the Green Bank Telescope (GBT). Built by a consortium led by Sarah Church at Stanford, this new instrument provides fast astronomical imaging over the 75–116 GHz band and at high spatial resolution. The frequency range covered by Argus is of particular interest for star formation studies and will be excellent at probing cold, dense cores within star-forming regions, along with constraining the dynamics of filamentary structures withing giant molecular cloud complexes. In particular, the 3mm band covers a large number of important spectral lines, including CO (J=1-0) and its isotopologues, as well as HCO+, H13CO+, SiO, N2H+, HCN and HNC. These molecular transitions trace a combination of dense cold gas, shocked emission from jets and outflows as well as the signatures of infall, all of which are imperative constituents in the early stages of star formation. Argus on the GBT will provide the high sensitivity of a filled aperture along with a high angular resolution of 6-10", this resolution is well-matched to the mid- and far-infrared observations from the Spitzer, SOFIA, and Herschel telescopes. We report on the current status of Argus and present recent commissioning and early science highlights from Argus of 12CO, 13CO and HCO+ emission towards the massive star forming region, DR 21. Argus, currently under commissioning, is expected to be in full science mode in the winter semester of 2016.

Author(s): Nichol Cunningham[2], David T. Frayer[2], Sarah E. Church4, Matthew Sieth4, Andrew I. Harris5, Kieran Cleary[1], Joshua O. Gundersen[6], Paul Goldsmith3, Dongwoo Chung4, Anthony C. S. Readhead[1], todd gaier3, Pekka Kangaslahti3, Lorene Samoska3
Institution(s): *1. California Institute of Technology, 2. Green Bank Observatory, 3. Jet Propulsion Laboratory, 4. Stanford University, 5. University of Maryland, 6. University of Miami*

153.08 – An LMT/AzTEC 1.1 mm Survey of Dense Cores in the Monoceros R2 Giant Molecular Cloud

We present a census of dense gas cores in the MonR2 Giant Molecular Cloud with observations from the AzTEC instrument on the Large Millimeter Telescope (LMT) at λ = 1.1 mm. We detect 270 cores total, 84 with protostars, and 186 starless. AzTEC's excellent 8′′resolution allows for the identification of discrete 1.1 mm sources about 0.05 × 0.05 pc in size in this distant (830 pc) cloud. After performing total flux and half-power area corrections for under-detected low S/N cores, we find that the cores have a median mass ~ 2.8 M⊙ and a median deconvolved FWHM size ~ 0.09 pc. 58% of the cores (154) lie above the Bonnor-Ebert mass versus size stability line for cores with T~12K, suggesting they are unstable to further collapse. Bonnor-Ebert, Plummer-like, and Gaussian models are fit to 1-D and 2-D core radial column density profiles, with Plummer-like performing the best fit of the three models. We present a correlation between local core mass density and column density of gas (as traced by Herschel) characterized by a steep power-law that flattens above Σgas ~ 62 M⊙pc−2 (4.15 AV)smoothing over parsec scales. This core-gas correlation's resemblance to the star-gas correlation for YSOs in Gutermuth et al. (2011) yields an approximate Mstar ~ 0.4Mcore and indicates that stellar clustering is likely set by core clustering. Finally we derive an estimated global core formation efficiency that increases with increasing Herschel column density and asymptotically approaches CFE ~ 0.4 for AV > 15.

Author(s): Alyssa D Sokol[2], Robert A. Gutermuth[2], Grant Wilson[2], Stella Offner[2], Mark H. Heyer[2], Riwaj Pokhrel[2], Arturo Gomez-Ruiz[1], Abraham Luna[1]
Institution(s): *1. National Institute of Astrophysics, Optics and Electronics, 2. University of Massachusetts Amherst*

153.09 – High Resolution 33 GHz Observations of Embedded Star Formation in NGC 6240

Galaxy mergers provide an opportunity to understand star formation in extreme environments. These conditions were common in the early Universe when galaxy collisions were more prevalent. In this study, we observed the luminous infrared galaxy merger NGC 6240 at 33 GHz using the Very Large Array with the goal of estimating its star formation rate and star formation rate surface density. At 33 GHz, the galaxy is optically-thin, allowing us to peer into the active nuclear regions of the galaxy. We measure a star formation rate of 120 solar masses per year and a star formation surface density of 0.5-1x10^12 solar luminosities per kpc^2. Thus, although the nuclei of NGC 6240 contain active supermassive black holes, they are essentially Orion star-forming cores spread over their central half kpc.

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Institution(s): *1. Fisk-Vanderbilt Bridge Student, 2. National Radio Astronomy Observatory, 3. University of Virginia*

153.10 – The Dense Gas Fraction in the Central Molecular Zone in the Milky Way

The Central Molecular Zone (CMZ), a large reservoir of dense molecular gas occupying the central 500pc of the Milky Way, is an extreme star-formation environment where the validity of star formation prescriptions can be tested. The star formation rate (SFR) in the CMZ is about an order of magnitude lower than predicted by the currently accepted prescriptions. An international team lead by PIs Battersby and Keto conducted a survey from 2013-2016 called CMZoom using the Submillimeter Array (SMA) to characterize star formation within resolved molecular clouds in this extreme region. One of the main goals of this survey is to further quantify and understand the low SFR found in this region of the Galaxy. Here, we use the CASA software package to run synthetic observations of hydrodynamical simulations of molecular clouds and vary the observation parameters in such a way that we explore the real parameter space that was probed during the survey. The purpose of this is to investigate how the different observational parameters affect the resultant data. Afterwards, we estimate the "dense gas fraction" (DGF) found in regions across the CMZ. This estimate was found by using the interferometric flux from SMA and the single-dish flux from the Bolocam Galactic Plane Survey. We analyzed the effects that different locations of the CMZ had on these approximate DGF. With these simulations and DGF estimates, we are able to generate improved methods to analyze the data from this survey that will help understand star formation in an extreme environment.

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Contributing team(s): CMZoom

153.11 – Interactions of mid-infrared bubbles with the interstellar medium: are bubble rims associated with collapsing cores?

Mid-infrared bubbles expanding into the interstellar medium (ISM) are often proposed as a trigger for subsequent star formation, although the mechanisms of this triggering are not well understood. Better observational data of the ISM near bubbles can elucidate the connection between bubbles and nearby star formation. We used the VEGAS spectrometer on the Green Bank Telescope to simultaneously observe several Q-band emission lines between 45-49 GHz. We detected HC_3N, C34S, CH_3OH, and CS toward four mid-infrared (MIR) bubbles. Two of the bubbles are spatially coincident with dark filaments. We show that in both of these cases, the bubbles do not appear to be causing infall in the filaments. We also present the gas kinematics toward two gas clumps coincident with bubble rims. Both clumps show evidence of infall. Finally, we present trends seen in the chemical abundances relative to the bubble.

Author(s): Kathryn E. Devine[1], Johanna Mori[1], Christer Watson[2]
Institution(s): *1. College of Idaho, 2. Manchester University*

153.12 – Stars and Star Clusters: A Look at Intermediate-Mass Star-Forming Regions

Star-forming regions hosting intermediate-mass stars straddle the boundary separating the the low- and high-mass regimes. These intermediate-mass star-forming regions can be used to probe this transition from low- to high-mass star formation. Our team has assembled an all-sky catalog of 616 candidate intermediate-mass star forming regions (IMSFRs) selected by IRAS colors and refined by visual inspection of WISE imagery. We present here two outer-Galaxy star-forming regions, IRAS22451+6154 and IRAS23448+6010, that despite having similar IRAS colors and mid-infrared morphologies, have vastly different stellar content. We combine Gemini and IRTF NIR spectroscopy with WIYN and SOFIA imaging for a thorough look at the stellar content of these two regions.

Author(s): Michael J. Lundquist[1], Henry A. Kobulnicky3, Ryan M. Lau[2]
Institution(s): *1. Gemini Observatory, 2. Jet Propulsion Laboratory, 3. University of Wyoming*

153.13 – Investigating Star-Gas Correlation and Evolution in the 100pc Cygnus X Complex

We present a new analysis of the 25 square degree Cygnus-X Spitzer Legacy Survey. At 100 pc across and over a million solar masses, the Cygnus X molecular cloud complex is a true giant, dwarfing the nearby Orion clouds by an order of magnitude in mass. With our updated reduction of the mid-IR imaging survey and inclusion of UKIDSS near-IR photometry, we have produced a new catalog of over 20,000 young stellar objects with IR excess emission. In addition, we have constructed an associated completeness mapping product that characterizes relative sensitivity as a function of luminosity and spectral energy distribution shape. We will present early analysis from these new data products and extant maps of gas column density from the FCRAO 14m telescope that aims to explore environmental effects on the star-gas correlation at a range of size scales.

Author(s): Robert A. Gutermuth[1], Mark H. Heyer[1], Stella Offner[1]
Institution(s): *1. Univ. of Massachusetts*

153.14 – ATLASGAL: Chemical evolution of star forming clumps

Although massive stars are few in number, they impact their host molecular clouds, clusters, and galaxies in profound ways, playing a vital role in regulating star formation in their host galaxy. Understanding the formation of these massive stars is critical to understanding this evolution, but their rapid early development causes them to reach the main sequence while still shrouded in their natal molecular cloud. Many studies have investigated these regions in a targeted manner, but a full understanding necessitates a broader view at all stages of formation across many star forming regions.

We have used mid-infrared continuum surveys to guide selection of a statistically large sample of massive dust clumps from the 10,000 such clumps identified in the ATLASGAL Compact Source Catalogue (CSC), ensuring that all stages of the evolutionary process are included. A final sample of 600 fourth-quadrant sources within 1 degree of the Galactic plane were observed with the Mopra telescope with an 8 GHz bandwidth between 85.2 and 93.4 GHz.

We present an overview of our results. We have identified over 30 molecular lines, seven of which with detected hyperfine structure, as well as several mm-radio recombination line transitions. Source velocities indicate that these regions trace the Crux-Scutum, Norma, and Carina Sagitarius arms. We have performed an analysis of linewidth and line intensity ratios, correlating these with star formation stages as identified by IR brightness at the 70 and 24 µm bands, and present several molecular pairs whose linewidth and intensity might serve as significant tracers of the evolutionary stage of star formation. We comment on the results of PCA analysis of the measured parameters for the overall population and the star formation stage subgroups with an eye toward characterising early stellar development through molecular line observations.

Author(s): Charles C. Figura[3], James S Urquhart[2], Friedrich Wyrowski[1]
Institution(s): *1. Max Planck Institute for Radio Astronomy, 2. University of Kent, 3. Wartburg College*

153.15 – A Star-Formation Rate Atlas of the Nearby Universe

We present our work in constructing a star-formation rate (SFR) atlas of nearby galaxies. We utilize GALEX far-ultraviolet (FUV) data and Spitzer 24 micron data to compute the SFR map of each galaxy using the relation described in Leroy et al. (2008). For each galaxy, the 24 micron data were downloaded from the Spitzer Heritage Archive and subjected to outlier and overlap corrections through the automated Spitzer pipeline MOPEX. The FUV images were constructing using gphoton, and we then performed background subtraction using source-free regions away from the galaxy. These SFR maps represent an attempt to systematically characterize the local SFR in nearby galaxies, which we will then use to explore the relationship of SFR to the incidence of other phenomena such as supernovae and ultraluminous X-ray sources. We will make all SFR maps available to the community.

Author(s): Tristan Ashton[2], David Pooley[2], Saul A. Rappaport[1]
Institution(s): *1. MIT, 2. Trinity University*

153.16 – How Does Dense Molecular Gas Contribute to Star Formation in the Starburst Galaxy NGC 2146?

The starburst galaxy NGC 2146 is believed to have been formed approximately 800 Myr ago, when two galaxies collided with each other possibly leading to a burst of star formation. NGC 2146 is known as a starburst galaxy for the high frequency of star formation going on in its molecular clouds. These clouds serve as nurseries for star formation to occur. Hydrogen Cyanide (HCN) and Carbon monoxide (CO) are molecules found in molecular gas clouds. HCN molecules are tracers for high density star forming gas. Whereas, CO molecules are tracers for low density star forming gas. In this project, we are observing these two molecules and their proximity to where the stars are forming in the galaxy to determine if the star formation is occurring in the same area as the high and low density molecular gas areas in starburst galaxy NGC 2146.

Author(s): Alia Wofford[1]
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154 – Stellar Evolution, Stellar Populations Poster Session

154.01 – Comparing Stellar Populations of Galaxies Across the Hubble Sequence

From analysis of radial color gradients, it has been found that many late-type galaxies tend to become redder further out from the center of the galaxy (add references here). There are no feasible galaxy formation models that predict high metallicity in the outskirts of late-type galaxies, and these galaxies tend to show little evidence for significant amounts of dust at large radii. We therefore hypothesize the radial color gradients are primarily affected by stellar population ages. We observed irregular, elliptical, and spiral galaxies with the Infrared Sideport Imager (ISPI) on the 4-meter Blanco Telescope of Cerro Tololo Inter-American Observatory (CTIO) in Chile, using the J, H, and Ks near-infrared (NIR) filters. Elliptical aperture photometry was performed to obtain radial profiles of surface brightness, and of J-H and H-Ks colors. We analyze the relative contributions of stellar population ages, dust extinction and stellar metallicity to the radial color gradients. Detailed information like that gathered from this research, when expanded to statistical samples of nearby galaxies spanning a range of types, masses, and luminosities, is useful for comparison to studies of high-redshift galaxies and can serve as an observational benchmark that galaxy formation and evolution models must be able to reproduce.

Author(s): Sarina Marie Etheridge[2], Catherine Kaleida[3], Rolf Jansen[1]
Institution(s): *1. Arizona State University, 2. College of Charleston, 3. Space Telescope Science Institute*

154.02 – Kinematics of Hα Emitting Stars in Andromeda

Studying emission line stars helps improve our understanding of stellar evolution, types of stars, and their environments. In this study, we analyzed stars exhibiting Hα emission (Hα stars) in the Andromeda Galaxy. We used a combination of spectroscopic and photometric diagnostic methods to remove a population of foreground Milky Way (MW) star contaminants from our data set. The Hα stars were selected from a sample of 5295 spectra from the Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo (SPLASH) survey and accompanying photometric data from the Panchromatic Hubble Andromeda Treasury (PHAT) survey. Velocities of two classes of Hα stars, main sequence (MS) stars and asymptotic giant branch (AGB) stars, were analyzed through a novel Age-Velocity Difference Correlation (AVDC) method, which utilizes line-of-sight velocity differences (LOSVDs) in order to estimate the age of a rare stellar population. Histograms, weighted means, and weighted standard deviations of the LOSVDs were used to conclude that MS stars are more kinematically coherent than AGB stars, and that Hα stars are kinematically comparable and thus close in age to their non-Hα counterparts. With these results, it can definitively be inferred that mass loss is important in two stages of stellar evolution: massive MS and intermediate mass AGB. We hypothesized that this mass loss could either occur as a normal part of MS and AGB evolution, or that it could be emitted by only a subpopulation of MS and AGB stars throughout their life cycle. Our use of the novel AVDC method sets a precedent for the use of similar methods in predicting the ages of rare stellar subgroups.

This research was supported by NASA and the National Science Foundation. Most of this work was carried out by high school students working under the auspices of the Science Internship Program at UC Santa Cruz.

Author(s): Megha Ilango[1], Anita Ilango[1], Gabriel Damon[3], Laura Prichard[2], Puragra Guhathakurta[4]
Institution(s): *1. Cupertino High School, 2. Oxford University, 3. Santa Cruz High School, 4. UC Santa Cruz*
Contributing team(s): PHAT collaboration, SPLASH collaboration

154.03 – A Mysterious Population of Stars With Weak CN Absorption in the Disk of M31

From our study of certain stars in the Andromeda Galaxy, we found stars with clear evidence of the molecule cyanogen (CN) alongside molecules typically in oxygen-rich stars (TiO, Calcium) in their atmospheres. The juxtaposition of these molecules is amplified by our observation that stars do not normally simultaneously exhibit carbonaceous and oxygenaceous molecules. Due to the less apparent presence of CN in these stars compared to carbon stars, we initially named these stars 'weak CN' stars and assumed a relationship between these stars and carbon stars. To further deepen our understanding of the characteristics of these stars, we measured and analyzed their spectroscopic data, position on Color Magnitude Diagrams, variations in velocity, and placement in evolutionary stellar models. While spectra of weak CN and carbon stars indicated a shared presence of CN in both star groups, the placements of these stars on color magnitude diagrams suggested that these two populations are unrelated due to variations in brightness and temperature. Additional analyses of velocity, based on an observed correlation between velocity dispersion and age of a star (Dorman 2015), further implied that these weak CN stars are a younger and clearly separate group of stars. Finally, using stellar models to track changes in temperature and luminosity of stars over time, we mapped positions of weak CN stars to a region on the evolutionary path of massive stars. Based on our knowledge of this region, we found sufficient evidence to conclude that weak CN stars are part of a relatively unknown, young evolutionary phase of massive stars called red core Helium burning (RCHeB) stars. Over the course of our research, we also built a detection program to identify other weak CN stars based on their subtle spectral features. In the future, we hope to apply other limitations based on our knowledge of red core Helium burning stars to refine our search and expand our knowledge on this population of stars.

Author(s): Anika Kamath3, Alyssa Sales2, Atmika Sarukkai2, Puragra Guhathakurta5, Jon Hays1, Philip Rosenfield4
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Contributing team(s): SPLASH collaboration, PHAT collaboration

154.04 – The Red Supergiant Content of the LMC and SMC

We have investigated the red supergiant (RSG) population of the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC) through a radial velocity survey of 309 candidate RSGs in the LMC and 356 in the SMC, confirming the presence of 304 RSG in the LMC and 316 in the SMC. Using these spectra, we have measured effective temperatures and spectral types for each confirmed RSG. These data allow us to compare our sample of stars with the Geneva model evolutionary tracks. This work has been partially supported by the National Science Foundation AST-1612874.

Author(s): Kate Anne Evans1, Philip Massey1
Institution(s): *1. Lowell Observatory*

154.05 – Stellar Evolution of the Star Cluster NGC 602 and Massive Star Formation in the Low-Density Wing of the SMC

The young star cluster NGC 602 and its surroundings in the Wing of the Small Magellanic Cloud (SMC) exhibit active star formation despite the sparse supply of dense gas from which to form stars. This region is also associated with the huge ionized gas ring DEM167 in the SMC. Using archival optical photometric data from the Uppsala Schmidt Telescope and new near-UV photometric data from the Galaxy Evolution Explorer, we determine the colors and consequently the relative ages of ~1000 stars in this region. Furthermore, we incorporate spectra obtained with the ESO-VLT to more accurately determine the properties of luminous massive stars. These measurements are combined to explore the recent star formation history of this region near the tip of the SMC and to study how the young stellar populations relate to the ISM.

Author(s): Leah Fulmer2, Lida Oskinova1, Varsha Ramachandran1, Wolf-Rainer Hamann1, John S. Gallagher2
Institution(s): *1. Universität Potsdam - Institut für Physik, 2. University of Wisconsin - Madison*

154.06 – M dwarfs kink and TPAGB in the MIST and PARSEC Infrared Isochrones

We look into the “kink” feature along the main-sequence in the infrared color-magnitude diagrams and have compared to the observational data of several milky way globular clusters. Moreover, the effects of thermally pulsing asymptotic giant branch stars on the surface brightness fluctuation magnitudes and broadband colors are calculated and contrasted to the early-type galaxies. The latest version of MIST and PARSEC isochrones is employed for these studies.

Author(s): Hyun-chul Lee3, Jose Ortiz2, Dionicio Garza2, Wendy Montano1, Jessica Garza3, Iannelly Bernal3
Institution(s): *1. Nikki Rowe High School, 2. Robert Vela High School, 3. The University of Texas Rio Grande Valley*

154.07 – Rotation in Praesepe with K2

K2 observed Praesepe (=Beehive cluster=M44) in 2015, enabling determination of stellar rotation rates of more members, to smaller amplitudes and with a far better cadence, than has even been probed before. We find periods for ~86% of the members for which we have light curves. We can compare similar stars in Praesepe (~700 Myr) and the Pleiades (~125 Myr), all with K2 light curves. The distribution of P and V-K (as a proxy for mass), for stars earlier than mid-M (V-K~5), evolves considerably; stars later than that have little change from the Pleiades. As we could in the Pleiades, in Praesepe we can measure not only rotation periods but also study the shape of the light curves and to often detect evidence of multiple periods due to differential rotation, spot evolution, and/or binarity. About 30% of the members with rotation periods in both clusters have clear indications of more than one period in the light curve.

Author(s): Luisa M. Rebull1, John R. Stauffer1
Institution(s): *1. Caltech*
Contributing team(s): K2 Clusters Team

154.08 – Isochrone Fitting of Hubble Photometry in UV-Vis Bands

We present the results of isochrone fitting of color-magnitude diagrams from Hubble Space Telescope Wide Field Camera 3 (WFC3) and Advanced Camera for Surveys (ACS) photometry of the globular clusters M13 and M80 in five bands from the ultraviolet to near infrared. Fits from both the Dartmouth Stellar Evolution Program (DSEP) and the PAdova and TRieste Stellar Evolution Code (PARSEC) are examined. Ages, extinctions, and distances are found from the isochrone fitting, and metallicities are confirmed. We conduct careful qualitative analysis on the inconsistencies of the fits across all of the color combinations possible with the five observed bands, and find that the (F606W-F814W) color generally produces very good fits, but that there are large discrepancies when the data is fit using colors including UV bands for both models. Finally, we directly compare the two models by performing isochrone-isochrone fitting, and find that the age in PARSEC is on average 1.5 Gyr younger than DSEP for similar-appearing models at the same metallicity, and that the two models become less discrepant at lower metallicities.

Author(s): Hallie Barker1, Nathaniel Paust1
Institution(s): *1. Whitman College*

154.09 – Conservation of Angular Momentum Confirmed: Rotational Deceleration in an Intermediate-Age Star Cluster

The subgiant branch (SGB) of the extended main-sequence turn-off (eMSTO) Small Magellanic Cloud cluster NGC 419 is significantly broader at bluer than at redder colors. If we would assume that the widths of the features in color--magnitude space were entirely owing to a range in stellar ages, the star-formation histories of the eMSTO stars and the blue SGB region would be significantly more prolonged than that of the red part of the SGB. This cannot be explained by assuming an internal age spread, a popular scenario to explain eMSTOs at intermediate ages (1--2 Gyr). We show that rotational deceleration of a population of rapidly rotating stars naturally explains the observed trend along the SGB. Our analysis shows that a "converging" SGB could be produced if the cluster is mostly composed of rapidly rotating stars that slow down over time owing to the conservation of angular momentum during their evolutionary expansion from main-sequence turn-off stars to red giants.

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154.10 – Follow up of stellar migrants from globular clusters using the Hobby-Eberly Telescope

Nearly all globular clusters contain at least two populations of stars. The first generation has abundances very similar to that of the average Milky Way halo stars at that metallicity. The second generation, presumably polluted by the massive stars of the first generation, have abundance patterns which include lower abundances of C, O, and Mg and higher abundances of N, Al and Na compared to first generation. Martell & Grebel (2010) identified a number of potential second generation stars using the CH and CN bandstrengths from SDSS-II/SEGUE spectra. We have followed up these candidates with moderate resolution spectra using HRS on the Hobby-Eberly Telescope. We present the success rate of finding globular cluster migrants and discuss the reasons why some stars exhibit a CN false positive signal in CN and CH.

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154.11 – Sakurai's Object Continues to Brighten and Expand

Sakurai's Object (V4334 Sgr), the prototype final flash object discovered in the mid-1990s, was observed to undergo rapid cooling becoming as faint as 25th magnitude at K during the first decade of the 21st century. A review of imaging data suggests the minimum K magnitude occurred about 2006. Sakuarai's Object was re-acquired at K in 2010. Between 2010 Sep and 2013 Apr Sakurai's object brightened more than 2 magnitudes to K=14.2. Here we report on a Gemini-NIRI K band AO image obtained in 2016 July. The Ks magnitude was 13.35. The AO image also records the continuing expansion of the debris cloud. The central star remains obscured. Spectro-spatial NIFS images of the spectral region around He I 1.0830 micron and a GMOS optical spectrum, both observed in 2015, will also be displayed.

Author(s): Kenneth H. Hinkle[1], Richard R. Joyce[1], Thomas Matheson[1]
Institution(s): *1. NOAO*

154.12 – Sizing Up Southern Red Dwarfs in the Solar Neighborhood

Red dwarfs comprise 75% of the stars in the Milky Way, yet determining one of their most fundamental characteristics --- age --- has proven difficult. Because no red dwarf has yet evolved beyond its main sequence life in the age of the Universe, as a class they are valuable touchstones fundamental to mapping the history of star and planet formation in the Milky Way, if their ages can be reliably determined. In the volume-limited RECONS 10 Parsec Sample census of 298 star systems, there are currently only two pre-main sequence young systems and three confirmed old subdwarf systems known. Four of these five extreme-age systems contain red dwarfs, but these are woefully insufficient to understand the complex star formation history of the Milky Way. Our all-sky study of ~1700 red dwarfs within 25 parsecs, supplemented with ~80 cool subdwarfs and ~90 young stars for comparison, will ultimately extend our calibration of red dwarf ages to populations that are statistically significant and robust, revealing for the first time the fractions of young and old systems out to 25 parsecs. Here we report our findings for the first ~600 stars south of Dec = 0.

We use the BT-Settl models in combination with Johnson-Kron-Cousins VRI, 2MASS JHK, and WISE All-Sky Release photometry to produce spectral energy distributions (SEDs) to determine the temperatures and
bolometric fluxes for the red dwarfs. The full suites of our photometric and astrometric data (including hundreds of accurate new parallaxes by the RECONS team from the CTIO/SMARTS 0.9m) allow us to also determine the bolometric luminosities and radii. This method of radius determination is validated by a comparison of our measurements to those found using the CHARA Array (Boyajian et al. 2012), which match within a few percent. These radii allow us to identify young/old stars via their correspondingly large/small radii, revealing a snapshot of relative stellar ages in the solar neighborhood from which we can begin to disentangle our Galaxy's history.

This effort has been supported by the NSF through grants AST-0908402, AST-1109445, and AST-1412026, and via observations made possible by the SMARTS Consortium.

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Contributing team(s): The RECONS Team

154.13 – Modeling the spatial distribution of fragments formed from tidally disrupted stars

Roughly once every 10^4 years, a star passes close enough to the supermassive black hole Sgr A* at the center of the Milky Way to be pulled apart by the black hole's tidal forces. The star is then 'spaghettified' into a long stream of mass, with approximately one half being bound to Sgr A* and the other half unbound. Hydrodynamical simulations of this process have revealed that within this stream, the local self-gravity dominates the tidal field of Sgr A*. This residual self-gravity allows for planetary-mass fragments to form along the stream that are then shot out into the galaxy at velocities determined by a spread of binding energies. We develop a Monte Carlo code in Python that models and plots the evolving position of these fragments for a variety of initial conditions that are likely realized in nature. This code utilizes an n-body integrator to differentially solve for the position, velocity, and acceleration of each fragment at every time step. We find that the while the most unbound fragments seem to escape the galaxy entirely, there could potentially be fragments travelling within a few hundred parsecs of our solar system.

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Contributing team(s): Banneker Institute

154.14 – Understanding Activity Cycles of Solar Type Stars with *Kepler*

As the era of exploring new worlds and systems advances we seek to answer the question: How common is our Sun? There is considerable evidence about the recurring activity cycles of our Sun but very little is known about the activity cycles of other stars. By calibrating the full frame images from the original Kepler mission that were taken once a month over the course of four years, we are able to do relative photometry on roughly 5 million stars. By building a model of the pixel response function we were able to achieve 0.8% precision photometry. We identify 50,000 solar type stars based on magnitude, surface gravity, and temperature cuts. We observe the relative increase and decrease in brightness of the stars indicating signs of activity cycles similar to our Sun. We continue to explore how a data driven pixel response function model could improve our precision to 0.1% photometry measurements.

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154.15 – Extension of H-alpha/H-beta Photometry to Additional Luminosity Classes and Emission Line Objects

In Joner & Hintz (2015) they presented a fully calibrated H-alpha index based on spectroscopic observations of main sequence stars ranging from O9 to K2. In that work they provided relations between the H-alpha index, temperature, and equivalent width. In Didelon (1982) the relation between spectral type and equivalent width is examined with a clear difference between luminosity classes. In this poster we will present results from a spectroscopic examination of the H-alpha/H-beta relations. First we will examine the equivalent width as a function of luminosity class. Then we will examine the extension of the H-alpha system for application to emission line objects.

We would like to acknowledge use of the Dominion Astrophysical Observatory 1.2-m Telescope.

Author(s): Eric G. Hintz[1], Michael D. Joner[1]
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154.16 – Calibrating the Luminosity of Carbon Stars: An Archival Study of Galaxies in the Nearby Universe

Carbon stars are a luminous but poorly constrained end stage of stellar evolution for stars with masses a few times the mass of the Sun. These stars may account for up to 40% of the luminosity in distant, unresolved galaxies. Recent studies have shown that the uncertainty in the contribution of carbon stars to a galaxy's total luminosity can cause galactic mass and age estimates to vary by a factor of 2. Using archival HST data for ~ 40 galaxies in the Local Group we explore how the carbon star luminosities correlate with the properties (e.g. age, chemical abundance) of the underlying stellar populations in each galaxy. Our study will place much needed constraints on stellar evolution models of carbon stars. This will in turn greatly improve estimates of masses and ages of distant galaxies, which are critical to our understanding of galaxy evolution.

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154.17 – Detailed Iron-Group Abundances in a Very Metal-Poor Main Sequence Turnoff Star

We have obtained Keck HIRES and HST STIS high resolution, high signal-to-noise spectra of the very metal-poor ([Fe/H] ~ -2.9) main-sequence turnoff star BD+03 740. A detailed chemical composition analysis based on synthetic spectrum computations has been conducted. Our initial focus has been on the iron-group elements in the Z = 21-28 range. This study takes advantage of recent improvements in neutral and ionzied species transition data for all of these elements except Sc (Z = 21) by the Wisconsin atomic physics group (see a companion presentation on Cr II at this meeting). Several metal-poor abundance surveys have concluded that there are large overabundances of Co and underabundances of Cr with respect to Fe for stars with [Fe/H] < -2.5. Neither of these anomalies is seen in BD+03 740. We discuss the implications of this result for early iron-group synthesis in the Galaxy.

This work has been supported by HST STScI Program GO-14232; and NSF grants AST-1211585 and AST-1616040 to CS; AST-1516182 to JEL and EDH; NASA grant NNX16AE96G to JEL

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154.18 – A Multi-Fiber Spectroscopic Search for Low-mass Young Stars in Orion OB1

We present here results of a low resolution spectroscopic followup of candidate low-mass pre-main sequence stars in the Orion OB1 association. Our targets were selected from the CIDA Variability Survey of Orion (CVSO), and we used the Michigan/Magellan Fiber Spectrograph (M2FS) on the Magellan Clay 6.5m telescope to obtain spectra of 500 candidate T Tauri stars distributed in seven 0.5 deg diameter fields, adding to a total area of ~5.5 deg2. We identify young stars by looking at the distinctive Hα 6563 Å emission and Lithium Li I 6707 Å absorption features characteristic of young low mass pre-main sequence stars. Furthermore, by measuring the strength of their Hα emission lines, confirmed T Tauri stars can be classified as either Classical T Tauris (CTTS) or Weak-line T Tauris (WTTS), which give indication of whether the star is actively accreting material from a gas and dust disk surrounding the star, which may be the precursor of a planetary system. We confirm a total of 90 T Tauri stars, of which 50% are newly identified young members of Orion; out of the 49 new detections,15 are accreting CTTS, and of these all but one are found in the OB1b sub-region. This result is in line with our previous findings that this region is much younger than the more extended Orion OB1a sub-association. The M2FS results add to our growing census of young stars in Orion, that is allowing us to characterize in a systematic and consistent way the distribution of stellar ages across the entire complex, in order to building a complete picture of star formation in this, one of nearest most active sites of star birth.

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154.19 – An Analytical Approach to the Evolution and Death of AGB Stars

Pop. I and II stars have a significant amount of metals throughout their structure, In the final stages of their evolution, intermediate mass stars (between 0.7 and 2 solar masses) ascend the Asymptotic Giant Branch (AGB). During their last few hundred thousand years on the AGB, these stars quickly lose their envelopes, recycling their metals as dust into the interstellar medium. The rate at which this happens consequently impacts the formation rate of stars, stellar systems, and the wider distribution of s-process isotopes.

At the end of their life cycles, AGB stars experience a steep increase in mass loss rate. We can define the death line in two steps. First we define the critical mass loss rate to be where the mass loss rate equals the initial mass divided by the evolution time. Then the death line is where the rate of change of logMdot equals the rate of change of logL. Most of the stars we observe to be rapidly losing mass appear in the death zone between 0.1 and 10 times the critical mass loss rate.

Assuming the mass loss rate increases exponentially with time, or, equivalently, the luminosity increases as a power of a characteristic exponent b, then the width of the death zone is the change in logL. This directly implies time is inversely proportional to b. This can be found for any mass-loss rate formula near the death line. By combining this with what we know about the initial-final mass relation and the core mass-luminosity relation, we can test for b with three observables — duration (width) of the death zone, the amplitude of mass loss variations (when L varies on an observable time scale such as a shell flash), and distributions of luminosity and pulsation period.

By applying the initial mass function (IMF) and star formation rate (SFR) of an observed region, we can relate these observables to the characteristic exponent. We will need to look at nearby regions where we can see large numbers of AGB stars, such as the Magellanic clouds. We will show that by fixing the death line and the characteristic exponent that intermediate changes in the mass loss rate better fit observations than extreme values. This is consistent with dust-driven as opposed to pulsation-driven processes.

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154.20 – Investigating the Common Origins of Stars Using Dynamical Modeling

Dynamical modeling of stars' orbits past in time is a robust method in finding stars of common birth origins. Here we present a dynamical study using the Python package *galpy* to investigate: 1) solar twins and the possibility of them having common birth origins with our Sun or each other and 2) the planet-hosting star iota Horologii proposed to have formed in the Hyades cluster. Solar twins are stars with spectra nearly identical to the Sun. Using a large sample of solar twins, we applied a standard Galactic model to investigate whether these stars have common origins with the Sun or each other at their respective ages, finding only very weak associations. In our investigation of the planet-hosting star iota Horologii, we challenge previous claims in favor of iota Horologii being an evaporated Hyades star. In our dynamical model, we compare the location of iota Horologii back in time to the average location of a representative sample of true Hyades stars, finding this star to have never converged with the cluster. Our results reveal the fundamental importance of dynamical modeling in the identification of stellar siblings.

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154.21 – A near-infrared surface compositional analysis of blue straggler stars in open cluster M67.

Blue straggler stars (BSSs) are stars whose evolutions have been directly impacted by binary system interactions. By obtaining additional mass from a companion, BSSs are able to live prolonged lives on the main sequence. BSSs bring confusions to studies that rely on a standard stellar evolutionary track when modeling stellar populations, since the presence of BSSs can make a population appear younger than it actually is. It is important to have a better understanding of the mechanisms that drive BSS formation so that BSSs may be correctly accounted for in future studies.

What we know about BSS formation is that they form in one of two ways. Either from a close binary system in which one star accretes mass from its companion star or from a hierarchical trinary system in which a close inner binary merges as a result of perturbations from a farther-orbiting third star. What we don't know are the relative frequencies of these two formation mechanisms. To investigate this problem, We obtained IGRINS near-IR (H- & K-band) high resolution spectra of 6 BSSs and 12 red giant stars in open cluster M67. Using a grid of synthetic spectra obtained from the line analysis code MOOG, we identified and fit abundances for absorption lines of iron, carbon, nitrogen, and oxygen. The latter three elements can be affected by internal hydrogen fusion, mixing, and binary mass transfer. In the BSS mass accretion mechanism, there should be enhanced abundances of these elements on the surfaces of BSSs. By analyzing the abundances of these elements in our BSS spectra, we determine the formation mechanism for each member of our BSS sample.

Funding for this research comes from the John W. Cox endowment for the Advanced Studies in Astronomy. For support of this work we acknowledge NSF grants AST-1211585 and AST-1616040 to CS. The successful development of the IGRINS spectrograph has resulted from the combined efforts of teams at the University of Texas at Austin and the Korea Astronomy and Space Science Institute; their work is gratefully acknowledged.

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154.22 – The Evolutionary Status of the Enigmatic Field Star RZ Piscium: A Search for Comoving Companions

The evolutionary status of the variable field star RZ Psc is currently indeterminate. While its space motion appears to favor young-star status, various aspects of the star's spectral and temporal behavior support both young- and evolved-star models. In particular, RZ Psc exhibits a large infrared excess, abrupt optical dropouts (which are indicative of non-periodic occultations by a dusty disk), a large ratio of X-ray to bolometric luminosity (see abstract by Punzi et al., this meeting), emission-line variability, and (potentially) radial velocity variability. To break this degeneracy, we have conducted a search for infrared- and X-ray-bright stars in the field that are comoving with RZ Psc. Data spanning mid-infrared to X-ray wavelengths (2MASS, WISE, WIYN 0.9m, and XMM-Newton images) were used to identify stars within ~15' of RZ Psc that lie at a comparable distance from Earth. Proper motions of these candidate stars were then cross-correlated with those of RZ Psc. This search has yielded a potential comoving companion at a separation of ~2.3' (~33 kAU, assuming a distance of 240 pc to RZ Psc). The spectral characteristics of the potential companion are indicative of a flaring, main-sequence, late-M star. If confirmed by follow-up observations and analysis, the existence of this main-sequence, low-mass companion would favor post-main sequence status for RZ Psc.

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154.23 – Neutron-Capture Elements in Low Metallicity Stars within the Inner Galactic Halo

The inner galactic halo is home to some of the oldest and low metallicity stars known. These stars are local enough to observe heavy element synthesis in the oldest stars in our galaxy. The purpose of this research is to analyze the distributions of neutron capture elements in low metallicity stars to help us understand the nature of first stars, which are responsible for the chemical enrichment of our galaxy, and consequently get man closer to an answer to some of the most fundamental questions about the universe.. The researchers will analyze and measure the stellar abundances of metal poor stars using MOOG's spectral synthesis. Heavy element formation is connected to stellar evolution, thus by observing the chronometric ages of the distributions of Thorium/Europium, one can determine the age of the oldest stars. Analyzing the distribution of Uranium and Thorium as chronometers can set a lower limit on the age of the Universe. The chemical composition in our oldest observable stars resemble that of the earliest stars. This demonstrates that these stars were not synthesized internally but a result of previous deaths of stars generations before. This in turn provides useful information about the first star's formation, evolution and nucleosynthesis of stars, and the arrangement of the structure of the early Universe. The most r-process rich halo stars abundances are consistent with a scaled solar system r-process abundance distribution. Also, there is symmetry in the rare earth elements in the stars within the Galactic halo. However the lighter n-capture abundances don't conform to the solar pattern. This suggests the possibility of multiple synthesis mechanisms for the n capture elements. The combinations could include the main r-process, V-P process (core collapsed super-novae), charged particle reactions with Beta delayed fission, and the weak r-process. The weak r-process is sometimes called the incomplete r-process does not have enough neutrons to supply the reaction for heavier elements.

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154.24 – A Fast Method to Predict Distributions of Binary Black Hole Masses Based on Gaussian Process Regression

With more observations from LIGO in the upcoming years, we will be able to construct an observed mass distribution of black holes to compare with binary evolution simulations. This will allow us to investigate the physics of binary evolution such as the effects of common envelope efficiency and wind strength, or the properties of the population such as the initial mass function.
However, binary evolution codes become computationally expensive when running large populations of binaries over a multi-dimensional grid of input parameters, and may simulate accurately only for a limited combination of input parameter values.
Therefore we developed a fast machine-learning method that utilizes Gaussian Mixture Model (GMM) and Gaussian Process (GP) regression, which together can predict distributions over the entire parameter space based on a limited number of simulated models. Furthermore, Gaussian Process regression naturally provides interpolation errors in addition to interpolation means, which could provide a means of targeting the most uncertain regions of parameter space for running further simulations.
We also present a case study on applying this new method to predicting chirp mass distributions for binary black hole systems

(BBHs) in Milky-way like galaxies of different metallicities.

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154.25 – Automated Detection of Dwarf Galaxies and Star Clusters in SMASH through the NOAO Data Lab

We present an automated method, using the NOAO Data Lab environment, for the detection of dwarf galaxy-scale objects in catalog data from the Survey of the Magellanic Stellar History (SMASH). SMASH has imaged ~480 square degrees of the southern sky, over a partially filled area of 2400 square degrees, to 24th mag in gri (uz~23) using the Dark Energy Camera (DECam). The NOAO Data Lab (http://datalab.noao.edu) is being developed to support community research of the massive data sets now being derived from NOAO's wide-field telescopes, in particular DECam. A key feature of the Data Lab is the ability to perform efficient automated analysis of catalog and imaging data. Our method, which is an example of this feature, allows for the rapid search of candidate dwarf galaxies and stellar clusters in deep catalog data. Using SMASH as the catalog data source, we easily recover the previously discovered Hydra II dwarf galaxy and SMASH-I LMC globular cluster, as well as a number of other potentially interesting candidate stellar systems.

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Institution(s): *1. NOAO*
Contributing team(s): SMASH Collaboration, NOAO Data Lab Team

154.26 – A Novel Approach to Constraining Uncertain Stellar Evolution Models

Stellar evolution models are fundamental to nearly all studies in astrophysics. They are used to interpret spectral energy distributions of distant galaxies, to derive the star formation histories of nearby galaxies, and to understand fundamental parameters of exoplanets. Despite the success in using stellar evolution models, some important aspects of stellar evolution remain poorly constrained and their uncertainties rarely addressed. We present results using archival Hubble Space Telescope observations of 10 stellar clusters in the Magellanic Clouds to simultaneously constrain the values and uncertainties of the strength of core convective overshooting, metallicity, interstellar extinction, cluster distance, binary fraction, and age.

Author(s): Philip Rosenfield[1], Leo Girardi[2], Julianne Dalcanton[5], L. C. Johnson[7], Benjamin F. Williams[5], Daniel R. Weisz[6], Alessandro Bressan[4], Morgan Fouesneau[3]
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154.27 – On the Quantification of Incertitude in Astrophysical Simulation Codes

We present a pedagogical study of uncertainty quantification (UQ) due to epistemic uncertainties (incertitude) in astrophysical modeling using the stellar evolution software instrument MESA (Modules and Experiments for Stellar Astrophysics). We present a general methodology for UQ and examine the specific case of stars evolving from the main sequence to carbon/oxygen white dwarfs. Our study considers two epistemic variables: the wind parameters during the Red Giant and Asymptotic Giant branch phases of evolution. We choose uncertainty intervals for each variable, and use these as input to MESA simulations. Treating MESA as a "black box," we apply two UQ techniques, Cauchy deviates and Quadratic Response Surface Models, to obtain bounds for the final white dwarf masses. Our study is a proof of concept applicable to other computational problems to enable a more robust understanding of incertitude. This work was supported in part by the US Department of Energy under grant DE-FG02-87ER40317.

Author(s): Melissa Hoffman[2], Maximilian P. Katz[2], Donald E. Willcox[2], Scott Ferson[1], F. Douglas Swesty[2], Alan Calder[2]
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155 – Ground Based Facilities & Instrumentation Poster Session

155.01 – Re-development of the Mount Evans Womble Observatory

Mount Evans in the Colorado Front Range hosts one of the highest altitude observatories in the USA, at an elevation of 14,148 ft (4,312 m). The observatory is operated under a Forest Service use permit, recently renewed for another 30 years. At times, observing conditions (seeing, water vapor column, etc.) can be as good as anywhere. The existing twin 0.72 m f/21 R-C telescopes are solar powered and internet connected. However, jet stream winds in 2012 destroyed the 15 year old, 22.5 ft diameter Ash dome. The replacement, custom dome design/install was rushed, and suffers from a number of flaws. Given that, plus the aging telescope and operating system, we are planning, and seeking partners and investor funds, to re-develop the facility. Facets of this may include replacing the twin apertures with a single full-aperture telescope for remote operations and sky monitoring, replacing the flawed dome with an innovative dome design, renewable power upgrades, and outreach programs for the many thousands of mountain visitors seasonally. As elsewhere, we are grappling with increases in atmospheric water vapor and out-of-control regional light pollution growth, but believe that the site continues to hold great potential. Interested parties are invited to contact the first author for further information. Website: http://www.du.edu/~rstencel/MtEvans .

Author(s): Robert E. Stencel[1]
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155.02 – Instruments at the Lowell Observatory Discovery Channel Telescope (DCT)

The Lowell Observatory Discovery Channel Telescope (DCT) has been in full science operation for 2 years (2015 and 2016). Five instruments have been commissioned during that period, and two additional instruments are planned for 2017. These include:

+ Large Monolithic Imager (LMI) - a CCD imager (12.6 arcmin FoV)

+ DeVeny - a general purpose optical spectrograph (2 arcmin slit length, 10 grating choices)

+ NIHTS - a low resolution (R=160) YJHK spectrograph (1.3 arcmin slit)

+ DSSI - a two-channel optical speckle imager (5 arcsec FoV)

+ IGRINS - a high resolution (45,000) HK spectrograph, on loan from the University of Texas.

In the upcoming year, instruments will be delivered from the University of Maryland (RIMAS - a YJHK imager/spectrograph) and from Yale University (EXPRES - a very high resolution stabilized optical echelle for PRV).

Each of these instruments will be described, along with their primary science goals.

Author(s): George H. Jacoby[1], Thomas A. Bida[1], Debra Fischer[5], Elliott Horch[2], Alexander Kutyrev[3], Gregory N. Mace[4], Philip Massey[1], Henry G. Roe[1], Lisa A. Prato[1]
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155.03 – First Light of the Renovated Thacher Observatory

The Thacher Observatory, originally a collaboration between UCLA (P.I. G. Abell), Caltech, Pomona College, and the Thacher School, was built in the early 1960s. The goal of the facility was to serve as a training ground for undergraduate and graduate students in Los Angeles area colleges and also to provide hands-on technical training and experience for Thacher students. It was the birthplace of the Summer Science Program which continues today at other campuses. The observatory has now been fully renovated and modernized with a new, 0.7m telescope and dome that can be controlled remotely and in an automated manner. Science programs involving accurate and precise photometry have been initiated, and we project that we will be presenting the first scientific results of the renovated observatory at this meeting.

Author(s): Katie O'Neill[1], Yao Yin[1], Nick Edwards[1], Jonathan Swift[1]
Institution(s): *1. The Thacher School*

155.04 – Quality Control of The Miniature Exoplanet Radio Velocity Array(MINERVA)

The MINiature Exoplanet Radial Velocity Array, also known as MINERVA , is a network of four robotic 0.7 meter telescopes that is conducting a Radial Velocity survey of the nearest, brightest stars in search of small and rocky exoplanets. The robotic telescope array is located in Fred Lawrence Whipple Observatory in Arizona. MINERVA began science operations in 2015 and we are constantly improving its observing efficiency. We will describe performance statistics that we have developed in Python to proactively identify problems before they impede observations. We have written code to monitor the pointing error for each telescope to ensure it will always be able to acquire a target in the 3 arcminute field of view of its acquisition camera, but there are still some issues that need to be identified. The end goal for this research is to automatically address any common malfunction that may cause the observation to fail and ultimately improve our observing efficiency.

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155.05 – Brown University Radio Student Telescope (BURST)

The Brown University Radio Student Telescope (BURST) is a rooftop low frequency radio interferometer that we hope to potentially use to observe radio transients, non-thermal radio emission from Galactic synchrotron and supernova remnants, and extragalactic radio sources. It was built by a group of Brown undergraduates this past summer. An overview of the design, ultimate installation, challenges in implementation and data acquisition will be covered in the poster.

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Institution(s): *1. Brown University*

155.06 – Weizmann Fast Astronomical Survey Telescope (WFAST)

The Weizmann Fast Astronomical Survey Telescope (W-FAST) is an experiment designed to explore variability on sub-second time scales. When completed it will consist of two robotic 55-cm f/2 Schmidt telescopes. The optics is capable of providing ~0.5" image quality over 23 deg^2. The focal plane will be equipped with fast readout, low read-noise sCMOS detectors. The first generation focal plane is expected to have 6.2 deg^2 field of view. WFAST is designed to study occultations by solar system objects (KBOs and Oort cloud objects), short time scale stellar variability, and high resolution imaging via proper coaddition.

Author(s): Guy Nir[2], Eran Oded Ofek[2], Sagi Ben-Ami[1], Ilan Manulis[2], Avishay Gal-Yam[2], Oz Diner[2], Michael Rappaport[2]
Institution(s): *1. Harvard Smithsonian Astrophysical Observatory, 2. Weizmann Institute*

155.07 – Estimating Noise in the Hydrogen Epoch of Reionization Array

The Hydrogen Epoch of Reionization Array (HERA) is a radio telescope dedicated to observing large scale structure during and prior to the epoch of reionization. Once completed, HERA will have unprecedented sensitivity to the 21-cm signal from hydrogen reionization. This poster will present time- and frequency-subtraction methods and results from a preliminary analysis of the noise characteristics of the nineteen-element pathfinder array.

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Institution(s): *1. Brown University*
Contributing team(s): HERA Team

155.08 – Spectrographs and Large Telescopes: A Study of Instrumentation

It is a truth universally acknowledged, that a telescope in possession of a large aperture, must be in want of a high resolution spectrograph. Subsystems of these instruments require testing and upgrading to ensure that they can continue to be scientifically productive and usher in a new era of astronomical research. The Planet Finder Spectrograph (PFS) and Magellan Inamori Kyocera Echelle (MIKE), both on the Magellan II Clay telescope at Las Campanas Observatory, and the Giant Magellan Telescope (GMT) Consortium Large Earth Finder (G-CLEF) are examples of such instruments. Bluer flat field lamps were designed for PFS and MIKE to replace lamps no longer available in order to ensure continued, efficient functionality. These newly designed lamps will result in better flat fielding and calibration of data, and thus result in increased reduction of instrument noise. When it is built and installed in 2022, G-CLEF will be be fed by a tertiary mirror on the GMT. Stepper motors attached to the back of this mirror will be used to correct misalignments in the optical relay system. These motors were characterized to ensure that they function as expected to an accuracy of a few microns. These projects incorporate several key aspects of astronomical instrumentation: designing, building, and testing.

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155.09 – Use of the Half-Degree Imager as a Photometric Instrument

The Half-Degree Imager (HDI) is currently in use on the WIYN-9.9m telescope at Kitt Peak National Observatory. HDI is relatively new, having come on-line approximately 2 years ago. While it has one of the largest imaging surfaces for a single chip it also serves the consortium as our primary photometry instrument. We explore the quality of the photometry obtained with the HDI and illustrate that good photometric results can be obtained with this instrument. More technical aspects of this imager are given in the oral special session on Friday, January 6, 2017.

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Contributing team(s): WIYN-0.9m Consortium

155.10 – On-Sky Performance Verification of the CHARIS IFS

The Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) is an integral field spectrograph (IFS) built for the Subaru telescope. CHARIS has been delivered to the observatory and now sits behind the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) and AO188 adaptive optics systems. CHARIS is designed to detect objects five orders of magnitude dimmer than their parent star down to an 80 milliarcsecond inner working angle. CHARIS is a lenslet-based IFS and has two fundamental operating modes. In characterization mode, CHARIS has a 'high-resolution' prism providing an as-built average spectral resolution of R75.2, R65.2, and R77.1 in J, H, and K bands respectively. Unique to CHARIS is a second mode designed for discovery, with a 'low-resolution' prism providing an as-built spectral resolution of R18.4 that spans the full J+H+K spectrum (1.15-2.37 microns). This discovery mode has already proven better than 5-sigma detections of HR8799c,d,e when combining ADI+SDI. Using SDI alone, planets c and d have been detected in a single 24 second image. The CHARIS team is optimizing instrument performance and refining ADI+SDI recombination to maximize our contrast detection limit. In addition to the new observing modes, CHARIS has demonstrated a design with high robustness to spectral crosstalk. The integrated spectral cross-contamination has not exceeded 4%, thanks to a combination of post-lenslet tolerances and a carefully designed pinhole grid mask directly printed onto the back side of the lenslet array in black chrome. CHARIS is in the final stages of commissioning, with the instrument open for science observations beginning February 2017. A Wollaston prism upgrade to the instrument will be commissioned later in 2017. Here we review the science case, design, on-sky performance, and lessons learned both in hardware and operationally that are directly applicable to future exoplanet instruments such as the WFIRST CGI IFS.

Author(s): Tyler Dean Groff4, Jeffrey K. Chilcote[1], Jeremy Kasdin5, Timothy Brandt[2], Michael Galvin5, Craig Loomis5, Michael Carr5, Gillian R. Knapp5, Olivier Guyon[6], Nemanja Jovanovic[6], Julien Lozi[6], Naruhisa Takato[6], Masahiko Hayashi3
Institution(s): *1. Dunlap Institute for Astronomy and Astrophysics, University of Toronto, 2. Institute for Advanced Study, 3. NAOJ, 4. NASA Goddard Space Flight Center, 5. Princeton University, 6. Subaru Telescope*

155.11 – Photometric Calibration of the Gemini South Adaptive Optics Imager

The Gemini South Adaptive Optics Imager (GSAOI) is an instrument available on the Gemini South telescope at Cerro Pachon, Chile, utilizing the Gemini Multi-Conjugate Adaptive Optics System (GeMS). In order to allow users to easily perform photometry with this instrument and to monitor any changes in the instrument in the future, we seek to set up a process for performing photometric calibration with standard star observations taken across the time of the instrument's operation. We construct a Python-based pipeline that includes IRAF wrappers for reduction and combines the AstroPy photutils package and original Python scripts with the IRAF apphot and photcal packages to carry out photometry and linear regression fitting. Using the pipeline, we examine standard star observations made with GSAOI on 68 nights between 2013 and 2015 in order to determine the nightly photometric zero points in the J, H, Kshort, and K bands. This work is based on observations obtained at the Gemini Observatory, processed using the Gemini IRAF and gemini_python packages, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the National Research Council (Canada), CONICYT (Chile), Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina), and Ministério da Ciência, Tecnologia e Inovação (Brazil).

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155.12 – DuOCam: A Two-Channel Camera for Simultaneous Photometric Observations of Stellar Clusters

We have designed the Dual Observation Camera (DuOCam), which uses commercial, off-the-shelf optics to perform simultaneous photometric observations of astronomical objects at red and blue wavelengths. Collected light enters DuOCam's optical assembly, where it is collimated by a negative doublet lens. It is then separated by a 45 degree blue dichroic filter (transmission bandpass: 530 - 800 nm, reflection bandpass: 400 - 475 nm). Finally, the separated light is focused by two identical positive doublet lenses onto two independent charge-coupled devices (CCDs), the SBIG ST-8300M and the SBIG STF-8300M. This optical assembly converts the observing telescope to an f/11 system, which balances maximum field of view with optimum focus. DuOCam was commissioned on the McDonald Observatory 0.9m, f/13.5 telescope from July 21st - 24th, 2016. Observations of three globular and three open stellar clusters were carried out. The resulting data were used to construct R vs. B-R color magnitude diagrams for a selection of the observed clusters. The diagrams display the characteristic evolutionary track for a stellar cluster, including the main sequence and main sequence turn-off.

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155.13 – Spectro-spatial reconstruction of Wide Field Imaging Interferometry Testbed (WIIT) data

The Wide-field Imaging Interferometry Testbed (WIIT) is a double Fourier interferometer (DF) operating at optical wavelengths, and provides data that are highly representative of those from a space-based far-infrared interferometer like SPIRIT. Developed at NASA's Goddard Space Flight Center, this testbed produces high-quality interferometric data and is capable of observing spatially and spectrally complex hyperspectral test scenes, from geometrically simple to astronomically representative test scenes.

Here we present the reconstruction of WIIT data via spectro-spatial Fourier transformation, where the spectral domain and the spatial domain are synthesized independently, offering the opportunity to apply algorithms classically used in spectroscopy and radio interferometry. For this current study, the test scene under consideration spatially consists of four reference point sources intended for spectral and spatial calibration, and six science sources, comprised of binary systems. Each binary pair member has a unique spectrum. Our results demonstrate the synthesis of real double Fourier interferometry data, and we compare them with synthesized datacubes reconstructed from simulated data generated by the Far-infrared Interferometer Instrument Simulator (FIInS).

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Institution(s): *1. NASA Goddard Space Flight Center, 2. The Institute of Optics - University of Rochester*

155.14 – Simulations and Interpretations of BETTII Observations

BETTII (Balloon Experimental Twin Telescope for Infra-red Interferometry) is an 8-meter baseline far-infrared (30-90 microns) interferometer mission on a balloon. Its capabilities of spatially resolved spectroscopy with 0.5" resolution are aimed at studying clustered star formation and galaxy evolution. With its 9x9 detector arrays, we can perform relative astrometry over a 2'x2' field of view and get source spectral and size information. Since BETTII is a two-element fixed baseline length interferometer and balloon flight time is short, its u-v coverage is very limited. Standard inversion techniques cannot be used to image the emission as is typically done for radio interferometers.

We simulate the BETTII observations using a hypothetical star forming region as the input and taking into account the instrument characteristics and limitations. We derive astrometric, spectroscopic, and morphological information from the simulated output through model fitting. Varying the input model parameters that we use to define the dust emission from the protostar, we produce sets of simulated outputs. By comparing these outputs with the hypothetical observations, we explore how well the BETTII observations constrain the defining parameters of the young stellar system.

Author(s): Arnab Dhabal[2], Lee G. Mundy[2], Maxime Rizzo[1], Stephen Rinehart[1], Roser Juanola-Parramon[1]
Institution(s): *1. NASA Goddard Space Flight Center, 2. University of Maryland*

155.15 – Monitoring Telluric Water Absorption with CAMAL

Ground-based observations are severely limited by telluric water vapor absorption features, which are highly variable in time and significantly complicate both spectroscopy and photometry in the near-infrared (NIR). To achieve the stability required to study Earth-sized exoplanets, monitoring the precipitable water vapor (PWV) becomes necessary to mitigate the impact of telluric lines on radial velocity measurements and transit light curves. To address this issue, we present the Camera for the Automatic Monitoring of Atmospheric Lines (CAMAL), a stand-alone, inexpensive 6-inch aperture telescope dedicated to measuring PWV at the Whipple Observatory. CAMAL utilizes three NIR narrowband filters to trace the amount of atmospheric water vapor affecting simultaneous observations with the MINiature Exoplanet Radial Velocity Array (MINERVA) and MINERVA-Red telescopes. We present the current design of CAMAL, discuss our calibration methods, and show PWV measurements taken with CAMAL compared to those of a nearby GPS water vapor monitor.

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155.16 – Wide Band Artificial Pulsar

The Wide Band Artificial Pulsar (WBAP) is an instrument verification device designed and built by the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virgina. The site currently operates the Green Bank Ultimate Pulsar Processing Instrument (GUPPI) and the Versatile Green Bank Astronomical Spectrometer (VEGAS) digital backends for their radio telescopes. The commissioning and continued support for these sophisticated backends has demonstrated a need for a device capable of producing an accurate artificial pulsar signal. The WBAP is designed to provide a very close approximation to an actual pulsar signal. This presentation is intended to provide an overview of the current hardware and software implementations and to also share the current results from testing using the WBAP.

Author(s): Zackary Parsons[1]
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155.17 – Preparing ZEUS-2 for Observing Run at the APEX Telescope

ZEUS-2 is a direct detection grating spectrometer that was designed to maximize sensitivity for the detection of the far-infrared fine-structure lines from distant star forming galaxies as they are redshifted into the short submillimeter windows. ZEUS-2 employs two NIST TES bolometer arrays as its detector: one tuned to 400 μm and the other that consists of two sub-arrays, one tuned to 215 μm and the other tuned to 645 μm. Therefore, by placing bandpass filters directly above the detector ZEUS-2 can address four telluric windows (200 μm, 350 μm, 450 μm, and 650 μm) simultaneously on extended objects, and two windows (200 and 650 μm, or 350 and 450 μm) simultaneously on point sources. ZEUS-2 has now been deployed four times on the APEX telescope in Chile and demonstrated background limited performance both at 350 and 450 μm. As part of my NSF REU experience at Cornell in the summer of 2016, I helped with testing of ZEUS-2 in the lab and improving components for its use on the telescope. This poster will cover the principles of the ZEUS-2 instrument and some of the recent scientific results.

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155.18 – Developing a Single-shot Polarimeter for Astronomy with Stessed-engineered Optics

True single-shot polarimetry can be accomplished by utilizing a stress-engineered optic, with birefringence that varies spatially along its cross-section (Ramkhalawon et al. 2012). As light passes through such an optic, it will acquire a PSF that is unique to its polarization, providing the ability to measure all four Stokes parameters in a single image. This technique has not yet been adapted to astronomy. Our effort to do so faces several challenges, including the measurability of these PSFs for low polarizations, and through atmospheric turbulence. Current research demonstrates that low polarizations can remain measurable with the correct selection of stressed-optic and CCD parameters. Additionally, if signal is adequate (10^7 photons), then we demonstrate that turbulence does not negatively impact measurability. These results are leading toward the University of Denver's development of the first polarimeter to utilize these techniques in astronomy. This instrument will have intended applications of studying exoplanets and contributing to polarimetry surveys. The authors are grateful to the estate of William Herschel Womble for the support of astronomy at the University of Denver.

Author(s): Tristan Wolfe[1], Robert E Stencel[1]
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155.19 – Design Considerations for the Installation of an Iodine (I_2) Cell onto TRES

The radial velocity (RV) method utilizes the reflex motion of a target star to predict the presence of one or multiple exoplanets. However, the disparity in mass between planet and host star often results in RV oscillations below the precision of most modern spectrographs. Such is the case of TRES, the Tillinghast Reflector Echelle Spectrograph located in the Fred Lawrence Whipple Observatory in Mt. Hopkins, Arizona, with a radial velocity (RV) precision of ~ 20 m s^{-1}, dominated by instrumental effects. Since 1992, the iodine cell technique, presented in Butler et al.(1992) has become widely used for the reduction of RV measurement errors. Here, we describe the beginning stages in the installation of one such cell onto TRES. After traveling to the telescope site to perform the first fitting of the iodine stage, I designed, built and fitted the first prototype of an improved thermal insulation system for the front end of the spectrograph, where the cell will be mounted. Here I present such a design, as well as a detailed description of the current state of the project. We expect the iodine cell to be fully functional in approximately 1 year. Once the cell is installed, we expect errors in radial velocity measurements to decrease by an order of magnitude from the aforementioned 20 m s^{-1}. This increase in precision will come with an increase in stability of radial velocity measurements, allowing TRES to perform in-house spectroscopy of more nearby bright targets and high-cadence exoplanet follow-up.

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155.20 – A dispersed fringe sensor prototype for the Giant Magellan Telescope

The Giant Magellan Telescope (GMT) will employ seven 8.4m primary mirror segments and seven 1m secondary mirror segments to achieve the diffraction limit of a 25.4m aperture. One challenge of the GMT is keeping the seven pairs of mirror segments in phase. We present a conceptual opto mechanical design for a prototype dispersed fringe sensor. The prototype, which operates at J-band and incorporates an infrared avalanche photodiode array, will be deployed on the Magellan Clay Telescope to verify the sensitivity and accuracy of the planned GMT phasing sensor.

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Institution(s): *1. Harvard Smithsonian Center for Astrophysics*

155.21 – Camera Development for the Cherenkov Telescope Array

With the Cherenkov Telescope Array (CTA), the very-high-energy gamma-ray universe, between 30 GeV and 300 TeV, will be probed at an unprecedented resolution, allowing deeper studies of known gamma-ray emitters and the possible discovery of new ones. This exciting project could also confirm the particle nature of dark matter by looking for the gamma rays produced by self-annihilating weakly interacting massive particles (WIMPs). The telescopes will use the imaging atmospheric Cherenkov technique (IACT) to record Cherenkov photons that are produced by the gamma-ray induced extensive air shower. One telescope design features dual-mirror Schwarzschild-Couder (SC) optics that allows the light to be finely focused on the high-resolution silicon photomultipliers of the camera modules starting from a 9.5-meter primary mirror. Each camera module will consist of a focal plane module and front-end electronics, and will have four TeV Array Readout with GSa/s Sampling and Event Trigger (TARGET) chips, giving them 64 parallel input channels. The TARGET chip has a self-trigger functionality for readout that can be used in higher logic across camera modules as well as across individual telescopes, which will each have 177 camera modules. There will be two sites, one in the northern and the other in the southern hemisphere, for full sky coverage, each spanning at least one square kilometer. A prototype SC telescope is currently under construction at the Fred Lawrence Whipple Observatory in Arizona. This work was supported by the National Science Foundation's REU program through NSF award AST-1560016.

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156 – Catalogs Poster Session

156.01 – The SUPERBLINK all-sky catalog of 2.8 million stars with proper motions larger than 40 mas/yr, enhanced with data from the first GAIA release

An updated version of the SUPERBLINK all-sky catalog of 2.8 million stars with proper motions larger than 40 mas/yr is presented. This version incorporates data from the GAIA first release (DR1), and identifies the photometric counterparts of the stars in variety of other catalogs including ROSAT, GALEX, APASS, SDSS, 2MASS and WISE. All bright stars ($0<V<12$) have proper motions and parallaxes from GAIA; for stars in the faint magnitude range ($12<V<21$), proper motions are recalculated, whenever possible, using 2MASS, GALEX, or SDSS positions as a first epoch and GAIA positions as a second epoch. Parallax measurements from the literature are also included, whenever available, for stars with no current GAIA parallaxes. In addition, photometric distances are provided for stars with no trigonometric parallax measurement, using color-magnitude relationships recalibrated with the new GAIA parallaxes; these stars constitute the majority of objects in the SUPERBLINK catalog, and overwhelmingly consist of M dwarfs and white dwarfs in the Solar vicinity. We examine the completeness and magnitude limit of the GAIA first data release for stars with large proper motions.

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156.02 – The Reliability of Galaxy Classifications by Citizen Scientists

Citizen scientists are becoming more and more important in helping professionals working through big data. An example in astronomy is crowdsourced galaxy classification. But how reliable are these classifications for studies of galaxy evolution? We present a tool in order to investigate those morphological classifications and test it on a diverse population on our campus. We observe a slight offset towards earlier Hubble types in the crowdsourced morphologies, when compared to professional classifications.

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156.03 – Cross-matching within the Chandra Source Catalog

Cross-matching among overlapping source detections in the development of the Chandra Source Catalog (CSC) presents considerable challenges, since the Point Spread Function (PSF) of the Chandra X-ray Observatory varies significantly over the field of view. For the production of the second release of the CSC we have developed a cross-match tool that is based on the Bayesian algorithms by Budavari, Heinis, and Szalay (ApJ 679, 301 and 705, 739), making use of the error ellipses for the derived positions of the detections.
However, calculating match probabilities only on the basis of error ellipses breaks down when the PSFs are significantly different. This is an issue that is not commonly addressed in cross-match tools. We have applied a satisfactory modification to the algorithm that, although not perfect, ameliorates the issue for the vast majority of such cases.
A separate issue is that as the number of overlapping detections increases, the number of matches to be considered increases at an alarming rate, requiring procedural adjustments to ensure that the cross-matching finishes within a Hubble time.
We intend to make the tool available as a general purpose cross-match engine for calculating match probabilities between sources in multiple catalogs simultaneously.
This work has been supported by NASA under contract NAS 8-03060 to the Smithsonian Astrophysical Observatory for operation of the Chandra X-ray Center.

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156.04 – Classifying TDSS Stellar Variables

The Time Domain Spectroscopic Survey (TDSS), a subprogram of SDSS-IV eBOSS, obtains classification/discovery spectra of point-source photometric variables selected from PanSTARRS and SDSS multi-color light curves regardless of object color or lightcurve shape. Tens of thousands of TDSS spectra are already available and have been spectroscopically classified both via pipeline and by visual inspection. About half of these spectra are quasars, half are stars. Our goal is to classify the stars with their correct variability types. We do this by acquiring public multi-epoch light curves for brighter stars (r<19.5mag) from the Catalina Sky Survey (CSS). We then run a number of light curve analyses from VARTOOLS, a program for analyzing astronomical time-series data, to constrain variable type both for broad statistics relevant to future surveys like the Transiting Exoplanet Survey Satellite (TESS) and the Large Synoptic Survey Telescope (LSST), and to find the inevitable exotic oddballs that warrant further follow-up. Specifically, the Lomb-Scargle Periodogram and the Box-Least Squares Method are being implemented and tested against their known variable classifications and parameters in the Catalina Surveys Periodic Variable Star Catalog. Variable star classifications include RR Lyr, close eclipsing binaries, CVs, pulsating white dwarfs, and other exotic systems. The key difference between our catalog and others is that along with the light curves, we will be using TDSS spectra to help in the classification of variable type, as spectra are rich with information allowing estimation of physical parameters like temperature, metallicity, gravity, etc. This work was supported by the SDSS Research Experience for Undergraduates program, which is funded by a grant from Sloan Foundation to the Astrophysical Research Consortium.

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Contributing team(s): The TDSS Collaboration

157 – Societal Matters Poster Session

157.01 – The AAS Working Group on Accessibility and Disability (WGAD): Year 1 Highlights

The AAS Working Group on Accessibility and Disability (WGAD) was formed in January of 2016 with the express purpose of seeking equity of opportunity and building inclusive practices for disabled astronomers at all career stages. In our first year, the WGAD has been actively developing resources and the online infrastructure for the dissemination of information and engagement with the astronomy community. Our official WGAD website has gone live, and we have used both the access: astronomy google group and blog to discuss specific issues of disability justice and to raise awareness for less-discussed barriers to access. The WGAD has developed relationships and collaboration with AAS inclusion committees (SGMA, CSMA, CSWA) so our work can recognize and address the intersections of identity astronomers occupy. In this presentation, we summarize our year one activities, focusing on our recently developed set of recommendations for journal accessibility to ensure everyone can engage with journal content and navigate the submission process. We will also discuss ongoing and future endeavors: a best practices guide for accessibility to be available via our website, and a site visit program.

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157.02 – Astronomy Allies

Imagine you are a grad student, at your first conference, and a prominent senior scientist shows interest in your work, and he makes things get way too personal? What would you do? Would you report it? Or would you decide, after a few other instances of harassment, that maybe you shouldn't pursue astronomy? Harassment is under-reported, the policies can be difficult to understand or hard to find, and it can be very intimidating as a young scientist to report it to the proper individuals. The Astronomy Allies Program is designed to help you with these sorts of problems. We are a group of volunteers that will help by doing the following: provide safe walks home during the conference, someone to talk to confidentially, as an intervener, as a resource to report harassment. The Allies are a diverse group of scientists committed to acting as mentors, advocates, and liaisons. The Winter 2015 AAS meeting was the first meeting that had Astronomy Allies, and Astronomy Allies provided a website for information, as well as a twitter, email, and phone number for anyone who needs our help or would like more information. We posted about the Astronomy Allies on the Women In Astronomy blog, and this program resonates with many people: either they want to help, or they have experienced harassment in the past and don't want to see it in the future. Harassment may not happen to most conference participants, but it's wrong, it's against the AAS anti-harassment policy (http://aas.org/policies/anti-harassment-policy), it can be very damaging, and if it happens to even one person, that is unacceptable. We intend to improve the culture at conferences to make it so that harassers feel they can't get away with their unprofessional behavior.

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158 – HAD IV: Poster Session

158.01 – This Month in Astronomical History: Preliminary Survey Results

This Month in Astronomical History is a short (~500 word) column on the AAS website that revisits significant astronomical events or the lives of people who have made a large impact on the field. The monthly column began in July 2016 at the request of the Historical Astronomical Division. Examples of topics that have been covered include Comet Shoemaker-Levy's collision with Jupiter, the discovery of the moons of Mars, the life of Edwin Hubble, Maria Mitchell's comet discovery, and the launch of Sputnik II. A survey concerning the column is in progress to ensure the column addresses the interests and needs of a broad readership, including historians, educators, research astronomers, and the general public. Eleven questions focus on the style and content of the column, while eight collect simple demographics. The survey has been available on the AAS website since and was mentioned in several AAS newsletters; however, non-members of AAS were also recruited to include respondents from a variety of backgrounds. Preliminary results of the survey are presented and will be used to hone the style and content of the column to serve the widest possible audience. Responses continue to be collected at: https://goo.gl/forms/Lhwl2aWJl2Vkoo7v1

Author(s): Teresa Wilson[1]
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158.02 – Oxford Astronomer John Knight Fotheringham (1874-1936) as Unwitting Godfather of J.R.R. Tolkien's Fictional Luni-solar Holiday "Durin's Day"

It is well known that famed fantasy author J.R.R. Tolkien incorporated a great deal of general astronomical knowledge into his Middle-Earth novels and other works, including references to the phases and motion of the moon, the seasonal cycle of the constellations, and the historical use of meteoritic iron. Various authors have also demonstrated his use of various scientific hypotheses of his time, such as Wegener's continental drift and the conflicting pre-Apollo models of lunar formation, as well as specific astronomical events, such as the spectacular auroral displays in 1926, a December 8, 1927 lunar eclipse, and several spectacular comets visible in 1927. An astronomical mystery remains concerning one of Tolkien's most famous works, *The Hobbit* (written between the summer of 1930 and January 1933, and finally published in 1937). One of the important plot points is a message hidden in an heirloom map that explains that the secret entrance to a treasure-loaded mountain kingdom can only been found with the last ray of sunlight on a holiday that is notoriously difficult to calculate, known as Durin's Day. Tolkien scholars have pondered why the author transformed the date, initially the last ray of sunlight on the first day of the first lunar cycle of Autumn, into a complex affair that was difficult to predict. This presentation summarizes evidence that the answer involves Tolkien's probable knowledge of highly publicized work by his Oxford colleague, J.K. Fotheringham, on not only the visibility of the young waxing crescent moon, but the importance of lunar phases in dating historical events, including the crucifixion (research that would have keenly resonated with the devout Tolkien). In addition, Tolkien was involved in university politics at the same time that Fotheringham was (unsuccessfully) maneuvering to become the Savilian Professor of Astronomy, namely 1930-1, the years of the early work on *The Hobbit*.

Author(s): Kristine Larsen[1]
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158.03 – Caroline Furness and the Evolution of Visual Variable Star Observing

An Introduction to the Study of Variable Stars by Dr. Caroline Ellen Furness (1869-1936), Director of the Vassar College Observatory, was published in October 2015. Issued in honor of the fiftieth anniversary of the founding of Vassar College, the work was meant to fill a void in the literature, namely as both an introduction to the topic of variable stars as well as a manual explaining how they should be observed and the resulting data analyzed. It was judged to be one of the hundred best books written by an American woman in the last hundred years at the 1933 World's Fair in Chicago. The book covers the relevant history of and background on types of variable stars, star charts, catalogs, and the magnitude scale, then describes observing techniques, including visual, photographic, and photoelectric photometry. The work finishes with a discussion of light curves and patterns of variability, with a special emphasis on eclipsing binaries and long period variables. Furness's work is therefore a valuable snapshot of the state of astronomical knowledge, technology, and observing techniques from a century ago. Furness's book and its reception in the scientific community are analyzed, and parallels with (and departures from) the current advice given by the AAVSO to beginning variable star observers today are highlighted.

Author(s): Kristine Larsen[1]
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158.04 – Changes in Latitude, Changes in Attitude: U.S. Naval Observatory Observations of Solar Eclipses

1869 to the Present

In anticipation of the 2017 August 21 total solar eclipse over the continental United States, the history of U.S. Naval Observatory eclipse observations illustrates the changes in science, technology, and policy over the past 148 years.
USNO eclipse observations began in 1869, when staff traveled to Des Moines, Iowa and the Bering Strait to look for intra-mercurial planets and to observe the solar corona. During the golden age of eclipse expeditions, the USNO officially participated in a dozen expeditions between 1869 and 1929. Seven of these expeditions were to US locations: 1869 in Iowa; 1878 in Colorado, Wyoming, and Texas; 1880 in California; 1900 in Georgia and North Carolina; 1918 in Oregon; 1923 in California; and 1925 in New York. A total solar eclipse has not traced a path across the width of the continental US since 1918 although several eclipses have passed over parts of the US since then.
A few official expeditions occurred later in the 20th century to measure the solar diameter, including a total eclipse in the northwest US in 1979 and an annular eclipse across the southeast in 1984. However, observations began transitioning to mostly personal adventures as individual astronomers arranged unofficial trips.
Historians can use the USNO Multi-year Interactive Computer Almanac (MICA) to compute local circumstances for solar eclipses world-wide starting with the annual eclipse of 1800 April 24, which was visible from Alaska. Those looking to make history in 2017 may consult the USNO 2017 August 21 Solar Eclipse Resource page (http://aa.usno.navy.mil/data/docs/Eclipse2017.php).

Author(s): Malynda R. Chizek Frouard[1], Linda Towne[1], George H. Kaplan[1]
Institution(s): *1. US Naval Observatory*

158.05 – Instrumentation for Infrared Astronomy in the Collections of the National Air and Space Museum, Smithsonian Institution

The National Air and Space Museum of the Smithsonian Institution is responsible for preserving the material heritage of modern astronomical history. We place emphasis on American accomplishments, on both airborne and spaceborne instrumentation, and on ground based instrumentation that stimulated and supported spaceborne efforts. At present the astronomical collection includes over 600 objects, of which approximately 40 relate to the history of infrared astronomy. This poster will provide a simple listing of our holdings in infrared and far-infrared astronomy, and will highlight particularly significant early objects, like Cashman and Ektron cells, Leighton and Neugebauer's Caltech 2.2 micron survey telescope, Low's Lear Jet Bolometer, Harwit's first Aerobee IR payload and Fazio's balloon-borne observatory. Elements from more recent missions will also be included, such as instruments from KAO, an IRAS focal plane instrument, FIRAS from COBE, the payload from Boomerang and Woody and Richards' balloonsonde payload. The poster author will invite AAS members to comment on these holdings, provide short stories of their experiences building and using them, and suggest candidates for possible collection.

Author(s): David H. DeVorkin[1]
Institution(s): *1. Smithsonian Inst.*

158.06 – Airborne Infrared Astronomical Telescopes

A unique program of infrared astronomical observations from aircraft evolved at NASA's Ames Research Center, beginning in the 1960s. Telescopes were flown on a Convair 990, a Lear Jet, and a Lockheed C-141 - the Kuiper Airborne Observatory (KAO) - leading to the planning and development of SOFIA: a 2.7 m telescope now flying on a Boeing 747SP. The poster describes these telescopes and highlights of some of the scientific results obtained from them.

Author(s): Edwin F. Erickson[1]
Institution(s): *1. NASA Ames Research Center*

158.07 – Urania in the Marketplace: The Blue Comet (A Railroad's Astronomical Heritage)

Between 1929 February 21 and 1941 September 27 the Central New Jersey Railroad operated a luxury passenger train between Jersey City and Atlantic City. Named *The Blue Comet*, the locomotive, tender, and coaches sported a unique royal blue paint scheme designed to evoke images of celestial bodies speeding through space. Inside each car were etched window panes and lampshades featuring stars and comets. Each coach sported the name of a famous comet on its side; these comets were of course named for their discoverers. Some of the astronomers honored in this unique fashion remain famous to this day, or at least their comets do. The names D'Arrest, Barnard, Encke, Faye, Giacobini, Halley, Olbers, Temple, Tuttle, and Westphal are familiar ones. But Biela, Brorsen, deVico, Spitaler, and Winnecke have now largely faded into obscurity; their stories are recounted here.

Although more than seventy years have elapsed since its last run, *The Blue Comet*, perhaps the most famous passenger train in American history, lives on in the memories of millions of passengers and railfans. This famous train returned to the attention of millions of television viewers on the evening of 2007 June 3, in an episode of the HBO series *The Sopranos*.

This work was supported by a faculty development grant from Valdosta State University.

Author(s): Kenneth S. Rumstay[1]
Institution(s): *1. Valdosta State Univ.*

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200 – Plenary Talk: The LED Outdoor Lighting Revolution: Opportunities, Threats and Mitigation, Martin Aubé (Cégep de Sherbrook)

200.01 – The LED outdoor lighting revolution : Opportunities, threats and mitigation

The presence of artificial light at night (ALAN) in environment is now known to have non negligible consequences on the night sky, the fauna, the flora and the human health. A real revolution is undergoing in the outdoor lighting industry threatens the night integrity. This revolution is driven by the advent of the cost-effective Light-Emitting Diode (LED) technology into the outdoor lighting industry. The LEDs provides many opportunities: they are long lasting, easily controlled, and generally allow a more efficient photometric design which, in term, may result in energy savings.

After explaining the complex and non-linear behaviour of the propagation of the ALAN into the nocturnal environment, we will outline the potential impact of the ALAN on the human health and on the night sky, and we will introduce some dedicated indicators for its evaluation. We will focus on the role of the blue content of the ALAN in the evaluation of its impact. More specifically we will show how white LED technology, that often shows increased blue light content, compares to the traditional High Pressure Sodium technology. Finally, we will identify the possible mitigations to restrict the adverse impacts of the white LEDs in the urban and rural environment.

Author(s): Martin Aube[1]
Institution(s): *1. Cegep de Sherbrooke*

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201 – AAS Prize Presentations: Buchalter Cosmology, Weber, George Van Biesbroeck, Tinsley, LAD Astrophysics Prize, Education

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202 – Extrasolar Planets: Characterization & Theory II

202.01 – Cloud and Haze in the Atmospheres of

Wide-Separation Exoplanets

Imaging and characterizing wide-separation exoplanets with spaceborne coronagraph will write a new chapter of exoplanet science. Most of the exoplanets to be observed by coronagraph will be located further away from their parent stars than is Earth from the Sun. These “cold” exoplanets have atmospheric environments conducive for the formation of water and/or ammonia clouds by condensation. Above the condensation clouds, photochemical processes driven by UV irradiation can lead to formation of haze particles. Understanding the cloud and haze in the atmosphere of wide-separation exoplanets is essential, because they determine the planets’ spectral signal and how well we can measure the planets’ atmospheric abundances. Using atmospheric chemistry and radiative transfer models, I find that the mixing ratio of methane and the pressure level of the uppermost cloud deck on these planets can be uniquely determined from their reflection spectra, if a strong band and a weak band of methane are measured at moderate spectral resolutions. This determination can however be biased by a haze layer above the cloud. To constrain the uncertainty, atmospheric photochemistry models are used to estimate the amount of haze particles.

Author(s): Renyu Hu[1]
Institution(s): *1. Jet Propulsion Laboratory*

202.02 – Formation of Hazes & Clouds on Tidally Locked Hot-Jupiters: Insights from Size Distribution Dynamics

We present the first application of a self-consistent, one-dimensional microphysical and vertical transport model based on the Community Aerosol and Radiation Model for Atmospheres (CARMA) to determine the size distribution of $MgSiO_3$ cloud particles at various altitudes for a grid of tidally locked hot-jupiters from first principles. Our models allow us to uncover a strong correlation between the total cloud mass, atmospheric mixing, and equilibrium temperature. Using the resulting cloud particle size distributions we calculate the atmospheric optical depth and find a strong correlation between atmospheric mixing, equilibrium temperature, and the pressure level where the atmosphere becomes opaque. We are further able to test assumptions made by other cloud modeling techniques and find that we do not recover a log-normal distribution of particle sizes for any set of parameters in our grid and that the largest particle size is not the dominant contributor to atmospheric opacity.

Author(s): Diana Powell[2], Xi Zhang[2], Peter Gao[1], Vivien Parmentier[3]
Institution(s): *1. California Institute of Technology, 2. UC Santa Cruz, 3. University of Arizona*

202.03 – Impact of Sulfur Hazes on the Reflected Light Spectra of Giant Exoplanets

Recent work has shown that photochemical hazes composed of elemental sulfur and its allotropes may arise in the atmospheres of warm and temperate giant exoplanets due to the photolysis of H_2S. We investigate the impact such a haze would have on an exoplanet's geometric albedo spectrum using a suite of established radiative-convective, cloud, and albedo models, and how this may impact future direct imaging missions, such as WFIRST. For Jupiter-massed planets, photochemical destruction of H_2S results in the production of ~1 ppmv of S_8 between 100 and 0.1 mbar. The S_8 mixing ratio is largely independent of the stellar UV flux, vertical mixing rates, and atmospheric temperature for expected ranges of those values, such that the S_8 haze mass is dependent only on the S_8 supersaturation, controlled by the local temperature. Nominal haze masses are found to drastically alter a planet's geometric albedo spectrum: whereas a clear atmosphere is dark at wavelengths between 0.5 and 1 µm due to molecular absorption, the addition of a sulfur haze boosts the albedo there to ~0.7 due to its purely scattering nature. Strong absorption by the haze shortward of 0.4 µm results in albedos <0.1, contrasting the high albedos produced by Rayleigh scattering in a clear atmosphere. These dramatic alteration in the geometric albedo spectra will lead to substantial color changes for hazy planets away from that expected for more Jupiter-like planets. For this reason colors are unlikely to provide definitive identification of warm Jupiter-like planets. The albedo change due to a sulfur haze is largely independent of the location of the haze in the atmosphere, but is a strong function of the haze optical depth as controlled by its column number density and mean particle size, though the absorption feature at short wavelengths remains robust. Detection of such a haze by future direct imaging missions like WFIRST is possible, though discriminating between a sulfur haze and any other reflective material, such as water ice, will require observations shortward of 0.4 µm, which is currently beyond WFIRST's grasp.

Author(s): Peter Gao[1], Mark S. Marley[1], Kevin Zahnle[1], Tyler D. Robinson[3], Nikole K. Lewis[2]
Institution(s): *1. NASA Ames Research Center, 2. Space Telescope Science Institute, 3. University of California, Santa Cruz*

202.04D – The Exo-Atmosphere of WASP-103b

Spectroscopic measurements of exo-atmospheres are essential for full characterization of an exoplanet's composition, temperature, and habitability. Given the state of our current technology, transiting hot Jupiters are the best candidates for both transmission and emission spectroscopy due to their large radii, extended atmospheres, and hot equilibrium temperatures. WASP-103b is a 1.5 Jupiter-radius gas giant at the edge of tidal disruption orbiting an F-star 470 pc away. Its very-hot temperature (2890 K), ultra-short period (0.92 day), and UV-quiet host star make WASP-103b a compelling target for exo-atmosphere observations. The presence of a nearby companion star complicates analyses of the WASP-103 system, and is likely physically associated with the host star and planet. We apply state-of-the-art Gaussian process regression to provide precise solutions to faint signals, with models that are flexible enough to accommodate extreme detector systematics and unknown noise sources. Through a combination of spaced-based emission spectra and multi-telescope ground-based transmission spectra and photometry, we show that WASP-103b has no obvious molecular absorption in the near-infrared, anomalously strong Rayleigh scattering, and the potential for a stratospheric thermal inversion. WASP-103b, along with other highly-irradiated hot Jupiters, will be a key planet for validating hypotheses about the existence and origin of thermal inversions, and developing analysis methods viable for exo-atmospheric studies of the future.

Author(s): Kimberly Michelle Star Cartier[1], Jason Wright[1], Thomas G. Beatty[1]
Institution(s): *1. Pennsylvania State University*

202.05 – Probing the Physics and Chemistry in Hot Jupiter Exoclimes for Future Missions

Unique and exotic planets give us an opportunity to understand how planetary systems form and evolve over their lifetime, by placing our own planetary system in the context of vastly different extrasolar systems. In particular, close-in planets such as Hot Jupiters provide us with valuable insights about the host stellar atmosphere and planetary atmospheres subjected to such high levels of stellar insolation.

Observed spectroscopic signatures from a planet reveal all spectrally active species in its atmosphere, along with information about its thermal structure and dynamics, allowing us to characterize the planet's atmosphere. NASA’s upcoming missions will give us the high-resolution spectra necessary to constrain such atmospheric properties with unprecedented accuracy. However, to interpret the observed signals from exoplanetary transit events with any certainty, we need reliable atmospheric modeling tools that map both the physical and chemical processes affecting the particular type of planet under investigation. My work seeks to expand on past efforts in these two categories for irradiated giant exoplanets. These atmospheric models can be combined with future mission simulations to build tools that allow us to self-consistently “retrieve” the signatures we can expect to observe with the instruments.

In my work thus far, I have built the robust Markov Chain Monte Carlo convergence scheme, with an analytical radiative equilibrium formulation to represent the thermal structures, within the NEMESIS atmospheric radiative transfer modeling and retrieval tool. I have combined this physics-based thermal structure with photochemical abundance profiles for the major gas atmospheric constituents, using the NASA Astrobiology Institute's VPL/Atmos photochemistry model, which I recently extended to giant planet regimes. Here I will present my new Hot Jupiter models and retrievals results constructed from these latest enhancements. For comparison, I will show applications to both archival data from present missions and JWST/NIRSpec simulations, and discuss any new information we expect to reliably extract from the upcoming *JWST* mission.

Author(s): Mahmuda Afrin Badhan[4], Ravi Kumar Kopparapu[4], Shawn Domagal-Goldman[1], Drake Deming[4], Eric Hébrard[3], Patrick GJ Irwin[5], Natasha Batalha[2], Avi Mandell[1]
Institution(s): *1. NASA Goddard Space Flight Center, 2. Pennsylvania State University, 3. University of Exeter, 4. University of Maryland College Park, 5. University of Oxford*

202.06 – Through the Looking-Glass: Reflected Light from Other Worlds

High-resolution spectroscopy (R>100,000) is a robust and powerful tool for directly characterizing exoplanet atmospheres that is applicable to both transiting and non-transiting planets, as well as those with relatively large projected separation angles. In the infrared, the technique has unambiguously revealed the presence of complex molecules, such as water, in hot Jupiters, as well as measuring exoplanet rotation rates and their day-to-night winds. In the optical, the technique is highly suited to characterizing the atmosphere of our nearest rocky neighbor, Proxima b, by detecting the Doppler shift and modulation of its host star spectrum as reflected by the planet's dayside. However, the technique is currently not yet robustly proven at optical wavelengths. Here, we present new results on the non-transiting hot Jupiter, 51 Peg b, using 5 half nights of optical HARPS-N spectroscopy from the 3.5m TNG telescopes. We aimed to detect reflected light from the planet's dayside and obtain one of the most detailed exoplanet reflection spectra to date, spanning 387-691 nm in bins of 50nm. Our goal is to strongly constrain previous claims of a very high albedo or highly inflated radius for 51 Peg b and assess the potentially cloudy nature of the planet. This will also guide us in using high-resolution spectroscopy to characterize Proxima b in the era of the extremely large telescopes.
This work was performed in part under contract with the California Institute of Technology/Jet Propulsion Laboratory funded by NASA through the Sagan Fellowship Program executed by the NASA Exoplanet Science Institute.

Author(s): Jayne Birkby[1], Roi Alonso[2], Sergio Hoyer[2], Mercedes Lopez-Morales[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Instituto de Astrofisica de Canarias*

202.07D –
Searching for new diagnostics of exoplanet atmospheres

By characterizing the atmospheres of exoplanets we learn about their physical properties and chemical composition. This knowledge will ultimately lead to better understanding of the processes that govern planetary formation and evolution. In the light of upcoming space- and ground-based observatories that will enable remarkable advancement in our observational capabilities, it is important to keep searching for new diagnostic tools that may help us place more robust and reliable constraints on different atmospheric properties. As part of my Ph.D. thesis I investigated new methods for probing the atmospheres of exoplanets. I this talk I will present how observing the spectral signatures of Raman scattering imprinted in the reflected light of gaseous exoplanets at short optical wavelengths can be used to constrain the bulk composition of an exoplanet atmosphere, its temperature, and the presence and/or the altitude of thick clouds. I will discuss the prospects for detecting these signatures in nearby exoplanets using the next generation of observational facilities. I will finish by presenting my recent work on looking for new diagnostics of extended exoplanet atmospheres which may help us to better understand the processes of atmospheric escape and mass loss in exoplanets close to their host stars.

Author(s): Antonija Oklopcic[1], Christopher M. Hirata[2], Kevin Heng3
Institution(s): *1. California Institute of Technology, 2. Ohio State University, 3. University of Bern*

203 – AGN, QSO, Blazars: Energetics & Physics

203.01 – A Radiative Transport Model for Blazars

Blazars are observed across the electromagnetic spectrum, often with strong variability throughout. The underlying electron distribution associated with the observed emission is typically not computed from first principles. We start from first-principles to build up a transport model, whose solution is the electron distribution, rather than assuming a convenient functional form. Our analytical transport model considers shock acceleration, adiabatic expansion, stochastic acceleration, Bohm diffusion, and synchrotron radiation. We use this solution to generate predictions for the X-ray spectrum and time lags, and compare the results with data products from BeppoSAX observations of X-ray flares from Mrk 421. This new self-consistent model provides an unprecedented view into the jet physics at play in this source, especially the strength of the shock and stochastic acceleration components and the size of the acceleration region.

More recently, we augmented the transport model to incorporate Compton scattering, including Klein-Nishina effects. In this case, an analytical solution cannot be derived, and therefore we obtain the steady-state electron distribution computationally. We compare the resulting radiation spectrum with multi-wavelength data for 3C 279. We show that our new Compton + synchrotron blazar model is the first to successfully fit the FermiLAT gamma-ray data for this source based on a first-principles physical calculation.

Author(s): Tiffany Lewis[1], Finke Justin[2], Peter A. Becker[1]
Institution(s): *1. George Mason University, 2. Naval Research Laboratory*

203.02D – Kepler and K2 Light Curves of Active Galaxies: Optical Time Domain Windows into the Central Engine

We have used the Kepler spacecraft, the most precise photometer ever built, to measure aperiodic variability in active galactic nuclei. Kepler's high cadence and even sampling make it an exquisite instrument for astrophysics far beyond exoplanets, especially in the study of active galactic nuclei, which have long been known for their strong optical variability. Because of the very small size of accretion disks, this variability provides the only direct probe of their interior physics. In order to find AGN for study with the Kepler and K2 missions, we have conducted an X-ray survey of the Kepler and K2 fields of view with the Swift XRT, locating hundreds of new AGN that sample a wide parameter space in black hole mass and accretion rate. This survey also yielded an abundant sample of X-ray bright variable stellar targets. We then built a custom pipeline to handle Kepler light curves of extended objects (the AGN host galaxies) with stochastic variability. This was necessary, since the default Kepler pipeline was not optimized for such objects. Power spectral density (PSD) analysis of the AGN light curves exhibit characteristic timescales on the order of 2.5 days to 80 days, consistent with the physical timescales believed to be important in the disk. Optical spectral follow-up of the full sample enables comparison with physical parameters such as black hole mass, Eddington ratio and bolometric luminosity. The black hole mass relationship with characteristic timescale is consistent with an extrapolation of the relationship seen in stellar mass black holes, implying accretion similarities across many orders of magnitude. One object hosts a strong candidate for an optical quasi-periodic oscillation (QPO), the characteristic frequency of which correctly predicts the measured single-epoch black hole mass. The sample also contains bimodal flux distributions, which may indicate accretion states. Many of the high-frequency power spectral density (PSD) slopes are generally consistent with damped random walk models, but these fail to describe the full range of variability observed. The light curves continue to provide a fertile testing bed for the various predictions of accretion disk simulations.

Author(s): Krista Lynne Smith4, Richard Mushotzky4, Patricia T. Boyd3, Steve B. Howell2, Neil Gehrels3, Dawn M. Gelino1
Institution(s): *1. Caltech, 2. NASA ARC, 3. NASA GSFC, 4. University of Maryland College Park*

203.03D – Excitation Mechanisms of Near-Infrared Emission Lines in LINER Galaxies

I will present high spatial resolution, integral field spectroscopic observations of the nearby LINER (low ionization nuclear emission line region) galaxy NGC 404. LINERs are found at the centers of ~1/3 of galaxies within 40 Mpc, but their physical nature is not well understood. Although NGC 404 is thought to host a intermediate mass black hole at its center, it is unclear whether accretion onto the black hole or another mechanism such as shock excitation drives its LINER emission. We use the OSIRIS near-infrared integral field spectrograph at Keck Observatory behind laser guide star adaptive optics to map the strength and kinematics of [FeII], H_2, and hydrogen recombination lines in the nucleus of NGC 404. These observations have a spatial pixel sampling of 0.5 pc and span the central 30 pc of the galaxy. We find that the ionized and molecular gas show differences in their morphology and kinematics on parsec scales. In particular, there are regions with line ratios of [FeII]/Pa-β that are much higher than previously seen in spatially integrated spectra, significantly restricting the possible excitation mechanisms of the near-infrared emission lines in this source. We are also applying these analysis techniques to 10 additional nearby LINERs, a part of a larger sample of 14 sources, to understand what drives the emission lines in these active galaxies. As a part of this program, I worked on the upgrade of the detector in the OSIRIS spectrograph, which has allowed observations for this survey obtained since January 2016 to be taken with increased instrument sensitivity of a factor of ~2 at J-band wavelengths (1.2 - 1.4 microns) and ~1.6 at H- and K-band wavelengths (1.5 - 2.4 microns). I will present results from the LINER survey, the OSIRIS detector upgrade, and also touch on related work using stellar orbits around the Milky Way supermassive black hole Sgr A* to constrain the mass and distance to our own Galactic Center.

Author(s): Anna Boehle1
Institution(s): *1. UCLA*

203.04 – The Similarity of Luminosity in Quasar Doppelganger Pairs

Quasars, the accreting supermassive black holes at the centers of galaxies, are among the most luminous objects in the universe and in principle ideal for use as so-called "standard candles" with applications in cosmology. Despite possessing a number of spectral features long known to correlate with luminosity, quasars have failed to realize their potential. We have employed spectral principal component analysis to identify more than 1000 quasar pairs from the Sloan Digital Sky Survey with virtually identical ultraviolet spectra, which we call doppelgangers, in order to understand the limits of determining luminosity from spectral features alone. While the majority of doppelgangers have very similar luminosity, there exists a surprisingly large scatter and objects with identical spectra can differ in luminosity by factors of four or larger. We offer some possible physical explanations for this large variance and how it quantifies the problem of ever using quasars as standard candles based on spectral features.

Author(s): Michael S. Brotherton2, Thomas Bernard Rochais2, Vikram Singh2, William T. Chick2, Jaya Maithil2, Jessica Sutter2, Zhaohui Shang1
Institution(s): *1. Tianjin Normal University, 2. Univ. of Wyoming*

203.05D – Probing Feedback with the Thermal Sunyaev-Zel'dovich Effect

The thermal Sunyaev-Zel'dovich (tSZ) effect imparts a spectral distortion to the Cosmic Microwave Background (CMB) at millimeter wavelengths, the amplitude of which provides a redshift independent probe of the thermal energy of diffuse ionized gas. With the goal of constraining the impact of feedback from active galactic nuclei on the diffuse circumgalactic environment, we have analyzed the tSZ contribution to the stacked spectral energy distributions of both radio galaxies and optically selected quasars, using millimeter and far-infrared surveys from the Atacama Cosmology Telescope and the Herschel Space Observatory. I will present the results of these studies and discuss the evidence we find for the tSZ effect associated with both these samples. While the tSZ signal from radio galaxies is consistent with expectations from purely gravitational heating, the tSZ amplitude associated with the quasar sample is found to be indicative of an additional heating source for the expected range of quasar host halo masses. We attribute this excess thermal energy to feedback influencing the circumgalactic environments of these systems. I will discuss the consequences of these results and additionally provide forecasts for tSZ measurements from future samples and surveys.

Author(s): Devin T Crichton1
Institution(s): *1. Johns Hopkins University*
Contributing team(s): Atacama Cosmology Telescope Collaboration

204 – Star Formation: Galactic to Extragalactic

204.01 – Mapping the High-Dimensional ISM with Kinetic Tomography

The interstellar medium (ISM) of a galaxy plays a critical role in its chemical evolution, via flows of enriched material into and out of star-forming molecular clouds, and even more expansive flows on kiloparsec scales through the disk and halo. The Milky Way is the only large galaxy in which we can resolve these motions at the level of individual molecular clouds, measure the kinematics of interstellar dust, and map the full three-dimensional velocity field of multiple ISM components; all of these are necessary to understand the evolution of spiral arms and molecular clouds, along with the redistribution of heavy elements throughout the Galaxy. I will present early results from a novel technique called "kinetic tomography", in which we combine stellar reddening (from Pan-STARRS), interstellar emission (CO and HI), and interstellar absorption (from APOGEE) data into high-dimensional datasets, and then extract distance-resolved kinematic information on multiple phases of the ISM. These methods are providing new views on the evolution of molecular clouds and chemical mixing in the ISM.

Author(s): Gail Zasowski2, Joshua Eli Goldston Peek2, Kirill Tchernyshyov1
Institution(s): *1. Johns Hopkins University, 2. Space Telescope Science Institute*

204.02D – Deciphering Galactic Hydrogen with 21-SPONGE

Neutral hydrogen (HI) in the interstellar medium (ISM) is crucial to the life cycles of galaxies. The balance between disparate phases of HI -- including the cold neutral (CNM) and warm neutral (WNM) medium -- governs the formation of dense, star-forming material, and reflects the nature of feedback in galaxies. To probe the multi-phase structure of HI, we present results from

21-SPONGE: the largest and most sensitive survey for Galactic HI absorption ever at the Karl G. Jansky Very Large Array (VLA). Complemented by HI emission from the Arecibo Observatory, 21-SPONGE is uniquely sensitive to CNM and WNM temperatures from 10-10^4 K and column densities from 10^{18}-10^{22} cm^{-2}. Despite our unprecedented sensitivity, the maximum temperature we detect for individual spectral lines is Ts~1500 K, although stacking analysis of 21-SPONGE absorption lines indicates the presence of pervasive, high-Ts WNM population with Ts~7000 K. To understand the physics underlying these results, we developed Autonomous Gaussian Decomposition (AGD), a Python-based tool for efficiently and objectively analyzing spectral lines. By applying AGD to 21-SPONGE and 1000s of synthetic HI spectra from 3D numerical simulations, we correct our measurements for completeness and observational biases. We further prove that we can successfully recover the temperatures and densities of real clouds along simulated lines of sight. In addition, we show that absorption line shapes are sensitive to the strength and topology of the Lyman alpha radiation field and its role in HI excitation, which are poorly-constrained yet important for understanding the energy balance of the ISM. Our results are among the first to statistically quantify the success of observational methods at reproducing true HI properties, and represent crucial steps towards understanding the role of HI in star formation.

Author(s): Claire Murray4, Snezana Stanimirovic4, Miller Goss1, Carl E. Heiles2, John Miller Dickey3, Robert Lindner4, Brian L Babler4
Institution(s): *1. NRAO, 2. University of California - Berkeley, 3. University of Tasmania, 4. University of Wisconsin - Madison*

204.03D – Bridging the Gap from Galactic to Extragalactic: Star Formation and Giant Molecular Clouds within the Nearby Spiral Galaxy NGC 300

The questions surrounding the origins of stars are of key importance in astrophysics across a huge range in physical scales. However, until recently, investigations have been restricted to either detailed studies targeting a few nearby regions in the Milky Way, or kpc- or larger-scale studies of entire galaxies. Between these two scales lies a crucial gap in understanding. In this thesis work, I have taken steps in bridging this gap between Galactic and extragalactic star formation. I will present the results of a campaign of observations and modeling targeting the nearby spiral galaxy NGC 300. Using an extensive suite of multi-wavelength data I have characterized the star formation activity and molecular gas in a large sample of star-forming regions within this galaxy. Additionally, I have assembled an extensive (300 clouds) and high resolution (10 pc) catalog of Giant Molecular Clouds (GMCs) based on ALMA CO observations. This unprecedented look at the population of GMCs in a nearby spiral galaxy reveals an astonishing range of morphologies and properties in the Molecular Gas as well as providing a key testbed for comparison with GMCs in the Milky Way and other nearby galaxies. The GMCs in NGC 300 appear to have similar global properties and show scaling relations consistent with those seen in the Milky Way. Furthermore, the star formation rate appears to correlate with the mass of molecular gas with approximately 250 Gyr depletion time, extending the relation discovered in the Milky Way linearly to larger scales. These results suggest a level of universality in the star formation process within spiral galaxy disks like our own Milky Way.

Author(s): Christopher Faesi1
Institution(s): *1. Harvard Univ.*

204.04D – Untangling the magnetic fields in spiral galaxy NGC 6946 with wide-band polarimetry

We present 13 cm polarization observations of nearby spiral galaxy NGC 6946. These data provide a new perspective into the magnetic field structure of this galaxy. Previous observations show strong depolarization between 6 cm and 22 cm, and we show that the morphology of the 13 cm polarization bridges this gap. We combine all available high resolution polarization observations to fit models of the line of sight magnetic field structure across the disk. We find simple screens of Faraday rotation, differential Faraday rotation, and internal Faraday dispersion are insufficient to explain the observed depolarization, and present the results of the best fit models. We discuss how future broadband observations and improved models will help reconstruct the full 3D model of the magnetic field structure in the disks and haloes of galaxies.

Author(s): Anna Williams2, George Heald1, Eric M. Wilcots2, Ellen Gould Zweibel2
Institution(s): *1. CSIRO, 2. University of Wisconsin-Madison*

204.05D – The EDGE--CALIFA Survey: Molecular Gas Depletion Time in Galaxy Centers

We present the first results of the EDGE--CALIFA survey, combining the power of optical Integral Field Unit and millimeter-interferometric observations to study the variations of molecular gas depletion time in the centers of 86 galaxies. Our key findings are the following. (1) About 25% of our sample shows deviations from the Kennicutt-Schmidt relation, namely a shorter depletion time in the centers relative to the disks. If the galaxy centers undergo star formation cycles, then they spend 25% of their duty cycles in a burst-mode period. (2) Barred galaxies tend to have shorter depletion time in the centers, presumably due to the dynamical effects induced by bars. (3) Galaxies with shorter depletion time in the centers tend to have higher ratio of stellar to molecular gas gravity, because that ratio sets the gravitational pressure per unit molecular gas mass that must be balanced by the energy and momentum feedback from star formation to maintain thermal and dynamical equilibrium states. (4) Both depletion time and bar dynamics affect the gradient of gas-phase metallicities, where unbarred galaxies with shorter depletion time in the centers show the steepest gradient, presumably due to high star formation activities that inject more metals and lack of gas mixing because bars are not present. We discuss possible scenarios that may cause the variations of depletion time in the centers and their implications within the context of galaxy evolution.

Author(s): Dyas Utomo2, Leo Blitz2, Alberto D. Bolatto4, Tony H. Wong3, Eve C. Ostriker1
Institution(s): *1. Princeton University, 2. University of California, Berkeley, 3. University of Illinois, 4. University of Maryland*
Contributing team(s): the EDGE--CALIFA collaboration

205 – First Galaxies & Early Universe

205.01 – The pair and major merger history of galaxies up to z=6 over 3 square degrees

A major goal in extragalactic astronomy is understanding how stars and gas are put into galaxies. As such we present the pair fraction and derived major merger and stellar mass assembly histories of galaxies up to z = 6. We do this using new techniques from photometric redshift probability distribution functions, and state of the art deep near-infrared data from the UDS, VIDEO and UltraVISTA COSMOS fields for galaxies at z < 3, and CANDELS data for galaxies at 3 < z < 6. We find that major mergers at high redshift are not the dominant mode of placing stars into galaxies, but that star formation is a more important process by factors of 10 or higher. At z < 3 major mergers will at most double the masses of galaxies, depending on the stellar mass or number density selection method. At z < 1 we find that major mergers deposit more stellar mass into galaxies than star formation, the reverse of the process seen at higher redshifts. However, at z > 1 there must be a very important unknown mode of baryonic acquisition within galaxies that is not associated with major mergers. We further discuss how the merger history stays relatively constant at higher redshifts, and show the comparison of our results to theoretical predictions.

Author(s): Christopher Conselice2, Carl Mundy2, Kenneth Duncan1
Institution(s): *1. Leiden Observatory, 2. Univ. of Nottingham*

205.02D – The formation and evolution of high-redshift dusty galaxies

Star formation and chemical evolution are among the biggest questions in galaxy formation and evolution. High-redshift dusty galaxies are the best sites to investigate mass assembly and growth, star formation rates, star formation history, chemical enrichment, and physical conditions. My thesis is based on two populations of high-redshift dusty galaxies, submillimeter galaxies (SMGs) and quasar 2175 Å dust absorbers, which are selected by dust emission and dust absorption, respectively.
For the SMG sample, I have worked on the gravitationally lensed dusty, star-forming galaxies (DSFGs) at $2.8 < z < 5.7$, which were first discovered by the South Pole Telescope (SPT) and further confirmed by ALMA. My thesis is focused on the stellar masses and star formation rates of these objects by means of multi-wavelength spectral energy distribution (SED) modelling. The data include HST/WFC3, Spitzer/IRAC, Herschel/PACS, Herschel/SPIRE, APEX/Laboca and SPT. Compared to the star-forming main sequence (MS), these DSFGs have specific SFRs that lie above the MS, suggesting that we are witnessing ongoing strong starburst events that may be driven by major mergers. SPT0346-52 at z = 5.7, the most extraordinary source in the SPT survey for which we obtained Chandra X-ray and ATCA radio data, was confirmed to have the highest star formation surface density of any known galaxy at high-z.
The other half of my thesis is focused on a new population of quasar absorption line systems, 2175 Å dust absorbers, which are excellent probes of gas and dust properties, chemical evolution and physical conditions in the absorbing galaxies. This sample was selected from the SDSS and BOSS surveys and followed up with the Echelle Spectrographs and Imager on the Keck-II telescope, the Red & Blue Channel Spectrograph on the Multiple Mirror Telescope, and the Ultraviolet and Visible Echelle Spectrograph onboard the Very Large Telescope. We found a correlation between the presence of the 2175 Å bump and other ingredients including high metallicity, high depletion level, overall low ionization state of gas, neutral carbon and molecules. I have also pushed forward this study by using HST IR grism to link the absorber and the host galaxy.

Author(s): Jingzhe Ma[7], Anthony H. Gonzalez[7], Jian Ge[7], Joaquin D. Vieira[8], Jason X. Prochaska[5], Justin Spilker[6], Maria Strandet[3], Matthew Ashby[1], Pasquier Noterdaeme[2], Britt Lundgren[9], Yinan Zhao[7], Tuo Ji[4], Shaohua Zhang[4], Paul Caucal[2]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Institut d'Astrophysique de Paris, 3. Max-Planck-Institut für Radioastronomie, 4. Polar Research Institute of China, 5. UC Santa Cruz, 6. University of Arizona, 7. University of Florida, 8. University of Illinois at Urbana-Champaign, 9. University of Wisconsin – Madison*
Contributing team(s): SPT SMG collaboration

205.03 – Physical and observable properties of the first galaxies

The Hubble Ultra Deep Field and Frontier Fields have discovered over 1,500 galaxies at redshifts greater than 6. We present observational predictions for this high-redshift population, using the Renaissance Simulations, a suite of high-resolution cosmological simulations, that enables the correlation between key observables and the physical properties of the first galaxies in the Universe. Using a sample of over 3,000 resolved galaxies along with the formation of 10,000 massive Population III stars, we show that the luminosity function flattens above a UV magnitude of −14 but does not drop to zero even to our resolution limit of M_UV = −4. We find that dark matter halos below the atomic cooling limit (~10^8 M_sun) can form stars if they are chemically enriched, and they have similar mass-to-light ratios as local ultra-faint dwarfs. We utilize stellar population synthesis models, dust extinction using Monte Carlo methods, and photo-ionization modeling, all sourced from the simulation data, to obtain synthetic observations of the first galaxies. Using these results, we will be able to constrain the following properties of the first galaxies: (1) star formation histories and stellar populations, (2) nebular emission and dust extinction, and (3) the faint end of the luminosity function.

Author(s): John Wise[1], Kirk Stuart Simeon Barrow[1], Brian W. O'Shea[2], Michael L. Norman[3], Hao Xu[3]
Institution(s): *1. Georgia Institute of Technology, 2. Michigan State University, 3. UC - San Diego*

205.04D – High-Redshift Astrophysics Using Every Photon

Large galaxy surveys have dramatically improved our understanding of the complex processes which govern gas dynamics and star formation in the nearby universe. However, we know far less about the most distant galaxies, as existing high-redshift observations can only detect the very brightest sources. Intensity mapping surveys provide a promising tool to access this poorly-studied population. By observing emission lines with low angular resolution, these surveys can make use of every photon in a target line to study faint emitters which are inaccessible using traditional techniques. With upcoming carbon monoxide experiments in mind, I will demonstrate how an intensity map can be used to measure the luminosity function of a galaxy population, and in turn how these measurements will allow us to place robust constraints on the cosmic star formation history. I will then show how cross-correlating CO isotopologue lines will make it possible to study gas dynamics within the earliest galaxies in unprecedented detail.

Author(s): Patrick Breysse[1], Ely Kovetz[1], Mubdi Rahman[1], Marc Kamionkowski[1]
Institution(s): *1. Johns Hopkins University*

205.05 – RELICS: Reionization Lensing Cluster Survey

Hubble and Spitzer imaging programs observing galaxy cluster lenses have delivered some of the highest redshift galaxy candidates to date (z ~ 9 - 11, or 540 - 410 Myr after the Big Bang). These magnified galaxies are intrinsically faint, and thus more representative of the sources believed to be primarily responsible for reionization. Magnified galaxies are also observed brightly enough to be prime targets for detailed follow-up study with current and future observatories, including JWST. Building on the successes of CLASH and the Frontier Fields, we have begun RELICS, the Reionization Lensing Cluster Survey. By observing 41 massive clusters for the first time at infrared wavelengths, RELICS will deliver more of the best and brightest high-redshift candidates to the community in time for the November 2017 JWST GO Cycle 1 call for proposals. I will present our early results. I will also discuss prospects for JWST to follow-up known candidates and discover new galaxies at even higher redshifts (z > 11). The discovery efficiency gains from lensing will be even more pronounced at z > 11 if luminosity function faint end slopes are steeper than alpha ~ -2, as suggested by current models and observational extrapolations.

Author(s): Dan A. Coe[1]
Institution(s): *1. STScI*
Contributing team(s): RELICS Team

205.06D – Magnetizing the Universe during the Epoch of Reionization

Magnetic fields are speculated to play a significant role in early star formation, in particular, in the collapse dynamics at formation to influence the IMF, which may be imprinted in the local metal-poor population. These fields may arise by the amplification of primordial fields during the formation of the first stars (Population III) as well as their feedback. We study the former using cosmological magneto-hydrodynamic (MHD) simulations following the evolution of the magnetic field given a uniform primordial field from cosmological initial conditions to the formation of a single Pop III star and 2 Myr after its supernova. We find that a seed field of $B = 10^{-15}$ G can be maximally amplified by 6 orders of magnitude at the density peak and by a factor of 100 around the shell of the supernova shock. These stars then enrich their surroundings, setting the stage for the formation of the first metal-poor stars. We also explored the collapse dynamics of metal-poor mini-halos by running simulations with varying

Lyman-Werner background strength and metallicity. We produce a fit for the minimum mass for collapse as a function of the two parameters. Furthermore, Pop III stars provide a significant fraction of ionizing photons for reionization at high redshift ($z > 10$). We modify existing semi-numeric methods to include Pop III stars as ionizing sources. We find that the characteristic HII bubble sizes at all redshifts is decreased in comparison with models that only consider atomic-cooling halos and calculate an optical depth, $\tau_e = 0.0569$, consistent with the latest results from Planck. The resulting ionization fields from this method can then be used to efficiently model the ionizing UV background in numerical simulations. These results are essential to building a full MHD simulation of the first galaxies.

Author(s): Daegene Koh[1], John Wise[1]
Institution(s): *1. Georgia Institute of Technology*

206 – Space Missions from Cubesats to LUVOIR

206.01D – The Behavior of Warm Molecules in Planet-forming Disks and CHESS: a Pathfinder UV Spectrograph for the LUVOIR Surveyor

Understanding the evolution of gas over the lifetime of protoplanetary disks provides us with important clues about how planet formation mechanisms drive the diversity of exoplanetary systems observed to date. In the first part of my talk, I will discuss how we use emission line observations of molecular hydrogen (H_2) in the far-ultraviolet (far-UV) with the Cosmic Origins Spectrograph (COS) on the *Hubble Space Telescope* to study the warm molecular regions (a < 10 AU) of planet-forming disks. We compare the observations with analytic disk models that produce synthetic H_2 profiles, and we statistically determine the disk representations that best replicate the data. I will discuss the results of our comparisons and how the modeled radial distributions of H_2 in the disk help provide important constraints on the effective density of gas left in the inner disk of protoplanetary disks at various disk evolutionary stages. Finally, I will talk about follow-up studies that look to connect the warm, UV-pumped molecular populations of the inner disk to thermally-excited molecules observed in similar regions of the disk in the near- to mid-IR.
In the second part of my talk, I will discuss the observational requirements in the UV and IR band passes to gain further insights into the behavior of the warm, gaseous protoplanetary disk, focusing specifically on a spectrograph concept for the next-generation LUVOIR Surveyor. I will discuss a testbed instrument, the Colorado High-resolution Echelle Stellar Spectrograph (CHESS), built as a demonstration of one component of the LUVOIR spectrograph and new technological improvements to UV optical components for the next generation of near- to far-UV astrophysical observatories. CHESS is a far-UV sounding rocket experiment designed to probe the warm and cool atoms and molecules near sites of recent star formation in the local interstellar medium. I will talk about the science goals, design, research and development (R&D) components, and calibration of the CHESS instrument. I will end by presenting the initial data reduction and results of the flight observations taken during the second launch of CHESS.

Author(s): Keri Hoadley[1], Kevin France[1]
Institution(s): *1. University of Colorado - Boulder*

206.02 – Optics Technologies for LUVOIR & HabEx: Polarization & Mirror Count

We show that polarization aberrations and mirror count will limit the optical system performance of LUVOIR and HabEx and thus both their exoplanet science yield and their UV science. In addition we show how increased mirror count reduces optical system transmittance and increases cost in large aperture telescopes. We make the observation that orthogonally polarized light does not interfere to form an intensity image. We show how the two polarization aberrations (diattenuation & and retardance) distort the system PSF, decrease transmittance, and increase the unwanted background above that predicted using scalar models. An optical system corrected for geometric path difference errors is a necessary but not sufficient condition for the perfect image formation needed to directly image terrestrial exoplanets. Geometric (trigonometric) path difference errors are controlled using adaptive optics (tip-tilt & wavefront), active metrology and precision pointing. However, image quality is also determined by several physical optics factors: diffraction, polarization, partial coherence, and chromatism all of which degrade image quality and are not corrected through the control of geometric path difference. The source of physical optics errors lies in the opto-mechanical packaging of optical elements, masks, stops and the thin film coatings needed to obtain high transmittance. Adaptive optics corrects wavefront errors described by geometric or optical path length errors but not those wavefront errors introduced by physical optics. We show that for large telescopes each reflection costs over $100 million to increase the collecting area in order to recover lost SNR. Examples will be shown. The LUVOIR and HabEx systems will need fewer optical surfaces than current systems

Author(s): James B. Breckinridge[1]
Institution(s): *1. College of Optical Sciences, University of Arizona*

206.03 – A new active method to correct for the effects of complex apertures on coronagraph performance

The increasing complexity of the aperture geometry of the future space (WFIRST, LUVOIR) and ground based-telescope (E-ELT, TMT) will limit the performance of the next generation of coronagraphic instruments for high contrast imaging of exoplanets. We propose here a new closed-loop optimization technique to use the deformable mirrors to correct for the effects of complex apertures on coronagraph performance. This method is a new alternative to the ACAD technique previously developed by our group. This technique allows the use of any coronagraph designed for continuous apertures, with complex, segmented, apertures, maintaining high performance in contrast and throughput. Finally, this closed loop technique allows flexibility to adapt for changing pupil geometries (e.g. in case of segment failure or maintenance for ground-based telescopes), or "manufacturing imperfections in the coronagraph assembly and alignment.
We present a numerical study on several pupil geometries (segmented LUVOIR type aperture, WFIRST, ELTs) for which we obtained high contrast levels with several deformable mirror setups (size, number of actuators, separation between them), coronagraphs (apodized pupil lyot and vortex coronagraphs) and spectral bandwidths. Finally, using the results of this study, we will present recommendations for future coronagraphic instruments.

Author(s): Johan Mazoyer[2], Laurent Pueyo[2], Mamadou N'Diaye[2], Kevin Fogarty[2], Marshall D. Perrin[2], Remi Soummer[2], Colin Arthur Norman[1]
Institution(s): *1. Johns Hopkins University, 2. Space Telescope Science Institute*

206.04 – Improving HST/WFC3 photometric calibration

I will discuss improvements in the photometric calibration of the Wide Field Camera 3 (WFC3) imaging channels based on the analisys of 6 years of standard star observations acquired between 2009 and 2015. Observations of the three white dwarf standard stars, GD 153, GD 71, and G191B2B and of the G-type star P330E were obtained at multiple dither positions . Departing from previous practice, chip-dependent inverse sensitivities for the WFC3/UVIS channel are computed at r=10 pixels for the 42 full frame filters (excluding the 20 quad filters); and these data also provide encircled energy fractions as a function of filter. Chip-dependent inverse sensitivities differ on average by 3% from previous computations, primarily due to drizzling effects. I describe the UVIS 2.0 (chip-dependent) philosophy and discuss the esults in the context of prior photometric calculations. Further, I will also discuss the status of the WFC3/IR photometric calibration, in view of updated linearity corrections and updated dark reference files.

Author(s): Susana E. Deustua[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): WFC3 Team

206.05 – CubeSats for Astrophysics: The Current Perspective

Cubesats are small satellites built to multiples of 1U (1000 cm3). The 2016 NRC Report "Achieving Science with CubeSats" indicates that between 2013 and 2018 NASA and NSF sponsored 104 CubeSats. Of those, only one is devoted to astrophysics: HaloSat (PI: P. Kaaret), a 6U CubeSat with an X-ray payload to study the hot galactic halo.
Despite this paucity of missions, CubeSats have a lot of potential for astrophysics. To assess the science landscape that a CubeSat astrophysics mission may occupy, we consider the following parameters:
1–Wavelength: CubeSats are not competitive in the visible, unless the application (e.g. high precision photometry) is difficult to do from the ground. Thermal IR science is limited by the lack of low-power miniaturized cryocoolers and by the large number of infrared astrophysical missions launched or planned. In the UV, advances in δ-doping processes result in larger sensitivity with smaller apertures. Commercial X-ray detectors also allow for competitive science.
2–Survey vs. Pointed observations: All-sky surveys have been done at most wavelengths from X-rays to Far-IR and CubeSats will not be able to compete in sensitivity with them. CubeSat science should then center on specific objects or object classes. Due to poor attitude control, unresolved photometry is scientifically more promising that extended imaging.
3–Single-epoch vs. time domain: CubeSat apertures cannot compete in sensitivity with big satellites when doing single-epoch observations. However, time-domain astrophysics is an area in which CubeSats can provide very valuable science return.
Technologically, CubeSat astrophysics is limited by:
1–Lack of large apertures: The largest aperture CubeSat launched is ~10 cm, although deployable apertures as large as 20 cm could be fitted to 6U buses.
2–Poor attitude control: State-of-the-art systems have demonstrated jitter of ~10" on timescales of seconds. Jitter imposes limits on image quality and, coupled with detector errors, limits the S/N.
Other technology limitations include the lack of high-bandwidth communication and low-power miniaturized cryocoolers. However, even with today's technological limitations, astrophysics applications of CubeSats are only limited by our imagination.

Author(s): David R. Ardila3, Evgenya Shkolnik[1], Varoujan Gorjian [2]
Institution(s): *1. Arizona State University, 2. Jet Propulsion Laboratory, 3. The Aerospace Corporation*

206.06 – The Crisis in Astrophysics and Planetary Science: How Commercial Space and Program Design Principles will let us Escape

Astrophysics and planetary science are in crisis. The large missions we need for the next generation of observations cost too much to let us do more than one at a time. This spreads the science out onto a generational timescale, inhibiting progress in both fields. There are two escape paths. In the long run, but still well within our planning horizon, commercial space will bring mission costs down substantially allowing parallel missions at multiple wavelengths or to multiple destinations. In the short run, adopting prudent principles for designing a research program will let us maintain vitality in the field by retaining breadth at a modest cost in depth.

Author(s): Martin Elvis[1]
Institution(s): *1. Harvard-Smithsonian CfA*

206.07 – Exoplanet mass determination using precision imaging astrometry and coronagraphy

Performing simultaneous high-contrast imaging and astrometry observations of a star increases the detection efficiency and characterization accuracy of single- and multiple- planetary systems around nearby stars. Combining the data generated with both techniques allows solving the Semi-Major Axis, period, and planetary mass in the system faster and more precisely than using imaging or astrometry data separately. In addition, it allows the planetary mass to be measured independently from its brightness, resolving the mass/albedo degeneracy when only direct imaging observations are available. Independent albedo determination allows calibrated planet photometry to be obtained, enabling better atmosphere characterization.

To perform both direct imaging and astrometry observations, the telescope requires two instruments: a high-performance coronagraph to perform direct imaging, and a wide field camera astrometry accuracy able to deliver sub-micro arc second astrometry accuracy if earth-like planetary science is pursued. Such accuracy is only possible after calibrating relative distortions between astrometry observations, which at the sub-micro arc second regime dominates the error budget. We propose to utilize a diffractive pupil, in which an array of dots on the primary mirror generates polychromatic diffraction spikes in the focal plane, to calibrate the dynamic distortions of the optical system. In this talk, we present the results of the NASA TDEM effort to demonstrate the diffractive pupil concept on wide-field images while simultaneously performing high-contrast imaging. We also discuss the opportunity that this mission architecture could offer to future probe missions and flagships such as HabEX and LUVOIR.

Author(s): Eduardo Bendek[2], Ruslan Belikov[2], Emily R Finan3, Olivier Guyon3, Eugene Pluzhnik[2], Stephen Ammons[1]
Institution(s): *1. Lawrence Livermore National Laboratory, 2. NASA Ames, 3. University of Arizona*

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207 – Black Holes II

207.01 – Tidal Disruption Events Across Cosmic Time

Tidal disruption events (TDEs) of stars by single or binary super-massive black holes illuminate the environment around quiescent black holes in galactic nuclei allowing to probe dorment black holes. We predict the TDE rates expected to be detected by next-generation X-ray surveys. We include events sourced by both single and binary super-massive black holes assuming that 10% of TDEs lead to the formation of relativistic jets and are therefore observable to higher redshifts. Assigning the Eddington luminosity to each event, we show that if the occupation fraction of intermediate black holes is high, more than 90% of the brightest TDE might be associated with merging black holes which are potential sources for eLISA. Next generation telescopes with improved sensitivities should probe dim local TDE events as well as bright events at high redshifts. We show that an instrument which is 50 times more sensitive than the *Swift* Burst Alert Telescope (BAT) is expected to trigger ~10 times more events than BAT. Majority of these events originate at low redshifts ($z<0.5$) if the occupation fraction of IMBHs is high and at high-redshift ($z>2$) if it is low.

Author(s): Anastasia Fialkov[1], Abraham Loeb[1]
Institution(s): *1. Harvard*

207.02 – What sets the line widths in tidal disruption events?

The optical and UV spectra of flares from the tidal disruption of stars by massive black holes (TDEs) vary greatly between individual events. In particular, the line widths can differ by at least a factor of five even for events with similar values inferred for the black hole mass. Additionally, the lines narrow over time in some events, and this detail has proven difficult to explain based on hydrodynamical modeling. We present radiative transfer calculations to help understand these aspects of line formation from TDEs, with a focus on the role of electron scattering in both static and outflowing reprocessing envelopes.

Author(s): Nathaniel Roth[2], Daniel Kasen[1]
Institution(s): *1. Univ. of California, Berkeley, 2. University of Maryland, College Park*

207.03 – Discovery of transient infrared emission from dust heated by stellar tidal disruption flares

Stars that pass within the tidal radius of a supermassive black hole will be disrupted, yielding a flare of thermal emission. Due to their high black body temperature, these tidal disruption flares (TDFs) are typically observed at UV/optical and X-ray wavelengths. Using images from the Wide-field Infrared Survey Explorer (WISE), we recently discovered that TDFs also produce transient mid-infrared (3-4 micron) emission. Our observations are readily explained by dust heated to its sublimation temperature due to the intense radiation of the flare. From the break in the infrared light curve we infer that this hot dust is located ~0.1 pc from the supermassive black hole. The detection of TDF dust reprocessing is an important breakthrough because: (i) the reprocessed emission provides a unique tool to study dust at the center of inactive galaxies, and (ii) the shape of the reprocessing signal can be used to estimate the bolometric luminosity of the flare. To obtain well-sampled reprocessing light curves, we recently started monitoring new TDFs with both *Spitzer* and ground-based JHK-band observations. Results from this campaign will be presented.

Author(s): Sjoert Van Velzen[2], Julian H. Krolik[2], Varoujan Gorjian [1]
Institution(s): *1. JPL, 2. The Johns Hopkins University*

207.04 – New Results from Chandra on the X-ray Emission from the Massive Black Hole in the Compact Starburst Galaxy Henize 2-10

We present follow-up X-ray observations of the candidate massive black hole (BH) in the nucleus of the low-mass, compact starburst galaxy Henize 2-10. Using new high-resolution observations from the Chandra X-ray Observatory totaling 200 ks in duration, as well as archival Chandra observations from 2001, we demonstrate the presence of a previously unidentified X-ray point source that is spatially coincident with the known nuclear radio source in Henize 2-10 (i.e., the massive BH). We show that the hard X-ray emission previously identified in the 2001 observation is dominated by a source that is distinct from the nucleus, with the properties expected for a high-mass X-ray binary. The X-ray luminosity of the nuclear source suggests the massive BH is radiating significantly below its Eddington limit, and the soft spectrum resembles other weakly accreting massive BHs including Sagittarius A*. Analysis of the X-ray light curve of the nuclear source reveals the tentative detection of a ~9-hour periodicity, although additional observations are required to confirm this result. Our study highlights the need for sensitive high-resolution X-ray observations to probe low-level accretion, which is the dominant mode of BH activity throughout the Universe.

Author(s): Amy E. Reines[2], Mark Reynolds5, Jon M. Miller5, Gregory R. Sivakoff4, Jenny E. Greene3, Ryan C. Hickox[1], Kelsey E. Johnson[6]
Institution(s): *1. Dartmouth, 2. NOAO, 3. Princeton University, 4. University of Alberta, 5. University of Michigan, 6. University of Virginia*

207.05 – NuSTAR Discovery of a Possible Black Hole HMXB and Cygnus X-1 Progenitor

We report on NuSTAR observations of HD96670, a single line spectroscopic binary in the Carina OB association. We selected this source as a possible BH-HMXB candidate based on its 5.53d orbital period and 0.10 Msun mass function, both similar to Cyg X-1. HD96670 is a O8.5V main sequence star, and if its secondary were a BH, and its O star evolves to a O9Ib star like that in Cyg X-1, it would be high luminosity BH-HXMB. HD96670 is detected as a soft source in RASS and in the XMM slew survey. With a 150 ksec exposure with NuSTAR, we found a best-fit power law spectrum with photon index 2.4 - 2.6 and factor of ~2 variability. The mean Lx ~ 5 x 10^32 (5 - 30 keV) is consistent with that expected for accretion from the weak wind that late-type main sequence O stars usually show for plausible assumptions for the secondary if it is a ~5Msun BH. In the poster by Gomez and Grindlay, we show the detailed photometry and spectroscopy and PHOEBE modelling which point to the secondary indeed being a 5 Msun object, either an accreting BH or possibly a B8V star for which the X-ray spectrum would be expected to not show the hard PL component. Additional X-ray observations at or near the optically determined phase of inferiour vs. superior conjunction will resolve the nature of the secondary. If it is indeed a BH, this points the way to a much larger population of low-luminosity (Weak Wind) BH-LMXBs, with longer lifetimes, than the presently explored systems which all (but one) have super-giant donors.

Author(s): Jonathan E. Grindlay[2], Charles James Hailey[1], Shuo Zhang[1], Kaya Mori[1], Sebastian Gomez[2], Jaesub Hong[2], John Tomsick3
Institution(s): *1. Columbia University, 2. Harvard-Smithsonian, CfA, 3. University of California*

207.06D – Spectral-Timing to Probe Strong Gravity in X-ray Binaries

X-ray spectral-timing seeks to investigate how matter behaves in strong gravitational fields. Observations suggest that different types of quasi-periodic oscillations (QPOs) are associated with different emission-region geometries (e.g. disk-like or jet-like) in the innermost part of an X-ray binary, close to the neutron star or black hole. We developed a technique for phase-resolved spectroscopy of QPOs, and have applied it to low-frequency QPOs from black hole X-ray binaries. On the QPO time-scale, we find that the energy spectrum changes not only in normalization, but also in spectral shape. We identify these changes as a phase-dependence of the intrinsic power-law emission as well as the response of the accretion disk to variable illumination by the power-law. We also look for systematic trends between different classes of sources and different accretion states. These trends help us to further constrain the origin of low-frequency QPOs and QPO evolution with the changing emission geometry in the strong-gravity regime.

Author(s): Abigail Stevens[1], Phil Uttley[1]
Institution(s): *1. Anton Pannekoek Institute*

207.07 – Finding Free-Floating Black Holes using Astrometric Microlensing

Our Galaxy most likely hosts 10-100 million stellar mass black holes. The exact number and mass function of these black holes contains important information regarding our Galaxy's star formation history, stellar mass function, and the fate of very massive stars.
However, isolated stellar black holes have yet to be detected. To date, stellar mass black holes have only been definitively detected in binary systems with accreting companions or merging to produce gravitational waves. In principle, the presence of isolated black holes can be inferred from astrometric and photometric signatures produced when they lens light from a background star. We attempt to detect the astrometric lensing signatures of several photometrically identified microlensing events, toward the Galactic Bulge. Long-duration events (t_Einstein > 100 days) were selected as the most likely black hole candidates and were observed using several years of laser-guided adaptive optics observations from the W. M. Keck telescopes. We present results from this search.

Author(s): Jessica R. Lu[1], Eran Oded Ofek4, Evan Sinukoff[2], Andrzej Udalski3, Szymon Kozlowski3
Institution(s): *1. UC Berkeley, 2. University of Hawaii, 3. Warsaw University Observatory, 4. Weizmann Institute*

207.08 – Improved Constraints to the Local Supermassive Black Hole Occupation Fraction

The occupation fraction of supermassive black holes (SMBHs) in local dwarf galaxies is thought to be related to the formation mechanism of the first black holes in the early Universe. Light black hole seeds, such as Pop III star remnants, are likely to result in a significantly higher occupation fraction compared to heavy seeds (~104 solar mass) arising from the global collapse of massive gas clouds. Chandra observations of nearby dwarf galaxies can push the detection threshold for SMBH activity down to the lowest observable Eddington ratios. This, folded with analytical prescriptions for the intrinsic occupation fraction across the mass spectrum, yields an observational constraints to the SMBH occupation fraction in the dwarf galaxy regime. Building on previous work by Miller et al. (2015), here we analyze a sample of ~240 early-type galaxies (D < 30 Mpc) with archival Chandra coverage, and report on our improved constraints to the local SMBH occupation fraction.

Author(s): Jianfeng Wu[2], Elena Gallo[2], Brendan P. Miller[1]
Institution(s): *1. College of St. Scholastica, 2. University of Michigan*

208 – HEAD II: The Physics of the Perseus Cluster, and Other Highlights, From Hitomi

Before the tragic loss of the spacecraft, the Soft X-ray Spectrometer on the Hitomi/Astro-H observatory observed the Perseus cluster of galaxies, producing X-ray spectral data with unprecedented spectral resolution. This session reviews the scientific impact of these transformation data on our understanding of cluster physics and the central active galaxy. We end with a discussion of Hitomi observations of the three other objects for which Hitomi data were obtained, the Crab Nebula, G21.5 and N132D

208.01 – Hitomi measurements of the dynamics of the intracluster medium in the Perseus Cluster

The Soft X-ray Spectrometer on Hitomi measured the velocity dispersion of the intracluster medium in the Perseus Cluster with a precision of 10 km/s. The dispersion in the region lying 30-60 kpc from the nucleus is 164 km/s meaning that turbulent energy density is less than 4% of the thermal energy. The implications for the operation of AGN Feedback in the cluster core will be discussed.

Author(s): Andrew C Fabian[1]
Institution(s): *1. University of Cambridge*
Contributing team(s): Hitomi Collaboration

208.02 – Hitomi results on the Perseus cluster thermodynamics, elemental abundances, and emission processes

Hitomi SXS spectrum of the Perseus cluster above E=2 keV is a treasure trove of emission lines, most of them seen for the first time from a diffuse source such as the plasma atmosphere of a galaxy cluster. Several trace elements are detected for the first time in the intracluster medium, lines from several key elements, such as S/Ar and Fe/Ni, are disentangled, and sensitivity to faint lines is dramatically higher compared to previous, lower-resolution cluster studies. This allows us to determine accurate relative abundances of heavy elements, a sensitive test for sources of enrichment of the intergalactic medium. For many elements, lines from multiple ions are observed, as well as multiple transitions from the same ion, providing plasma temperature diagnostics previously unavailable for clusters. The brightest line -- the resonant component of the Fe He-alpha triplet -- is found to be affected by resonant scattering. For the most prominent ions, very high-level transitions are observed, placing constraints on such emission mechanisms as charge exchange with cold gas. Finally, we do not observe a previously reported 3.5 keV emission line from the Perseus core and place an upper limit on it.

Author(s): Maxim L. Markevitch[1]
Institution(s): *1. NASA GSFC*
Contributing team(s): Hitomi collaboration

208.03 – Hitomi Results -NGC 1275: The Origin of Fe-Kα Line

NGC 1275 is a bright radio galaxy at a center of the Perseus cluster of galaxies, and its radio lobes formed by past jet activity are known to affect the intracluster medium. Hitomi observed the AGN and the surrounding region with the Soft X-ray Spectrometer (SXS) and Soft X-ray Imager (SXI). We present an analysis of the Hitomi data and archival data of other X-ray satellites, focusing on the nature of and origin of the Fe-Kα emission line complex at 6.4 keV.
The Hitomi SXS data resolve the line with a velocity dispersion of ~10 (500kms/sec), a redshift consistent with that of NGC1275 and an equivalent width against the hot gas and AGN continuum of ~7 eV or ~25 eV against the AGN continuum alone. Spatial analysis of the data shows that the Fe-Kα line originates within 20" (~7.5 kpc) of NGC1275. We will discuss the origin of the line, and the implications for the origin of the line in other radio loud AGN

Author(s): Richard Mushotzky[1]
Institution(s): *1. University of Maryland*
Contributing team(s): Hitomi Collaboration

208.04 – Highlights from Hitomi observations of non-Perseus targets

Before the tragic loss of the spacecraft due to attitude control problems, Hitomi observed three supernova remnants (SNR), N132D, G21.5-0.9, and the Crab Nebula, with the main purpose of initial in-orbit calibration. Here we present some scientific highlights of these observations.

N132D is a middle-aged, core-collapse SNR in the Large Magellanic Cloud (LMC). It was observed after the Perseus cluster. Even though the exposure was very short, the SXS clearly resolves the fine structure of He-like S K-shell emission. We detect a significant redshift that is consistent with the line-of-sight velocity of the LMC. Fe K emission is redshifted even more significantly, with a corresponding velocity of ~2000 km/s. This suggests a non-uniform velocity distribution of the Fe ejecta, probably due to an asymmetric supernova explosion.

G21.5-0.9 is a young plerionic composite-type SNR. Powered by the 62 ms rotation-powered pulsar J1833-1034, the SNR is dominated by non-thermal emission from the pulsar wind nebula, with extended limb-brightening and knots of X-ray emission. The Hitomi SXS, SXI, and HXI observations provide a high-statistics wide-band spectrum from a single satellite. We are currently searching for 1) emission or absorption line features, 2) a spectral break in the continuum, and 3) the pulse period. The status of the analysis and results will be presented.

The Crab was observed after all the instruments aboard Hitomi were turned on. We successfully obtain the pulse profile with all of the instruments. The X-ray polarization is being studied with the HXI and SGD. We also search for emission/absorption lines with the SXS, but no features have so far been significantly detected. We discuss the results in light of constraining the nature of the Crab's progenitor explosion.

Author(s): Hiroya Yamaguchi[4], Aya Bamba[7], Manabu Ishida[3], Satoru Katsuda[1], John Patrick Hughes[5], Greg Madejski[6], Yasushi Fukazawa[2]
Institution(s): *1. Chuo University, 2. Hiroshima University, 3. JAXA/ISAS, 4. NASA/GSFC, 5. Rutgers University, 6. Stanford University, 7. The University of Tokyo*
Contributing team(s): Hitomi Collaboration

209 – Making Great Observatories Even Better: Hubble's Hand in Studying the Multi-Wavelength Universe

Hubble has a long history of encouraging and facilitating multi-wavelength science through its joint observing programs. Since Cycle 9 of HST in the year 2000, scientists thinking about multi-wavelength projects with Hubble have been able to propose for an expanding list of facilities that now spans the Chandra X-ray Observatory, NOAO telescopes, Spitzer, XMM-Newton, and NRAO telescopes. This science is often more than the sum of its parts, and enables time-domain and synergistic astrophysics studies not possible with the traditional double-jeopardy approach to arranging observing campaigns. Almost 4000 HST orbits in about 350 joint observing programs have been awarded since the inception of the joint observing program framework, equivalent to more than a year's worth of Hubble observations. The purpose of this special session is to describe some of the important science results which have been enabled through the joint observing programs, and look ahead to enabling science from additional joint programs. The invited speaker list consists of astronomers who have authored papers resulting from data obtained through joint observing programs, and will highlight the breadth of science enabled from these several joint programs. We propose for a poster session to accompany the oral session, for additional contributions by the science community.

209.01 – Coordinated UV and X-ray Observations of AGN Outflows

Observations of AGN outflows have progressed from the era of single-object surveys to intensive monitoring campaigns spanning weeks to months. The combination of multiple observations, improved temporal coverage, multi-wavelength monitoring in both the X-ray and UV bands, and the baseline of prior historical observations has enabled determinations of the locations, mass flux, and kinetic luminosities of the outflowing absorbing gas in several AGN. Typically the mass flux and kinetic energy are dominated by the higher-ionization X-ray absorbing gas. But the higher-resolution UV observations give a kinematically resolved picture of the overall outflow. In most cases, the outflowing gas is located at parsec to kpc scales, with insufficient kinetic luminosity to have an evolutionary impact on the host galaxy. Multiple coordinated observations have also revealed a new class of UV and X-ray absorbers. They typically show transient, heavy X-ray obscuration in the low-energy spectrum characterized by high column densities of mildly ionized gas. These X-ray obscuration events are accompanied by the appearance of broad, fast, blue-shifted UV absorption lines of moderate ionization, comparable to the X-ray absorbing gas. In the best-studied case of NGC 5548, the strength of the broad UV absorption lines varies with the degree of soft X-ray obscuration first revealed by XMM-Newton spectra. The high outflow velocities, variability timescales of a day or less in the X-ray, and the broad widths suggest an origin in a wind from the accretion disk. This low-ionization component may represent the shielding gas necessary to facilitate disk winds driven by radiative acceleration in UV absorption lines.

Author(s): Gerard A. Kriss[1]
Institution(s): *1. STScI*

209.02 – Leo P: A very low-mass, extremely metal-poor, star-forming galaxy

Leo P is a low-luminosity dwarf galaxy just outside the Local Group with properties that make it an ideal probe of galaxy evolution at the faint-end of the luminosity function. Using combined data from 2 Hubble Space Telescope (HST) observing campaigns, the Very Large Array, the Spitzer Space telescope, as well as ground based data, we have constructed a robust evolutionary picture of Leo P. Leo P is one the most metal-poor, gas-rich galaxies ever discovered, has a stellar mass of a 5x105 Msun, comparable gas mass, and a single HII region. The star formation history reconstructed from the resolved stellar populations in Leo P shows it is unquenched, despite its very low mass. Based on the star formation history and metallicity measurements, the galaxy has lost 95% of its oxygen produced via nucleosynthesis, presumably to outflows. The neutral gas in the galaxy shows signs of rotation, although the velocity dispersion is comparable to the rotation velocity. Thus, Leo P bridges the gap between more massive dwarf irregular and less massive dwarf spheroidals on the baryonic Tully-Fisher relation. Furthermore, the galaxy hosts several, extremely dusty AGB candidates which will be probed with new HST and Spitzer observations. If confirmed as AGB stars, these may be our best local proxies for studying chemically unevolved star formation and subsequent dust production in metallicity environments comparable to the early universe.

Author(s): Kristen B. McQuinn[1]
Institution(s): *1. University of Texas*
Contributing team(s): Leo P team

209.03 – High Resolution Studies of Mass Loss from Massive Binary Stars

Mass loss from hot luminous single and binary stars has a significant, perhaps decisive, effect on their evolution. The combination of X-ray observations of hot shocked gas embedded in the stellar winds and high-resolution optical/UV spectra of the cooler mass in the outflow provides unique ways to study the unstable process by which massive stars lose mass both through continuous stellar winds and rare, impulsive, large-scale mass ejections. The ability to obtain coordinated observations with the Hubble Space Telescope Imaging Spectrograph (HST/STIS) and the Chandra High-Energy Transmission Grating Spectrometer (HETGS) and other X-ray observatories has allowed, for the first time, studies of resolved line emisssion over the temperature range of 104- 10^8K, and has provided observations to confront numerical dynamical models in three dimensions. Such observations advance our knowledge of mass-loss asymmetries, spatial and temporal variabilities, and the fundamental underlying physics of the hot shocked outflow, providing more realistic constraints on the amount of mass lost by different luminous stars in a variety of evolutionary stages. We discuss the impact that these joint observational studies have had on our understanding of dynamical mass outflows from massive stars, with particular emphasis on two important massive binaries, Delta Ori Aa, a linchpin of the mass luminosity relation for upper HRD main sequence stars, and the supermassive colliding wind binary Eta Carinae.

Author(s): Michael F. Corcoran[7], Theodore R. Gull[2], Kenji Hamaguchi[4], Noel Richardson[6], Thomas Madura[3], Christopher Michael Post Russell[2], Mairan Teodoro[7], Joy S. Nichols[1], Anthony F. J. Moffat[5], Tomer Shenar[5], Herbert Pablo[5]
Institution(s): *1. CfA, 2. NASA/GSFC, 3. San Jose State University, 4. UMBC, 5. University of Montreal, 6. University of Toledo, 7. USRA*

209.04 – Multi-wavelength Characterization of Exoplanet Host Stars with the MUSCLES Treasury Survey

High-energy photons (X-ray to NUV) from exoplanet host stars regulate the atmospheric temperature profiles and photochemistry on orbiting planets, influencing the long-term stability of planetary atmospheres and the production of potential "biomarker" gases. However, relatively few observational and theoretical constraints exist on the high-energy irradiance from typical (i.e., weakly active) M and K dwarf exoplanet host stars. In this talk, I will describe results from a panchromatic survey (Chandra/XMM/Hubble /ground) of M and K dwarf exoplanet hosts. The MUSCLES Treasury Survey (Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems) combines UV, X-ray, and optical observations with reconstructed Lyman-alpha and EUV (100-900 Ang) radiation to create 5 Angstrom to 5 micron stellar irradiance spectra that are available as a High-Level Science Product on STScI/MAST. I will discuss how we use multi-wavelength observations to study possible abiotic production of the suggested biomarkers O2 and O3, develop scaling relations to infer the high-energy particle fluxes from these stars based on solar UV flare/particle flux measurements, calibrate visible-wavelength proxies for the high-energy irradiance, and characterize the UV variability and flare frequency of "optically inactive" M dwarfs.

Author(s): Kevin France[2], Allison Youngblood[2], R. O. Parke Loyd[2], Christian Schneider[1]
Institution(s): *1. ESA, 2. Univ of Colorado*

209.05 – Extrasolar Storms: Mapping Cloud Cover Evolution with Joint HST-Spitzer Observations

Observations of directly imaged and transiting exoplanets and brown dwarfs reveal the wide-spread presence of condensate clouds. These clouds profoundly influence the energy transport through ultracool atmospheres and impact their pressure-temperature profiles. Yet, the structure and properties of these cloud layers remain mostly unexplored and pose one of the great challenges to our understanding ultracool atmospheres. I will show how using HST and Spitzer jointly -- by exploiting their photometric stability and sensitivity and combining their wavelength ranges -- allows us to address this challenge. With time-resolved spectroscopy and photometry of rotating brown dwarfs – rotational phase mapping — we are exploring the longitudinal structure of condensate clouds and with multiple epoch observations we are following the evolution of the cloud cover. These new observations are opening a new window on the dynamics of ultracool atmospheres.

Author(s): Daniel Apai[1]
Institution(s): *1. University of Arizona*
Contributing team(s): Extrasolar Storms Team

209.06 – Multi-Wavelength Spectroscopy of Super-Earth Atmospheres

The Kepler mission has revealed that super-Earths (planets with radii between 1 and 4 R_Earth) are the most common class of planets in the Galaxy, though none are known in our own Solar System. These planets can theoretically have a wide range of compositions which we are just beginning to explore observationally. While studies based on Kepler data have revolutionized many areas of exoplanet research, the relative faintness of most of the host stars in the Kepler field means that atmospheric characterization of these super-Earths with currently available instruments is extremely challenging. However, a handful of transiting super-Earths are within reach of existing facilities. We have pointed both the HST and Spitzer toward these systems in an effort to paint a thorough picture of their atmospheres. Our transmission spectroscopy observations explore the transition region between terrestrial planets and miniature gas giants, and contribute to distinguishing between low-density hydrogen-dominated atmospheres and compact high-metallicity atmospheres. Transmission spectroscopy over a wide wavelength range is also essential to understanding the properties and effects of clouds in these atmospheres. The results of this program will inform the direction to be taken by future multi-wavelength studies of these worlds, in particular those enabled when the HST joins forces with the upcoming JWST.

Author(s): Diana Dragomir[2], Björn Benneke[1], Ian Crossfield[3], Joshua Lothringer[4], Heather Knutson[1]
Institution(s): *1. Caltech, 2. MIT, 3. UC Santa Cruz, 4. University of Arizona*

209.07 – HST, ALMA, and revealing the throes of planet formation

In this talk, I will highlight some of the synergy between HST and ALMA. In particular, I will focus on the impact of these observatories in shaping our understanding of debris systems and planet-forming discs. Both HST and ALMA can resolve gas and dust distributions at very high resolution, but they each, e.g., probe very different dust grain sizes and gas line transitions. The observatories can thus provide complementary views of the dynamics, composition, and morphologies of discs during planet building and its aftermath. As examples, I will discuss new ALMA results for HD141569 and Fomalhaut, as well as discuss work from other groups on systems such as Beta Pic.

Author(s): Aaron C. Boley[1]
Institution(s): *1. The University of British Columbia*

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210 – The Presidential Transition: What Can We Expect?

A new president has been elected and the incoming administration is currently preparing to take charge. How does this transition process impact federal support of science, especially at NASA, NSF, and DOE? Policy experts will discuss the process of a presidential transition, with a particular emphasis on federal support of science.

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211 – The Value of Astronomical Data & Long Term Preservation

As more sky surveys collect large amounts of data, we automatically assume that all the data will be accessible, preserved and curated for eternity. However, as more data is accumulating, we will have to face some hard tradeoffs what to keep and what to discard, and how much to invest in long-term preservation. As these issues are becoming more and more acute, it is time to have a public discussion about how to make these difficult choices and how to create a sustainable data preservation strategy for the US Astronomy community. The session would feature five speakers and would have an extended open discussion.

211.01 – Alex Szalay: The long term future of astronomical archives

211.02 – Beth Wilman: Curating and Archiving LSST Data Products

211.03 – Lisa J. Storrie-Lombardi: NASA Astronomy Archives: Enabling Science Now and in the Future

211.04 – Robert J. Hanisch: Policy and Practice for Data Preservation at NIST

211.05 – Marc Postman: The PanSTARRS Public Data Archive: A Case Study in Data Preservation

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212 – Young Stellar Objects, Very Young Stars, T-Tauri Stars, H-H Objects

212.01 – Assessing Magnetospheric Accretion in Herbig Ae/Be Stars

Recent large spectropolarimetric surveys have found low magnetic field detection rates in Herbig Ae/Be stars. Efforts to measure and map young stars' magnetic fields have also noted that field structure and strength dramatically change with increasing stellar mass. These results are highly suggestive that the mechanisms for accretion and outflow in Herbig Ae/Be star+disk systems may differ from the magnetospheric accretion paradigm as envisaged for T Tauri star+disk systems. We have performed a high resolution optical spectroscopic campaign of ~60 Herbig AeBe stars including some multi-epoch observations; the timescales sampled range from high cadence (~minutes) to observations taken years spart, covering a wide range of kinematic processes. We find that the strength of variability increases with the cadence of the observations, and over all timescales sampled, the strongest variability occurs within the blueshifted absorption components of the Balmer series lines. We see no inverse P-Cygni signatures as are often seen in lower mass T Tauri stars and generally thought to be diagnostic of infall in accretion streams along the line of sight. We discuss the implications of these results in context of recent spectropolarimetric surveys for our understanding of how accretion is occurring in these objects, as well as ongoing radiative transfer modeling.

Author(s): Alicia Aarnio[1], John D. Monnier[1]
Institution(s): *1. University of Michigan*

212.02 – A WISE Study of Star Formation in Canis Major and Target Selection for JWST

With photometry from the Wide-field Infrared Survey Explorer (WISE), we searched for young stellar objects in a 100 square-degree field centered on the lightly studied Canis Major star-forming region. We found 144 candidates with mid-infrared excess primarily from envelope emission (Class I) and 335 with excess primarily from disk emission (Class II). Half of the candidates are spatially associated with a supernova remnant, suggesting a potential formation mechanism, but the ratio of Class I to Class II candidates, typically interpreted as a tracer of age, varies strongly around the remnant. Via a comparison to protostars characterized with the Herschel Space Observatory, we present new WISE criteria for the youngest (Class 0) protostars, finding seven candidates in Canis Major. We discuss the ability of the James Webb Space Telescope to spectroscopically determine the accretion properties of such protostars.

Author(s): William J. Fischer[2], Deborah Padgett[2], Karl R. Stapelfeldt[1], Marta M. Sewilo[2]
Institution(s): *1. JPL, 2. NASA Goddard Space Flight Center*

212.03D – Searching for the bottom of the IMF

The measurement of the substellar initial mass function (IMF) and its minimum mass and their dependence on environment would provide a fundamental test of theories of star formation. To provide better constraints on these properties of the IMF, we have performed a search for the least-massive members of nearby star-forming clusters and associations (150-300 pc, <10 Myr). To identify candidate brown dwarfs in these regions, we have measured proper motions for sources detected in multi-epoch images from the Spitzer Space Telescope. To enable these measurements and more fully realize IRAC's astrometric capabilities, we measured new distortion corrections for IRAC (0.004" systematic error; Esplin & Luhman 2016) and created a pipeline that extracts astrometric positions with errors of 0.02". The resulting proper motion samples of candidate brown dwarfs were then further refined using their color-magnitude diagrams constructed from deep optical and near-IR images. Through spectroscopic observations, we have confirmed many new members of the regions we studied including the least-massive members in several regions (~5 Jupiter masses).

Author(s): Taran Esplin[1], Kevin Luhman[1]
Institution(s): *1. Pennsylvania State University*

212.04 – A Newly Discovered Source with Peculiar Chemistry Near the HH 111/HH 121 Protostellar System

We present the results of Very Large Array NH_3 (1,1) and (2,2) observations of the HH 111 / HH 121 protostellar system located in L1617 in the Orion B molecular cloud. HH 111, with a spectacular collimated optical jet, is one of the most well-known Herbig-Haro objects. We report a detection of a new source (NH_3-S) in the vicinity of HH 111/HH 121 (~15 arcsec or 0.03 pc from the HH 111 jet source), in two epochs of ammonia observations. Interestingly, this constitutes the first detection of this source, in a region which has been thoroughly covered previously by both continuum and spectral line interferometric observations. Comparisons of these ammonia observations with those of several other tracers indicate peculiar chemistry in this clump. The position of the source with respect to the Herbig-Haro jet suggests that it may be an externally illuminated molecular clump. The Herbig-Haro objects thus provide a useful tool for studying molecular clumps through their elucidated response to radiation; in turn, the clumpiness of molecular clouds is of relevance to the initiation of star formation.

Author(s): Jennifer J. Wiseman[2], Marta M. Sewilo[2], Remy Indebetouw[3], Johan Lindberg[2], Steven B. Charnley[2], Jaime E. Pineda[1]
Institution(s): *1. Max Planck Institute for Extraterrestrial Physics, 2. NASA / GSFC, 3. University of Virginia*

212.05 – A Triple Protostar System in L1448 IRS3B Formed via Fragmentation of a Gravitationally Unstable Disk

Binary and multiple star systems are a frequent outcome of the star formation process; most stars form as part of a binary/multiple protostar system. A possible pathway to the formation of close (< 500 AU) binary/multiple star systems is fragmentation of a massive protostellar disk due to gravitational instability. We observed the triple protostar system L1448 IRS3B with ALMA at 1.3 mm in dust continuum and molecular lines to determine if this triple protostar system, where all companions are separated by < 200 AU, is likely to have formed via disk fragmentation. From the dust continuum emission, we find a massive, 0.39 solar mass disk surrounding the three protostars with spiral structure. The disk is centered on two protostars that are separated by 61 AU and the third protostar is located in the outer disk at 183 AU. The tertiary companion is coincident with a spiral arm, and it is the brightest source of emission in the disk, surrounded by ~0.09 solar masses of disk material. Molecular line observations from 13CO and C18O confirm that the kinematic center of mass is coincident with the two central protostars and that the disk is consistent with being in Keplerian rotation; the combined mass of the two close protostars is ~1 solar mass. We demonstrate that the disk around L1448 IRS3B remains marginally unstable at radii between 150~AU and 320~AU, overlapping with the location of the tertiary protostar. This is consistent with models for a protostellar disk that has recently undergone gravitational instability, spawning the companion stars.

Author(s): John J. Tobin[9], Kaitlin M. Kratter[7], Magnus Persson[1], Leslie Looney[8], Michael Dunham[5], Dominique Segura-Cox[8], Zhi-Yun Li[10], Claire J. Chandler[4], Sarah Sadavoy[2], Robert J. Harris[8], Carl Melis[6], Laura M. Perez[3]
Institution(s): *1. Chalmers University of Technology, Onsala Space Observatory, 2. Harvard-Smithsonian Center for Astrophysics, 3. Max Planck Institute for Radio Astronomy, 4. National Radio Astronomy Observatory, 5. SUNY - Fredonia, 6. UC San Diego, 7. University of Arizona, 8. University of Illinois, 9. University of Oklahoma, 10. University of Virginia*

212.06D – HST 1.6µm Imaging Survey of Orion Protostars

We present near-infrared 1.6µm HST NICMOS and/or WFC3 images of 244 protostars in the Orion A & B molecular clouds, the largest sample of protostars imaged in a single cloud complex to date. These protostars are part of the Herschel Orion Protostar Survey (HOPS), a multi-observatory program which obtained 1–870µm photometry, spectroscopy, imaging of 319 protostars in the Orion clouds. The HST images resolve structures illuminated in scattered light from the central protostar, including disks, cavities, and shadows cast in envelopes by disks, with better than 100 AU spatial resolution. We classify all the protostars into five morphological classes: non-detections, point sources, bipolar cavities, unipolar cavities and irregular sources. Sixteen of the bipolar sources show disks in absorption, revealing a minimum spatial extent of the disks. The resolved cavities allow us to directly measure the clearing of the envelopes by bipolar outflows. We map cavities for 30 of these sources by applying a custom edge detection technique to both the scattered light images and radiative transfer models with known cavity geometries. We constrain the shape of the cavities and estimate the fractional volumes of the collapsing cores dispersed by the outflows. Contrary to previous results, we do not find evidence that outflow cavities grow in volume as protostars evolve from Class 0 to flat spectrum sources. These results indicate that feedback by outflow clearing is not the primary agent for dissipating envelopes and halting accretion, and cannot explain the 30-40% star formation efficiency estimated for molecular cores.

Author(s): Joseph J. Booker[9], S. Thomas Megeath[9], William J. Fischer[1], Marina Kounkel[6], Charles A. Poteet[3], Elise Furlan[2], Amelia Marie Stutz[5], Manoj Puravankara[4], John J. Tobin[7], Zsofia Nagy[9], Dan M. Watson[8]
Institution(s): *1. Goddard Space Flight Center, 2. IPAC, 3. Space Telescope Institute, 4. Tata Institute of Fundamental Research, 5. Universidad de Concepcón, 6. University of Michigan, 7. University of Oklahoma, 8. University of Rochester, 9. University of Toledo*
Contributing team(s): Herschel Orion Protostar Survey

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213 – Innovations in Astronomy Teaching & Learning

The field of Astronomy Education Research is a quickly advancing area of study that gives insights into the teaching and learning of astronomy. Presenters in this special session will discuss the results of research on a variety of recent innovations in astronomy education for college-level instruction and lifelong learning. Topics will include innovations in Pedagogy, Assessment, and Curricular materials for face-to-face, and online college-level instruction as well as MOOCs (Massive Open Online Courses).

213.01 – Results of Studying Astronomy Students' Science Literacy, Quantitative Literacy, and Information Literacy

Introductory astronomy courses often serve as terminal science courses for non-science majors and present an opportunity to assess non future scientists' attitudes towards science as well as basic scientific knowledge and scientific analysis skills that may remain unchanged after college. Through a series of studies, we have been able to evaluate students' basic science knowledge, attitudes towards science, quantitative literacy, and informational literacy. In the Fall of 2015, we conducted a case study of a single class administering all relevant surveys to an undergraduate class of 20 students. We will present our analysis of trends of each of these studies as well as the comparison case study. In general we have found that students basic scientific knowledge has remained stable over the past quarter century. In all of our studies, there is a strong relationship between student attitudes and their science and quantitative knowledge and skills. Additionally, students' information literacy is strongly connected to their attitudes and basic scientific knowledge. We are currently expanding these studies to include new audiences and will discuss the implications of our findings for instructors.

Author(s): Sanlyn Buxner4, Chris David Impey4, Katherine B. Follette3, Erin F. Dokter4, Don McCarthy4, Beau Vezino4, Martin Formanek4, James M Romine[1], Laci Brock4, Megan Neiberding[2], Edward E. Prather4
Institution(s): *1. Independent, 2. NOAO, 3. Stanford University, 4. University of Arizona*

213.02 – A Preliminary Analysis of College Students' Preinstructional Ideas About Planet Formation

From as early as nursery school, children are taught about planet Earth and "our place in space." Learning about the Solar System transcends K-12 education, and is considered one of the top-ten most frequently discussed topics in undergraduate introductory astronomy courses for non-majors. All too frequently, however, the discussion stops after a brief overview of each planet, and students are left to ponder how the Solar System came to be in the first place. The topic of planet formation has grown in importance in any astronomy class in light of the discovery of nearly 5,000 exoplanet candidates, where the properties of exoplanetary systems have cast light on the general process of planet formation. This highly active research field has been slow to be properly represented in the astronomy classroom for non-majors. For this work, we presented students in six undergraduate 100 and 200-level astronomy courses at the University of Arizona with one of three short answer questions on the topic of planet formation. The questions were administered on the first day of the Fall 2016 semester before any related material was taught. We will present an analysis of these responses, and discuss any common trends, themes, and misconceptions that appear from the dataset. These responses will lend to the development of the Planet Formation Concept Inventory (PFCI) that will be used by ASTR 101 instructors to evaluate students' understanding of planet formation before and after instruction.

Author(s): Molly Simon[1], Chris David Impey[1], Sanlyn Buxner[1]
Institution(s): *1. University of Arizona*

213.03 – Using pedagogical discipline representations (PDRs) to enable Astro 101 students to reason about modern astrophysics

Instructors of introductory, college-level, general education astronomy (Astro 101) often want to include topics from the cutting-edge of modern astrophysics in their course. Unfortunately, the teaching of these cutting-edge topics is typically confined to advanced undergraduate or graduate classes, using representations (graphical, mathematical, etc.) that are inaccessible to the vast majority of Astro 101 students. Consequently, many Astro 101 instructors feel that they have no choice but to cover these modern topics at a superficial level. Pedagogical discipline representations (PDRs) are one solution to this problem. Pedagogical discipline representations are representations that are explicitly designed to enhance the teaching and learning of a topic, even though these representations may not typically be found in traditional textbooks or used by experts in the discipline who are engaged in topic-specific discourse. In some cases, PDRs are significantly simplified or altered versions of typical discipline representations (graphs, data tables, etc.); in others they may be novel and highly contextualized representations with unique features that purposefully engage novice learners' pre-existing mental models and reasoning difficulties, facilitating critical discourse. In this talk, I will discuss important lessons that my colleagues and I have learned while developing PDRs and describe how PDRs can enable students to reason about complex modern astrophysical topics.

Author(s): Colin Scott Wallace4, Edward E. Prather[1], Timothy G. Chambers3, Julia R. Kamenetzky5, Seth D. Hornstein[2]
Institution(s): *1. University of Arizona, 2. University of Colorado Boulder, 3. University of Michigan, 4. University of North Carolina at Chapel Hill, 5. Westminster College*

– Panel Discussion and Audience Q&A

213.04 – Astronomy for Astronomical Numbers with Massive Open Online Classes

Massive Open Online Classes (MOOCs) have shown their ability to reach missions of adults across the world with science content. We have been experimenting with pedagogy in two MOOCs, provided through Udemy and Coursera, that have reached over 80,000 people. Although the completion rate is low, just under 10%, the cumulative outreach impact of nearly half a million hours of astronomy video watched is substantial. A similar fraction of learners is heavily engaged and participate in online discussions, live question and answer sessions, and social media connected to the class. MOOCs are valuable for testing pedagogy that might later be employed in online for-credit classes, with the caveat that the motivations and modes of engagement of free-choice learners can differ from those of college students.

Author(s): Chris David Impey[1], Matthew Wenger[1], Sanlyn Buxner[1], Martin Formanek[1]
Institution(s): *1. Univ. of Arizona*

213.05 – Research on Peer Grading in an Astronomy Massive Open Online Course

Massive Open Online Courses (MOOCs) are opportunities for thousands of students to take university level courses at little to no cost. The aim of this talk is to present and analyze an often used assessment tool in MOOCs – peer grading. We collected a wealth of data on peer grading process during our session based MOOC "Astronomy: Exploring Time and Space" offered through Coursera in Spring 2015. We found that peer-grading participants are different from the general course population. Additionally, we found that peer grading participation is the single best predictor for course completion. We compared three different essay-based peer graded assignments throughout the course according to the lengths of submitted essays, time spent grading, number of essays graded by individual users, and a percentage of relevant videos watched. In all of these criteria participation in the first assignment turned out to be statistically significantly different from the other two. Finally we investigated validity and reliability of peer graders by comparing their grades with trained undergraduate graders and instructors on a subsample of 300 essays. Although we found out that validity and reliability of peer grading is limited, we were still able to show that results of peer grading strongly correlate with the final grades from the course and also invested effort in general. Therefore despite its shortcomings, peer grading still manages to identify good students and is very viable tool useful for MOOC-scale formative assessment.

Author(s): Martin Formanek[1], Chris David Impey[1], Matthew Wenger[1], Tenzin Sonam[1], Sanlyn Buxner[1]
Institution(s): *1. University of Arizona*

213.06 – Studying Student Motivations in an Astronomy Massive Open Online Class

Massive Open Online Courses (MOOCs) are large-scale, free classes open to anyone around the world and are are part of an educational industry that includes a growing number of universities. Although they resemble formal classes, MOOCs are of interest to instructors and educational researchers because they are unique learning environments where various people--particularly adult learners--learn science. This research project examined learners in an astronomy MOOC in order to better understand the motivations of MOOC learners. Using a well-tested instrument that examines student motivations for learning, we wanted to compare the motivations of MOOC learners to previous results in undergraduate classrooms. Our results show that our MOOC learners scored high in intrinsic motivation, self-efficacy, and self-determination. They differed from learners in traditional formal educational environments by having lower grade and career-related motivations. These results suggest that MOOC learners have characteristics of learners in so called “free-choice” learning environments, similar to other life-long learners.

Author(s): Matthew Wenger[1], Chris David Impey[1], Sanlyn Buxner[1], Martin Formanek[1]
Institution(s): *1. University of Arizona*

– Panel Discussion and Audience Q&A

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214 – Galaxies at High Redshift

214.01D – The diversity of evolutionary pathways of compact elliptical galaxies in cosmological simulations

Observations of the high-redshift universe have revealed a population of galaxies which are already very massive (~1e11 solar masses at z=2) and have typical sizes of < 2 kpc, much smaller than their counterparts in the local universe. How such dense, massive galaxies form, and why they appear to be less common at low redshift, have been questions of interest for both theorists and observers. I will discuss these questions in the context of the Illustris simulation, a hydrodynamical cosmological simulation in which tens of thousands of galaxies form, evolve, and interact with each other, situated within a cosmological context. I select a group of massive compact galaxies at z=2 in the simulation and trace them back and forth in time to discover both how they formed at high redshift, and what they evolve into at the present day. I find a variety of both progenitors (compact galaxies form in the simulation either via central starbursts generally brought on by mergers, or by racing out to the tip of the SF main sequence and forming very early) and descendants (many formerly-compact galaxies lurk at the core of a more massive galaxy today, others were consumed in mergers, and some evolve passively and undisturbed). I will also discuss the implications of these results for observational methods of connecting galaxy populations across redshifts - in particular, the assumption of a constant cumulative comoving number density - and suggest an improvement to this method which takes the complexity and variety of galaxies' evolutionary paths into account.

Author(s): Sarah Wellons[1]
Institution(s): *1. Harvard University*

214.02 – What drives the kinematic evolution of star-forming galaxies?

The increasing capabilities of optical and near-infrared integral field spectrographs have revealed the internal dynamics of hundreds of star-forming galaxies at 1<z<3. Such galaxies located on or above the star-forming galaxy main sequence (MS) exhibit systematically larger intrinsic velocity dispersions than their local star-forming counterparts. Although several plausible mechanisms have been proposed (e.g., star formation feedback, elevated gas supply, or galaxy interaction), it remains unclear what is the fundamental driver of the velocity dispersion enhancement. We investigate the origin of this kinematic evolution using a suite of cosmological simulations from the FIRE project. We find that the intrinsic velocity dispersions of galaxies traced by star-forming gas increase with redshift out to z~1, and then flatten at ~40 km/s beyond z=1. In line with the correlations seen in the IFS surveys, the intrinsic velocity dispersion is positively correlated with several quantities such as star formation rate and gas fraction. However, a causal link is still unclear. In fact, the evolution of SFR in these simulations shows a positive time delay with respect to that of the evolution of velocity dispersion, suggesting that star formation feedback does not cause the disturbed kinematics in these galaxies. Instead, our simulations show that the enhancement of velocity dispersions follows most closely (in time) with the highly stochastic accretion and merger histories.

Author(s): Chao-Ling Hung3, Christopher C. Hayward[2], Tiantian Yuan[1]
Institution(s): *1. Australian National University, 2. Center for Computational Astronomy, 3. University of Texas at Austin*

214.03D – Star formation history and chemical enrichment in the early Universe: clues from the rest-optical and rest-UV spectra of z~2-3 star-forming galaxies in the Keck Baryonic Structure Survey

Galaxies at the peak of cosmic star formation (z~2-3) exhibit significantly higher star formation rates and gas fractions at fixed stellar mass than nearby galaxies. These z~2-3 galaxies are also distinct in terms of their nebular spectra, reflecting important differences not only in the physical conditions of their interstellar medium (e.g., electron density and gas-phase metallicity), but also in the details of their massive stellar populations, especially their ionizing radiation fields. Jointly observing galaxies' HII regions, at rest-UV and rest-optical wavelengths, and massive stars, at rest-UV wavelengths, is central to constructing a framework for understanding the differences between z~2-3 and z~0 star-forming galaxies and for self-consistently explaining the trends observed in the high-redshift population. My thesis is based on data from the Keck Baryonic Structure Survey (KBSS), which uniquely combines observations of individual galaxies in these two bandpasses. In total, the near-infrared component of the KBSS includes spectra of >700 z~2-3 galaxies obtained with Keck/MOSFIRE. I will present these results along with a detailed analysis of the full rest-optical (3600-7000 Ang) nebular spectra of ~400 galaxies, showing that high-redshift galaxies exhibit uniformly high degrees of ionization and excitation with respect to most z~0 galaxies. Combined with observations of the same galaxies' rest-UV spectra (obtained with Keck/LRIS) and photoionization model predictions, these results suggest that the disparity arises from differences in the shape of the ionizing radiation field at fixed gas-phase oxygen abundance, most likely due to the effects of Fe-poor massive binary stars. My comprehensive spectroscopic study of an unprecedentedly large sample of z~2-3 galaxies offers compelling evidence that the distinct chemical abundance patterns observed in these galaxies are the result of systematic differences in their star formation histories.

Author(s): Allison L. Strom[1]
Institution(s): *1. Caltech*

214.04 – Fast-Timescale Star Formation at z ~ 1 Revealed by H alpha

Measuring scatter in the Star Formation Rate (SFR) - stellar mass (M*) correlation as a function of SFR timescale informs us whether galaxies evolve gradually or in bursts. We report the SFRs of individual, intermediate mass (9 < log M* < 10.5) galaxies at z ~ 1 using dust-corrected, fast-timescale H(alpha) grism spectroscopy in 3D-HST. We present measurements of intrinsic scatter in the SFR-M* correlation, and compare with scatter estimated using intermediate timescale, broadband SED-based SFR estimates. We also illustrate SFR calibrations that combine these Ha results with ancillary IR and UV photometry in CANDELS with the goal of achieving greater precision in SFR estimation.

Author(s): Peter Kurczynski3, Eric J. Gawiser3, Viviana Acquaviva2, Marc Rafelski4, Harry I. Teplitz1
Institution(s): *1. Infrared Processing and Analysis Center, MS 100-22, CalTech, 2. New York City College of Technology, 3. Rutgers University, 4. Space Telescope Science Institute*
Contributing team(s): UVUDF Team, CANDELS Team

214.05 – The Evolution of Massive Morphological Spheroid and Disk Galaxies in CANDELS from 11 to 6 Billion Years Ago

The premiere HST/WFC3 Treasury program CANDELS (Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey) has produced detailed visual classifications for statistically useful samples of bright (H>24.5mag) galaxies during and after z~2, the epoch of peak galaxy development. By averaging multiple classifications per galaxy that encompass spheroid-only, bulge-dominated, disk-dominated, disk-only, and irregular/peculiar appearances at visible rest-frame wavelengths, we find that 90% of massive (>1e10 Msun) galaxies at 0.6<z<2.5 have spheroid and/or disk morphologies. Morphological spheroids are physically distinct from disks in terms of Sersic indices, half-light sizes, and axial ratios from GALFIT measurements, and quenched (Q) vs. active star formation (SF) based on either specific SFR or rest-frame UVJ analyses. At all redshifts probed, disks with/without subdominant central mass concentrations are flat, larger and mostly SF, compared to spheroids and dominant 'bulges' which are round, smaller and evolving from 50% SF at z>2 to mostly Q at later times. Combining morphologies, structural properties, and SF nature, we find clear differences in the histories of spheroid and disk populations that are robust to selections based on visual or Sersic selection, and to either Q/SF divisor. Massive spheroids experience strong number density growth, substantial size growth, and rapid changes in SF fraction suggesting quenching processes that act on <0.5 Gyr timescales. In contrast, the massive disk population undergoes a steady addition of similar-size disks and a mild decline in average sSFR. Our results indicate that active SF in disks appears to slowly build up their inner mass (or bulge), which subsequently quenches these galaxies. Data-theory comparison is needed to better constrain which physical processes drive the transformation and quenching of massive galaxies.

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Contributing team(s): CANDELS Collaboration

214.06 – The ZINGRS Radio Survey: Probing metallicities at high-z with far-IR fine-structure lines and the radio continuum

The present day Universe is rich in metals that enable efficient cooling of gas in the ISM in order to form stars, create planets and make the building blocks of life as we know it. The Universe did not start in this state – we know that metals had to build up over time with successive generations of stars. Revealing the details of this evolution, however, is challenging and requires probes of metallicity that are not susceptible to dust extinction nor exhibit the degeneracies common to tracers in the visible regime. One possible indicator combines the far-IR fine structure lines with the radio continuum. Recently we have undertaken a multi-band radio continuum survey with the JVLA of high-z galaxies from ZINGRS. These observations will constrain the galaxies' thermal and nonthermal radio emissions and demonstrate the use of far-IR lines together with radio continuum as a metallicity indicator. ZINGRS, the ZEUS 1 and 2 INvestigated Galaxy Reference Sample, includes ~30 galaxies from z ~ 1 - 4.5 for which the far-IR fine-structure lines (e.g. [CII] 158, [NII] 122, [OIII] 88) have been observed with the ZEUS-1 and 2 instruments. This is the largest collection of far-IR fine-structure line detections at high-z and is ideal for demonstrating the use of this new indicator. Here we describe the theory behind the new indicator, give an overview of ZINGRS, and report on the status of our radio survey.

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215 – Cataclysmic Variables, Novae, & Symbiotic Stars

215.01 – Mind the Gap when Data Mining the Ritter-Kolb Cataclysmic Variable Catalogue

The cataclysmic variable (CV) binary consists of a white dwarf primary and a low-mass secondary which overflows its Roche lobe. The Ritter-Kolb catalogue (2003, A&A, 404, 301) is a collection (~1000) of CV binaries and related objects. We have mined this catalogue for CVs with unevolved secondaries whose mass ratio (secondary/primary) is known (~130). A plot of the secondary mass verses the log of the orbital period exhibits the well-known period gap at 2-3 hrs. In addition, this plot shows that the secondary masses just above the period gap are collectively much larger than those just below. The average of the first ten secondary masses above the period is 180% larger than the average below the gap.
The disrupted magnetic braking hypothesis (Howell, Nelson, and Rappaport 2001, ApJ, 550, 897 [HNR]) predicts that when the secondary becomes fully convective, the magnetic braking, which has driven the secondary out of thermal equilibrium, stops. In adjusting to thermal equilibrium the secondary shrinks below its Roche lobe and no longer loses mass. The binary system ceases to appear as a CV until gravitational radiation loss brings the secondary back in contact with its Roche lobe. This scenario is at odds with the apparent secondary mass loss across the period gap. Either the secondary continues to lose mass while crossing the period gap or the secondary masses are miscalculated!
Magnetic braking causes the secondary to expand or inflate larger than its single star counterpart. Any orbital parameter calculation which assumes a radius-mass relationship based on single main-sequence stars will overestimate the mass of the secondary. We can approximate this mass overestimation from calculations by HNR which take into account the thermal heating from magnetic braking. Using this approximation as a first-order correction to the secondary mass, we replot the deflated secondary mass versus the binary period. The deflated masses immediately above and below the period gap are similar and do not indicate secondary mass loss across the gap. Thus, magnetic braking not only explains the period gap but the apparent secondary mass shift across it. Orbital parameters must be based upon actual secondary mass-radius observations.

Author(s): Warren M. Sparks1, Edward M. Sion2
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215.02 – The Disk Instability Model for SU UMa systems - a Comparison of the Thermal-Tidal Model and Plain Vanilla Model

We utilize the time dependent accretion disk model described by Ichikawa & Osaki (1992) to explore two basic ideas for the outbursts in the SU UMa systems, Osaki's Thermal-Tidal Model, and the basic accretion disk limit cycle model. We explore a range in possible input parameters and model assumptions to delineate under what conditions each model may be preferred.

Author(s): John K. Cannizzo1
Institution(s): *1. NASA/GSFC/CRESST/UMBC*

215.03D – Radio Observations as a Tool to Investigate Shocks and Asymmetries in Accreting White Dwarf Binaries

In this dissertation, I use radio observations with the Karl G. Jansky Very Large Array (VLA) to reveal that colliding flows within the ejecta from nova explosions can lead to shocks that accelerate particles and produce radio synchrotron emission. In both novae V1723 Aql and V5589 Sgr, radio emission within the first one to two months deviated strongly from the classic thermal model for radio emission from novae. Three years of radio observations of V1723 Aql show that multiple outflows from the system collided to create non-thermal shocks with a brightness temperature of >10^6 K. After these shocks faded, the radio light curve became roughly consistent with an expanding thermal shell. However, resolved images of V1723 Aql show elongated material that apparently rotates its major axis over the course of 15 months. In the case of nova V5589 Sgr, I show that the early radio emission is dominated by a shock-powered non-thermal flare that produces strong (kT_X > 33 keV) X-rays. These findings have important implications for understanding how normal novae generate GeV gamma-rays.

Additionally, I present VLA observations of the symbiotic star CH Cyg and two small surveys of symbiotic binaries. Radio observations of CH Cyg tie the ejection of a collimated jet to a change of state in the accretion disk, strengthening the link between bipolar outflows from accreting white dwarfs and other types of accreting compact objects. Next, I use a survey of eleven accretion-driven symbiotic binaries to determine that the radio brightness of a symbiotic system could potentially be used as an indicator of whether it is powered predominantly by shell burning on the surface of the white dwarf or by accretion. This survey also produces the first radio detections of seven of the target systems. In the second survey of seventeen symbiotic binaries, I spatially resolve extended radio emission in several systems for the first time. The results from these surveys provide some support for the model of radio emission where the red giant wind is photoionized by the white dwarf, and suggest that there may be a greater population of radio faint, accretion driven symbiotic systems.

Author(s): Jennifer Helen Seng Weston[1]
Institution(s): *1. Columbia University*
Contributing team(s): The E-Nova Project

215.04 – SOFIA/FORCAST Observations of the Symbiotic Mira, R Aquarii

The FORCAST instrument on the Stratospheric Observatory for Infrared Astronomy (SOFIA) was used to observe the symbiotic Mira, R Aquarii (R Aqr) in September 2016. Images through several filters at wavelengths from 6.4 to 37.1 mu-m, and a grism spectrum covering 8.4 to 13.7 mu-m were obtained. R Aqr consists of an AGB star and a hot white dwarf in an eccentric binary orbit, an accretion flow onto the white dwarf, and the resulting jet. The images show a point source (~3.5" PSF at 37 mu-m) with the observed emission dominated by the dusty AGB star. The SOFIA data were obtained when the Mira phase was about 0.4 (minimum at phase 0.5) and the V magnitude was about 10. The measured fluxes range from about 700 Jy at the shorter wavelengths to about 80 Jy at 37 mu-m. These are a factor of 2 lower than the fluxes measured by ISO in May 1996, when the Mira phase was close to maximum and the V magnitude was about 8. We discuss the differences between the ISO and FORCAST measurements of the spectral energy distribution in the context of our proposed monitoring of the R Aquarii system with SOFIA as it approaches eclipse and periastron in its ~44 year orbit.

Author(s): Ravi Sankrit4, Eric B. Omelian3, L. Andrew Helton4, Uma Gorti[2], R. Mark Wagner[1]
Institution(s): *1. LBT Observatory, 2. NASA Ames/SETI, 3. NASA/SOFIA/LOGYX, 4. SOFIA/USRA*

215.05 – New Results on RZ Leo and CC Scl

Using HST COS ultraviolet spectra in time-tag mode and a long K2 observation, we have determined a spin period for the white in RZ Leo of 220 seconds, thus confirming this cataclysmic variable as a new member of the Intermediate Polar class of systems. The ultraviolet light curve of CC Scl at quiescence created from its COS spectral observations is dominated by its spin period of 195 seconds (that has only been previously observed during one of its outbursts). Spectra formed from the high and low sections of its light curve shows a temperature difference of several thousand degrees.

PS and ASM acknowledge support from NASA grant HST-GO13807 and from NSF grant AST-1514737.

Author(s): Paula Szkody[1], Anjum S. Mukadam[1], Boris T Gaensicke[2], Odette Toloza[2], Zhibin Dai3
Institution(s): *1. Univ. of Washington, 2. University of Warwick, 3. Yunnan Observatories*
Contributing team(s): HST GO12870 team

215.06 – The luminous red nova M101-OT2015-1: a candidate for common envelope ejection

Binary interaction is an important phase in the study of stellar evolution. Approximately 50% of O star population live in close binary systems as to allow interaction with the companion. Although massive binary progenitors have been associated with thermonuclear supernovae, stripped core collapse supernovae, cataclysmic variables, X-ray binaries, or the mind blowing massive binary black holes recently detected by LIGO, the exact evolutionary path followed by the system is still under debate. One of the critical phases is the common envelope (CE) phase, required to bring a long period binary into a much shorter orbit. Currently, this phase also represents a challenge for the current stellar evolution models. Given the uncertainty, observational constraints are valuable input to advance in this field. One particular class of transient objects, called Luminous Red Novae (LRNe), has been associated with the termination of the CE phase, when a total or partial ejection of the least bound layers of the primary star are expelled at the expense of decreasing the orbital energy of the system. In my talk I will discuss the results of 16 years of observations of M101-OT2015-1, a LRN in M101 galaxy. I will describe the progenitor star (system) and the main characteristics of the outburst. Finally, I will present the results of the evolution of its remnant in infrared wavelengths. Given the long time span of our observations, this event represents one of the best studied CE ejection candidate at extragalactic distances.

Author(s): Nadejda Blagorodnova[1], Mansi M. Kasliwal[1], Rubina Kotak[2]
Institution(s): *1. Caltech, 2. Queens University Belfast*

215.07 – The Peculiar Evolution of V1535 Sco

Multi-wavelength observations of the nova V1535 Sco revealed unusual behavior throughout its evolution in 2015. During the first 18 days of the outburst, radio observations were consistent with optically thin synchrotron emission and X-ray observations indicated the presence of relatively hard (kT>1.0 keV) photons. These are both evidence for the existence of strong shocks in the nova ejecta during its early evolution, most likely the result of the nova ejecta slamming into a stellar wind from the companion star. On day 7, a VLBA observation shows a compact component contributing approximately 73% of the emission at 5GHz on that day. From day 23 and to day 42, the radio spectral energy distribution was more consistent with optically thick thermal bremsstrahlung emission. Starting on day 54, the radio observations again show evidence of synchrotron emission, possibly the result of the slower-moving ejecta creating radiative shocks upon encountering material from a previous outburst.

Author(s): Justin D. Linford[2], Laura Chomiuk5, Thomas Nelson[8], Thomas Finzell5, Jennifer L. Sokoloski[1], Michael P. Rupen4, Koji Mukai7, Amy J. Mioduszewski[6], Jennifer Helen Seng Weston3
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216 – The Galactic Disk, Galactic Bulge, & Galactic Center

216.01 – Chemical Cartography in the Milky Way with SDSS/APOGEE: Multi-element abundances and abundance ratio variations

The SDSS/APOGEE project is measuring abundances of multiple elements for several hundred thousand stars across the Milky Way. These allow the mapping of abundances and abundance ratio variations. Results will be presented for multiple abundance ratios across of the Galactic disk. The interpretation of mean abundance maps is complicated by variations in star formation history across the disk and by changing abundance ratios that result from an overall metallicity gradient. Variations in chemical abundance sequences, however, show the potential for using abundance ratios to track the movement of stars through the disk, and provide key information for constraining Galaxy formation and chemical evolution models.

Author(s): Jon A. Holtzman[1], Sten Hasselquist[1], Jennifer Johnson[2], Jonathan C. Bird4, Steven R. Majewski3
Institution(s): *1. New Mexico State Univ., 2. Ohio State University, 3. University of Virginia, 4. Vanderbilt University*
Contributing team(s): SDSS/APOGEE team

216.02 – On the Radial Abundance Gradients of Europium and Oxygen of Stars Inside the Disk of a Simulated Milky Way

Studies of galaxy evolution and formation through simulations and observations have yielded valuable insight into the life of stars. Abundance gradients, in particular, provide useful information about the element assembly history in the Milky Way. To study these gradients we use data from a simulation titled Eris which has been constructed with the goal of reproducing the properties of the Milky Way, to find the gradients of stars located in the disk that have been enriched by Supernovae and Neutron Star Mergers. We compare these gradients to the observations acquired from looking at Cepheids and field stars in the disk of our Milky Way. We also aim to understand whether radial metallicity gradients can be used to differentiate between Neutron Star Merger versus Type II Supernovae enrichment.

Author(s): Krystal Ruiz-Rocha[1], Gabriela Montes[1], Enrico Ramirez-Ruiz[1]
Institution(s): *1. University of California, Santa Cruz*

216.03 – Multiple stellar populations and the origin of the double red clump in the Milky Way bulge

The presence of multiple stellar populations is now well established in most globular clusters in the Milky Way. Here we show that the double red clump and two populations of RR Lyrae stars observed in the bulge are another manifestation of the same multiple population phenomenon observed in halo globular clusters. We will discuss the implications of this result on the formation and structure of the Milky Way bulge.

Author(s): Young-Wook Lee[1]
Institution(s): *1. Yonsei University*

216.04 – Can Star-Disk Collisions Explain the Missing Red Giants Problem in the Galactic Center?

Observations have revealed a relative paucity of red giant (RG) stars within the central 0.5 pc in the Galactic Center (GC). Motivated by this finding we investigate the hypothesis that collisions of stars with a fragmenting accretion disk are responsible for the observed dearth of evolved stars. We use 3D hydrodynamic simulations to model a star with radius 10 $R_\odot$ and mass 1 $M_\odot$, representative of the missing population of RGs, colliding with high density clumps. We find that multiple collisions with clumps of relatively high column density $\geq 10^8$ g cm^{-2} can strip a substantial fraction of the star's envelope and in principle render it invisible to observations. Because the envelope is unbound on account of the kinetic energy of the star, any significant amount of stripping of the RG population in the GC should be mirrored by a systematic decay of their orbits and possibly by their enhanced rotational velocity. To be viable, this scenario requires that the total mass of the fragmenting disk has been substantial and several orders of magnitude higher than that of the early-type stars which now form the stellar disk in the GC.

Author(s): Tamara Bogdanovic[1], Thomas Kieffer[1]
Institution(s): *1. Georgia Institute of Technology*

216.05D – The Mysterious Galactic Center Radio Source N3

Here we report on multi-wavelength radio observations of the mysterious point source "N3" that appears to be located in the vicinity of the Galactic Center. VLA observations between 2 and 50 GHz reveal that N3 is a compact and bright non-thermal source (56 mJy at 10 GHz) which is superimposed upon the non-thermal radio filaments (NTFs) of the Radio Arc. Our highest frequency observations place a strict upper limit of 65x28 milli-arcseconds on the size of this source. We compare our observations to those of Yusef-Zadeh (1987) and Lang (1997) and conclude that N3 is variable over long time scales. Additionally, we present the detection of a compact molecular cloud located adjacent to N3 in projection. CH3CN, CH3OH, CS, HC3N, HNCO, SiO, SO, and NH3 are detected in the cloud and most transitions have FWHM line widths of ~20 km s-1. The rotational temperature determined from the metastable NH3 transitions ranges from 79 K to 183 K depending on the transitions used and the location in the cloud. We present evidence that this molecular cloud is interacting with N3. After exploring the relationship between the NTFs, molecular cloud, and N3, we conclude that N3 likely lies within the Galactic Center. We are able to rule out many possible physical counterparts, including an active star, HII region, young supernova, AGN, and micro-quasar. To further constrain the nature of N3, we also discuss new extremely high resolution observations of N3 taken with the VLBA, and what these observations reveal about the true nature of this mysterious source.

Author(s): Dominic Ludovici5, Cornelia C. Lang5, Mark Morris4, Robert Lucien Mutel5, Elisabeth A.C. Mills[1], James E Toomey3, Juergen Ott[2]
Institution(s): *1. Jan Jose State University, 2. NRAO, 3. United States Coast Guard Academy, 4. University of California, 5. University of Iowa*

216.06 – High Resolution Surveys of the Water and Methanol Star Formation Masers in the Central Molecular Zone

We present some of the first high resolution fully interferometric surveys of 6.7 GHz methanol and 22 GHz water masers towards the Central Molecular Zone (CMZ). These masers are good signposts for early (<0.05 Myrs) star formation. Using the Jansky Very Large Array (VLA), we searched the inner 3 x 0.7 deg of the Galactic Center (GC) for methanol masers with resolutions of 0.9" (0.04 pc) and 0.4 km/s (8 kHz) and an average channel sensitivity of ~0.01 Jy/beam. With this high resolution and sensitivity, we have detected ~100 methanol masers, which is over a factor of two more than has previously been detected. We have also conducted two surveys of water masers in this region. As part of the Survey of Water and Ammonia in the Galactic Center (SWAG), the Australia Telescope Compact Array (ATCA) was used to survey a variety of molecular lines, including the 22 GHz water line. With the ATCA, we have detected over 200 water masers using resolutions of 26" (1 pc) and 2 km/s (60 kHz) and an average channel sensitivity of ~0.01 Jy/beam. Afterward, we conducted the first on-the-fly (OTF) VLA survey of water masers with improved resolutions of 0.7" (0.03 pc) and 0.4 km/s (26 kHz) and an average channel sensitivity of ~0.05 Jy/beam. Although the analysis of this OTF survey is not yet complete, we have already identified water masers that were not visible in the SWAG data.

The improvement in the number of detected masers allows us to better analyze the distribution of these masers. We show that the SWAG water masers appear uniformly distributed along the

Galactic plane, despite the asymmetry of the molecular gas distribution, where ~2/3 of the gas mass is located at positive Galactic longitudes. The methanol masers follow the molecular gas distribution, with a majority of the masers being found at positive longitudes. This could indicate a difference in the star forming history of these two parts of the CMZ and/or that the 22 GHz water masers are contaminated by water masers produced from evolved stars as well as star forming regions, indicating that a larger percentage of 22 GHz water masers are produced by evolved stars than is currently thought. We show a tentative indication supporting the latter case.

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Institution(s): *1. Max-Planck-Institut fur Astronomie, 2. National Radio Astronomy Observatory, 3. New Mexico Institute of Mining and Technology, 4. Northwestern University*
Contributing team(s): SWAG

216.07 – Modelling the thermal X-ray emission around the Galactic center from colliding Wolf-Rayet winds

The Galactic center is a hotbed of astrophysical activity, with the injection of wind material from ~30 massive Wolf-Rayet (WR) stars orbiting within 12" of the super-massive black hole (SMBH) playing an important role. Hydrodynamic simulations of such colliding and accreting winds produce a complex density and temperature structure of cold wind material shocking with the ambient medium, creating a large reservoir of hot, X-ray-emitting gas. This work aims to confront the 3Ms of Chandra X-ray Visionary Program (XVP) observations of this diffuse emission by computing the X-ray emission from these hydrodynamic simulations of the colliding WR winds, amid exploring a variety of SMBH feedback mechanisms. The major success of the model is that it reproduces the spectral shape from the 2"-5" ring around the SMBH, where most of the stellar wind material that is ultimately captured by Sgr A* is shock-heated and thermalized. This naturally explains that the hot gas comes from colliding WR winds, and that the wind speeds of these stars are in general well constrained. The flux level of these spectra, as well as 12"x12" images of 4-9 keV, show the X-ray flux is tied to the SMBH feedback strength; stronger feedback clears out more hot gas, thereby decreasing the thermal X-ray emission. The model in which Sgr A* produced an intermediate-strength outflow during the last few centuries best matches the observations to within about 10%, showing SMBH feedback is required to interpret the X-ray emission in this region.

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216.08 – Probing the Southern Fermi Bubble in Ultraviolet Absorption

The Fermi Bubbles are two giant gamma-ray emitting lobes, extending 55° below and above the Galactic Center, that were discovered in 2010. While the Northern Bubble has been extensively studied in ultraviolet (UV) absorption, little is known about the UV properties of the Southern Bubble. We use UV absorption-line spectra from the *Hubble Space Telescope Cosmic Origins Spectrograph (HST/COS)* to probe the Southern Fermi Bubble using two sightlines to background AGN, one passing inside the Bubble (RBS 1768) and one passing just outside (RBS 2000). We used *VPFIT*, a Voigt profile fitting program to detect the existence of high-velocity absorption components and to measure the column density of different metal ions. We detected two high-velocity absorption components in both sightlines; one at v_{LSR} = -150 km s^{-1} and one at v_{LSR} = 160 km s^{-1}. We determined that the component at v_{LSR} = 160 km s^{-1} is due to the Magellanic Stream. Absorption is seen in ions of silicon, carbon and aluminium. The discovery that the high-velocity component is present in both sightlines shows that cool gas can extend further from the Galactic plane than the gamma-ray emitting regions. This could indicate past outflow activity prior to the creation of the Southern Bubble. This project was supported in part by the NSF REU grant AST-1358980 and by the Nantucket Maria Mitchell Association.

Author(s): Md. Tanveer Karim3, Andrew Fox[2], Edward B. Jenkins[1]
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217 – Plenary Talk: What We Don't Know about the Beginning of the Universe, Sean Carroll (Caltech)

217.01 – What We Don't Know about the Beginning of the Universe

The history of the universe from a few seconds after the Big Bang is fairly well-understood, but what happened before then is largely mysterious. Inflation is a popular paradigm, but raises a number of conceptual problems, both in its conception and its implementation. Before inflation, we don't know whether there was a true beginning or whether the universe has lasted eternally; which alternative is correct may come down to dimly-understood features of quantum gravity. I will discuss these issues, how they relate to later-universe cosmology, and the prospects for future progress.

Author(s): Sean Carroll[1]
Institution(s): *1. Caltech*

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219 – Extrasolar Planets: Characterization & Theory III

219.01 – Orbital Architectures of Planet-Hosting Binaries: Testing Co-alignment

Most planetary system only offer the possibility to measure the initial conditions of planet formation (e.g., protoplanetary disks) separately from the final outcome (e.g., planet demographics of field samples). Planet-hosting binaries offer the rare opportunity to observe both simultaneously. For example, in our previous work on the hierarchical triple system Kepler-444 that hosts five Mars-sized planets, we demonstrated that the present-day stellar orbits imply that the planets must have formed from a protoplanetary disk that was truncated at 1–2 AU. Here we will present new results from our continuing Keck adaptive optics program to monitor the stellar orbits of Kepler planet hosts that have binary companions at solar-system scales of 20–100 AU. The astrometric orbital arcs that we measure enable a fundamental test: whether or not the stellar orbits are seen edge-on and thus co-aligned with the transiting planets in the system. This orbit-orbit alignment test allows us to critically examine the possible formation pathways for these systems, thereby providing key insights into planet formation models that have been proposed to explain the origins of Kepler planets. We will also discuss preliminary results for a subset of our sample for which we have obtained resolved radial velocities with NIRSPAO that allow us to measure additional orbit parameters (eccentricity and semimajor axis). Full orbit determinations will allow us to address whether special conditions (e.g., circular orbits) are preferred for forming planets in binaries, which are the most common type of stellar system in the Galaxy.

Author(s): Trent J. Dupuy3, Adam L. Kraus3, Kaitlin M. Kratter[2], Lisa A. Prato[1]
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219.02 – Exploring the optical contrast effect in strong atomic lines for exoplanets transiting active stars

Transmission spectroscopy is a powerful tool for detecting and characterizing planetary atmospheres. Non-photospheric features on the stellar disk, however, can contaminate the planetary signal:

during transit the observed spectrum is weighted towards the features not currently being occulted by the planet. This contrast effect can mimic absorption in the planetary atmosphere for strong atomic lines such as Na I, Ca II, and the hydrogen Balmer lines. While the contrast effect is negligible for quiet stars, contributions to the transmission signal from active stellar surfaces can produce ~1% changes in the line core. It is therefore critical that these contrast signals be differentiated from true absorption features in the planetary atmosphere. Here we present our work on simulating the contrast effect for an active stellar surface. We discuss the particular case of HD 189733 b, a well-studied hot Jupiter orbiting an active K-dwarf, due to the plethora of atomic absorption signals reported in its atmosphere.
Specifically, we focus on Hα to address recent suggestions that the measured in-transit signals are a result of stellar activity. In the contrast model we include center-to-limb variations and calculate limb darkening parameters as a function of wavelength across the line of interest. The model includes contributions to the spectrum from spots, faculae and plages, filaments, and the bare stellar photosphere. Stellar rotation is also included. We find that it is very difficult to reproduce the measured in-transit Hα signals for reasonable active region parameters. In addition, it is difficult to create an in-transit contrast signature that lasts for the duration of the transit unless the planet is crossing an active latitudinal belt and is always obscuring active regions. This suggests that the Hα measurements arise predominantly in the planetary atmosphere. However, the contrast effect likely contributes to these signals. Furthermore, our results could be modified if the active regions of HD 189733 b have drastically different characteristics than solar active regions. Further observations of transits across active stars will aid in disentangling the planetary signals from the stellar.

Author(s): Paul W. Cauley[1], Seth Redfield[1]
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219.03 – Characterizing K2 Planetary Systems Orbiting Cool Dwarfs

The NASA K2 mission is using the repurposed Kepler spacecraft to search for transiting planets in multiple fields along the ecliptic plane. K2 observes 10,000 – 30,000 stars in each field for roughly 80 days, which is too short to observe multiple transits of planets in the habitable zones of Sun-like stars, but long enough to detect potentially habitable planets orbiting low-mass dwarfs. Accordingly, M and K dwarfs are frequently nominated as K2 Guest Observer targets and K2 has already observed significantly more low-mass stars than the original Kepler mission. While the K2 data are therefore an enticing resource for studying the properties and frequency of planetary systems orbiting low-mass stars, many K2 cool dwarfs are not well-characterized. We are refining the properties of K2 planetary systems orbiting cool dwarfs by acquiring medium-resolution NIR spectra with SpeX on the IRTF and TripleSpec on the Palomar 200". In our initial sample of 144 potential cool dwarfs hosting candidate planetary systems detected by K2, we noted a high contamination rate from giants (16%) and reddened hotter dwarfs (31%). After employing empirically-based relations to determine the temperatures, radii, masses, luminosities, and metallicities of K2 planet candidate host stars, we found that our new cool dwarf radius estimates were 10-40% larger than the initial values, indicating that the radii of the associated planet candidates were also underestimated. Refining the stellar parameters allows us to identify astrophysical false positives and better constrain the radii and insolation flux environments of bona fide transiting planets. I will present our resulting catalog of system properties and highlight the most attractive K2 planets for radial velocity mass measurement and atmospheric characterization with Spitzer, HST, JWST, and the next generation of extremely large ground- and space-based telescopes. We gratefully acknowledge funding from the NASA Sagan Fellowship Program, the NASA K2 Guest Observer Program, the NASA XRP Program, the John Templeton Foundation, the National Science Foundation Astronomy & Astrophysics Postdoctoral Program, and the National Science Foundation Graduate Research Fellowship Program.

Author(s): Courtney D. Dressing[1], Elisabeth R. Newton[3], Joshua Schlieder[4], Andrew Vanderburg[2], David Charbonneau[2], Heather Knutson[1]
Institution(s): *1. California Institute of Technology, 2. Harvard University, 3. Massachusetts Institute of Technology, 4. NASA Exoplanet Science Institute*
Contributing team(s): K2C2

219.04 – Confirming Variability in the Secondary Eclipse Depth of the Rocky Super-Earth 55 Cancri e

We present a reanalysis of Spitzer transit and secondary eclipse observations of the rocky super Earth 55 Cancri e using Pixel Level Decorrelation (Deming et al. 2015). Secondary eclipses of this planet were found to be significantly variable by Demory et al. (2016), implying a changing brightness temperature which could be evidence of volcanic activity due to tidal forces. If genuine, this result would represent the first evidence for such a process outside of bodies in our own solar system, and would further expand our understanding of the huge variety of planetary systems that can develop in our universe. Spitzer eclipse observations, however, are subject to strong systematic effects which can heavily impact the retrieved eclipse model. A reanalysis of this result with an independent method is therefore needed to confirm eclipse depth variability. We tentatively confirm variability, finding a shallower increase in eclipse depth over the course of observations compared to Demory et al. (2015).

Author(s): Patrick Tamburo[2], Avi Mandell[1], Drake Deming[2], Emily Garhart[2]
Institution(s): *1. NASA GSFC, 2. University of Maryland*

219.05 – The Ruinous Influence of Close Binary Companions on Planetary Systems

The majority of solar-type stars are found in binary systems, and the dynamical influence of binary companions is expected to profoundly influence planetary systems. However, the difficulty of identifying planets in binary systems has left the magnitude of this effect uncertain; despite numerous theoretical hurdles to their formation and survival, at least some binary systems clearly host planets. We present high-resolution imaging of nearly 500 Kepler Objects of Interest (KOIs) obtained using adaptive-optics imaging and nonredundant aperture-mask interferometry on the Keck II telescope. We super-resolve some binary systems to projected separations of under 5 AU, showing that planets might form in these dynamically active environments. However, the full distribution of projected separations for our planet-host sample more broadly reveals a deep paucity of binary companions at solar-system scales. When the binary population is parametrized with a semimajor axis cutoff a cut and a suppression factor inside that cutoff S bin, we find with correlated uncertainties that inside $a_{cut} = 47^{+59}/_{-23}$ AU, the planet occurrence rate in binary systems is only $S_{bin} = 0.34^{+0.14}/_{-0.15}$ times that of wider binaries or single stars. Our results demonstrate that a fifth of all solar-type stars in the Milky Way are disallowed from hosting planetary systems due to the influence of a binary companion.

Author(s): Adam L. Kraus[2], Michael Ireland[1], Andrew Mann[2], Daniel Huber[3], Trent J. Dupuy[2]
Institution(s): *1. Australian National University, 2. The University of Texas at Austin, 3. University of Sydney*

219.06 – Assessing the Effect of Stellar Companions to *Kepler* Objects of Interest

Unknown stellar companions to Kepler planet host stars dilute the transit signal, causing the planetary radii to be underestimated. We report on the analysis of 165 stellar companions detected with high-resolution imaging to be within 2" of 159 KOI host stars. The majority of the planets and planet candidates in these systems have nominal radii smaller than 6 R_{Earth}. Using multi-filter photometry on each companion, we assess the likelihood that the companion is bound and estimate its stellar properties, including stellar radius and flux. We then recalculate the planet radii in these systems, determining how much each planet's size is underestimated if it is assumed to 1) orbit the primary star, 2) orbit the companion star, or 3) be equally likely to orbit either star in the system. We demonstrate the overall effect of unknown stellar companions on our understanding of *Kepler* planet sizes.

Author(s): Lea Hirsch[2], David R. Ciardi[1], Andrew Howard[1]
Institution(s): *1. Caltech, 2. UC Berkeley*

219.07D – Hubble Case Studies of Transiting Giant Exoplanets

The study of planets around other stars has entered a science-rich era of characterization, in which detailed information about individual planets can be inferred from observations beyond mere detection, which only yields bulk properties like mass or radius. Characterization probes more revealing quantities such as chemical abundances, albedo, and temperature/pressure profiles, which allow us to address larger questions of planet formation mechanisms, planetary evolution, and, eventually, habitability and presence of biosignature gases. The primary method for characterization of close-in planets is transit spectroscopy. This dissertation talk will focus on transiting exoplanet case studies with the Hubble Space Telescope' Wide-Field Camera-3 (WFC-3) as a tool of exoplanet characterization in a near-infrared band dominated by strong water features. I will first present a characterization the WFC-3 systematic effects that must be mitigated to extract the incredibly small (tens to 200 parts per million) signals, and then a study of four transiting giant planets (HATS-7b, HAT-p-3b, HD 149026b, and WASP-18b) in transmission, and two (WASP-18b and CoRoT-2b) in eclipse. Finally, I will discuss the role of transit timing monitoring of WASP-18b with HST and other observatories as another clue to its evolution as a close-in, massive planet. The five planets range from Neptune-class to Super-Jupiter-class in size/mass. Though these planets may be relatively rare, their observability represents a unique opportunity to probe planet formation and evolution, as well as atmospheric structures in a high-irradiation environment. These observations also yield insights into aerosols (i.e. clouds/hazes) in the atmosphere; clouds and/or hazes should significantly impact atmospheric chemistry and observational signatures, and we as a community must get a better handle on the phenomenon of aerosols in advance of the next generation of space observatories, including JWST and WFIRST. Further, as part of a large Hubble program, we are working to advance the state of exoplanet atmosphere observations from single, planet-by-planet, case studies, to an understanding of the large, hot, gaseous planets as a population.

Author(s): Ashlee N. Wilkins[7], Drake Deming[7], Adrian Barker[6], Björn Benneke[1], Laetitia Delrez[5], Michaël Gillon[5], Douglas P. Hamilton[7], Emmanuel Jehin[5], Heather Knutson[1], Nikole K. Lewis[4], Nikku Madhusudhan[2], Avi Mandell[3], Peter R. McCullough[4], Hannah R Wakeford[3]
Institution(s): *1. California Institute of Technology, 2. Cambridge University , 3. NASA GSFC, 4. Space Telescope Science Institute, 5. Université de Liège, 6. University of Leeds, 7. University of Maryland*

219.08 – Bayesian Inference of Giant Exoplanet Physics

The physical processes within a giant planet directly set its observed radius for a given mass, age, and insolation. The important aspects are the planet's bulk composition and its interior thermal evolution. By studying many giant planets as an ensemble, we can gain insight into this physics. We demonstrate two novel examples here. We examine 50 cooler transiting giant planets, whose insolation is sufficiently low (T_eff < 1000 K) that they are not affected by the hot Jupiter radius inflation effect. For these planets, the thermal evolution is relatively well understood, and we show that the bulk planet metallicity increases with the total planet mass, which directly impacts plans for future atmospheric studies. We also examine the relation with stellar metallicity and discuss how these relations place new constraints on the core accretion model of planet formation. Our newest work seeks to quantify the flow of energy into hot Jupiters needed to explain their enlarged radii, in addition to their bulk composition. Because the former is related to stellar insolation and the latter is related to mass, we are able to create a hierarchical Bayesian model to disentangle the two effects in our sample of ~300 transiting giant planets. Our results show conclusively that the inflation power is not a simple fraction of stellar insolation: instead, the power increases with incident flux at a much higher rate. We use these results to test published models of giant planet inflation and to provide accurate empirical mass-radius relations for giant planets.

Author(s): Daniel Thorngren[1], Jonathan J Fortney[1]
Institution(s): *1. UCSC*

220 – AGN, QSO, Blazars: High Redshift

220.01D – Quasars at Cosmic Dawn: Discoveries and Probes of the Early Universe

High redshift quasars, as the most luminous non-transient objects in the early universe, are the most promising tracers to address the history of cosmic reionization and how the origins of super-massive black hole (SMBH) are linked to galaxy formation and evolution. Over the last fifteen years, more than 100 quasars within the first billion years after the Big Bang have been discovered with the highest redshift at 7.1. We have developed a new method to select z>~6 quasars with both high efficiency and high completeness by combing optical and mid-IR Wide-field Infrared Survey Explorer (WISE) photometric data. We have applied this method to SDSS footprint and resulted in the discovery of the most luminous z>6 quasar ever discovered, which hosts a twelve billion solar mass black hole. I will present detailed follow-up observations of the host galaxies and environment of the most luminous quasars using HST, LBT and ALMA, in order to constrain early black hole growth and black hole/galaxy co-evolution at the highest redshift. I will also present initial results from a new quasar survey, which utilizes optical data from DECaLS, which is imaging 6700 deg^2 of sky down to z_AB~23.0, and neaar-IR data from UHS and UKIDSS, which maps the whole northern sky at Decl.<+60deg. The combination of these datasets allows us to discover quasars at redshift z>~7 and to conduct a complete census of the faint quasar population at z~6.

Author(s): Feige Wang[2], Xue-Bing Wu[2], Xiaohui Fan[3], Jinyi Yang[2], Fuyan Bian[1], Ian D. McGreer[3], Richard F. Green[3], Qian Yang[2], Linhua Jiang[2], Ran Wang[2]
Institution(s): *1. Australian National University, 2. Peking Univeristy, 3. University of Arizona*
Contributing team(s): DECaLS team, UHS team

220.02D – Surveys of Luminous Quasars in the Post-reionization Universe at z=5-6

Quasars at z ~ 5 to 6, the post-reionization epoch, are crucial tools to explore the evolution of intergalactic medium (IGM), quasar evolution and the early super-massive black hole growth. The quasar luminosity function (QLF) and its evolution at z >~ 5 is also needed to estimate the contribution of quasars to the ionizing background during and after the reionization epoch. McGreer et al. (2013) provided the first complete measurement of the z ~ 5 QLF. However, their work focused on faint quasars over a small sky area; there were only 8 quasars with M1450 < -27.3. We have carried out a new quasar survey of luminous quasars at 4.7 < z < 5.4 over 14555 deg^2 with high completeness, selected using a combination of SDSS and WISE optical/NIR colors . Using this luminous z ~ 5 quasar sample, we present a new determination of the z ~ 5 QLF and discuss the evolution model of QLF at high redshift. Based on surveys of luminous quasars at z > 4, previous studies have concluded that the number density evolution steepens at high redshift, such that luminous quasars decline as a population more steeply at higher redshift (z ~ 5.5) than from z=4 to 5. However, quasars at redshifts 5.3 < z < 5.7 have been very challenging to select using conventional color selections, due to their similar optical colors to late-type stars, especially M dwarfs, resulting in a glaring redshift gap in quasar redshift distribution. We have developed a new selection technique for z ~ 5.5 quasars based on optical, near- and mid-infrared photometric data. Up to date, we have constructed an uniform luminous z ~ 5.5 quasar sample with 26 new quasars. Our final completed sample of quasars at z=5-6 will be used to study QLF, evolution model and IGM evolution in the post-deionization universe.

Author(s): Jinyi Yang[2], Xue-Bing Wu[2], Xiaohui Fan3, Feige Wang[2], Ian D. McGreer3, Fuyan Bian[1], Richard F. Green3, Qian Yang[2], Linhua Jiang[2], Ran Wang[2], Weimin Yi4
Institution(s): *1. Australian National University, 2. Peking Univeristy, 3. University of Arizona, 4. Yunnan Observatories*
Contributing team(s): UHS team

220.03D – The z~4 Quasar Luminosity Function: Implications for supermassive black hole growth, reionization, and future time domain surveys

Upcoming time-domain imaging surveys such as the LSST will detect over a million high-redshift (z > 4) quasars, making complete spectroscopic followup unfeasible. Statistical estimates such as luminosity functions and clustering measurements will require purely photometric methods for classifying objects, estimating redshifts and estimating selection functions. We develop these methods and constrain the optical, type I quasar luminosity function (QLF) at 3.75 < z < 4.5 for -27.5 < M_{1450} < -23.5. Using the Sloan Digital Sky Survey (SDSS) repeated imaging of the 275 sq. deg. equatorial region of the sky (50 < R.A. < +60; -1.26 < Dec. < +1.26) known as Stripe 82, we extracted 40 million new lightcurves using the LSST data management software and selected a statistical sample of z~4 quasars based on colors and variability metrics. We confirmed these using a spectroscopically complete 55 sq. deg. sub-region augmented with 102 new spectroscopic observations of quasars at z > 3.4 with i < 22.5. We present the first variability-selected QLF measurement at high redshift (z > 3.75) and constraint on the characteristic luminosity M^*_{1450} = -26.7 from a single, uniformly-selected survey at z~4.

Author(s): Yusra AlSayyad[1], Andrew J. Connolly3, Ian D. McGreer[2], Zeljko Ivezic3, Xiaohui Fan[2]
Institution(s): *1. Princeton University, 2. University of Arizona, 3. University of Washington*
Contributing team(s): LSST Data Management

220.04D – The High-Redshift Clustering of Photometrically Selected Quasars

We present the data from the Spitzer IRAC Equatorial Survey (SpIES) along with our first high-redshift (2.9<z<5) quasar clustering results using these data. SpIES is a mid-infrared survey covering ~100 square degrees of the Sloan Digital Sky Survey (SDSS) Stripe 82 (S82) field. The SpIES field is optimally located to overlap with the optical data from SDSS and to complement the area of the pre-existing Spitzer data from the Spitzer-HETDEX Exploratory Large-area (SHELA) survey, which adds ~30 square degrees of infrared coverage on S82. Additionally, SpIES probes magnitudes significantly fainter than WISE; depth which is crucial to detect faint, high-redshift quasars. Using the infrared data from SpIES and SHELA, and the deep optical data from SDSS, we employ the multi-dimensional Bayesian selection algorithm outlined in Richards et al. 2015 to identify ~5000 high-redshift quasar candidates in this field. We then combine these candidates with spectroscopically confirmed high-redshift quasars and measure the redshift space correlation function and the projected correlation function. Finally, using these results, we compute the linear bias to try to constrain quasar feedback models akin to those in Hopkins et al. 2007.

Author(s): John Timlin[1]
Institution(s): *1. Drexel University*

220.05 – New High-*z* Fermi BL Lacs with the Photometric Dropout Technique

Determining redshifts for BL Lacertae (BL Lac) objects using the traditional spectroscopic method is challenging due to the absence of strong emission lines in their optical spectra. We employ the photometric dropout technique to determine redshifts for this class of blazars using the combined 13 broad-band filters from *Swift*-UVOT and the multi-channel imager GROND at the MPG 2.2 m telescope at ESO's La Silla Observatory. The wavelength range covered by these 13 filters extends from far ultraviolet to the near-Infrared. We report results on 40 new Fermi detected BL Lacs with the photometric redshifts determinations for 5 sources, with 3FGL J1918.2-4110 being the most distance in our sample at z=2.16. Reliable upper limits are provided for 20 sources in this sample. Using the highest energy photons for these Fermi-LAT sources, we evaluate the consistency with the Gamma-ray horizon due to the extragalactic background light.

Author(s): A. Kaur[1], Arne Rau[2], Marco Ajello[1], Dieter Hartmann[1], Vaidehi Paliya[1], Jan Bolmer[2], Jochen Greiner[2], Patricia Schady[2]
Institution(s): *1. Clemson University, 2. MPE*

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221 – Star Associations, Star Clusters - Galactic & Extragalactic II

221.01D – NLTE Effects in Globular Cluster Integrated Light Spectra and Photometric Colors

Our overall goal is to investigate the effect that modelling the atmospheres and spectra of Galactic globular cluster (GGCs) members in non-local thermodynamic equilibrium (NLTE) has on the integrated light (IL) spectrum, and the derivation of GGC ages and metallicities ([Fe/H] values) from IL photometric color and spectrum fitting. We create synthetic GGC populations and associated colour-magnitude diagrams (CMDs) using the Kroupa initial mass function (Kroupa, P., 2001, MNRAS, 322, 231-246) and the Teramo isochrones (Pietrinferni, A. et al, 2004, ApJ, 612, 168-190) with ages ranging from 9 to 15 Gyr, and [Fe/H] = -1.49 to -0.66 with α = +0.4. We investigate the dependence of predicted LTE and NLTE colors on the method and resolution of CMD discretization, and on the definition of representative stellar parameters in a discretized CMD.

Author(s): Mitchell Young[1], C. Ian Short[1]
Institution(s): *1. Saint Mary's University*

221.02 – The Evolutionary Population Synthesis Model for Helium-Enhanced Stellar Populations

The discovery of multiple stellar populations in the Milky Way globular clusters has stimulated a great deal of researches on the helium enhanced stellar populations. Here, we present the evolutionary population synthesis models for integrated spectro-photometric evolution of simple stellar populations (SSPs) with varied initial helium abundances. The integrated properties of helium-enhanced SSPs depend on metallicity and age as are the normal-helium SSPs, but the properties vary greatly with the initial helium abundance. We will discuss how helium-enhanced stellar populations explain many interesting observations of globular clusters and their host galaxies.

Author(s): Chul Chung[1], Suk-Jin Yoon[2], Young-Wook Lee[2]
Institution(s): *1. Center for Galaxy Evolution Research, 2. Deparment of Astronomy, Yonsei University*

221.03 – Two Groups of Red Giants with Distinct Chemical Abundances in the Bulge Globular Cluster NGC 6553 Through the Eyes of APOGEE

Multiple populations revealed in globular clusters (GCs) are important windows to the formation and evolution of these stellar systems. The metal-rich GCs in the Galactic bulge are an indispensable part of this picture, but the high optical extinction in this region has prevented extensive research. In this work, we use the high resolution near-infrared (NIR) spectroscopic data from APOGEE to study the chemical abundances of NGC 6553, which is one of the most metal-rich bulge GCs. We identify ten red giants as cluster members using their positions, radial velocities, iron abundances, and NIR photometry. Our sample stars show a mean radial velocity of -0.14 km/s, and a mean [Fe/H] of -0.15. We clearly separate two populations of stars in C and N in this GC for the first time. NGC 6553 is the most metal-rich GC where the multiple stellar population phenomenon is found until now. Substantial chemical variations are also found in Na, O, and Al. However, the two populations show similar Si, Ca, and iron-peak element abundances. Therefore, we infer that the CNO, NeNa, and MgAl cycles have been activated, but the MgAl cycle is too weak to show its effect on Mg. The Si leakage from the MgAl cycle is negligible. Type Ia and Type II supernovae do not seem to have significantly polluted the second generation stars. Comparing the APOGEE results with other GC studies, we find that NGC 6553 shows similar chemical variations as other relatively metal-rich GCs. We also confront current GC formation theories with our results, and suggest possible avenues for improvement in the models.

Author(s): Baitian Tang[6], Roger Cohen[6], Douglas Geisler[6], Ricardo P. Schiavon[3], Steven R. Majewski[1], Sandro Villanova[6], Ricardo Carrera[2], Olga Zamora[2], D Garcia-Hernandez[2], Matthew D. Shetrone[7], Peter M. Frinchaboy[4], Jose Gregorio Fernandez Trincado[5]
Institution(s): *1. University of Virginia, 2. Instituto de Astrofisica de Canarias, 3. Liverpool John Moores University, 4. Texas Christian University, 5. Universite de Franche-Comte, 6. University of Concepcion, 7. University of Texas at Austin*
Contributing team(s): APOGEE Team

221.04 – RR Lyrae stars as a tracer of multiple stellar populations in globular clusters

In the multiple stellar population paradigm, we suggest that the observed period-shift of RR Lyrae variables between the two Oosterhoff groups is due to the “population-shift” within the instability strip (IS) with increasing metallicity. In the metal-poor group II globular clusters (GCs), the IS is populated by second generation stars with enhanced helium and CNO abundances, while the RR Lyrae stars in the metal-rich group I GCs are produced mostly by first-generation stars without these enhancements. When these models are extended to all metallicity regimes, the observed Oosterhoff dichotomies in the inner and outer halo GCs can be naturally reproduced. In order to achieve this, however, specific star formation histories are required for the inner and outer halos, which is consistent with the dual origin of the Milky Way halo. We further show that two sequences of RR Lyrae stars recently discovered in the Milky Way bulge can also be reproduced by our multiple population models.

Author(s): Sohee Jang[1], Young-Wook Lee[1]
Institution(s): *1. Yonsei Univ.*

221.05 – The Multiple Generations and Populations of the Massive Globular Cluster NGC 6273 (M 19)

Although nearly all Galactic globular clusters exhibit large, and often correlated, star-to-star light element abundance variations, most systems do not display the same complexity for elements heavier than Si. In fact, the internal abundance variations of [Fe/H], [α/Fe], and heavier elements typically do not exceed ~10%. However, a growing number of the most massive clusters now show evidence of extended star formation and chemical enrichment histories, and at least two of these "iron-complex" globular clusters (ω Cen and M 54) are strongly suspected to have formed in or near the cores of accreted dwarf galaxies. In this context, we present new spectroscopic and photometric data for the massive cluster NGC 6273 obtained with the Magellan-M2FS and HST-WFC3 instruments. We find that NGC 6273 exhibits considerable chemical complexity, and was able to form at least 2-3 distinct generations of stars with different chemical compositions. The cluster also contains a trace population of α-poor stars, similar to the Sagittarius field population near M 54, that may have been accreted from a progenitor system.

Author(s): Christian I. Johnson[3], Nelson Caldwell[3], Robert Michael Rich[5], Mario L. Mateo[6], John Ira Bailey[2], William I. Clarkson[7], Edward W. Olszewski[4], Matthew G Walker[1]
Institution(s): *1. Carnegie Mellon, 2. Leiden University, 3. Smithsonian Astrophysical Observatory, 4. University of Arizona, 5. University of California, Los Angeles, 6. University of Michigan, 7. University of Michigan-Dearborn*

221.06 – The High-mass Truncation of the Star Cluster Mass Function: Limits on Massive Cluster Formation

Long-lived star clusters serve as useful tracers of star formation, and massive clusters in particular are often associated with vigorous star formation activity. We examine how massive cluster formation varies as a function of star formation surface density (Σ_{SFR}) by comparing cluster populations from galaxies that span a wide range of characteristic Σ_{SFR} values. The Panchromatic Hubble Andromeda Treasury (PHAT) survey yielded an unparalleled census of young star clusters in M31 and allows us to examine massive cluster formation in a low intensity star formation environment. We measure the cluster mass function for a sample of 840 young star clusters with ages between 10-300 Myr. The data show clear evidence of a high-mass truncation: only 15 clusters more massive than 10^4 $M_\odot$ are observed, compared to ~100 expected for a canonical M^{-2} power-law mass function with the same total number of clusters above the catalog completeness limit. Adopting a Schechter function parameterization, we fit a characteristic truncation mass (M_c) of 8.5×10^3 $M_\odot$ — the lowest truncation mass ever reported. When combined with previous mass function results, we find that the cluster mass function truncation correlates strongly with the star formation rate surface density, where $M_c \propto \Sigma_{SFR}^{1.3}$. We also find evidence that suggests the observed M_c-Σ_{SFR} relation also holds for globular clusters, linking the two populations via a common formation pathway.

Author(s): L. C. Johnson[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): PHAT Team

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222 – Starburst Galaxies Near & Far

222.01D – Characterizing Lyman Alpha Scattering in Nearby Galaxies

The hydrogen emission line of Lyman alpha (Lyα) has long been recognized as key to studying high redshift star-forming galaxies. However, due to the resonance of the emission line, the path that a Lyα photon takes from emission to eventual escape from the galaxy is essentially a mystery. This scattering poses a problem for using Lyα as a key emission feature of galaxies because it results in Lyα not being observed in all star-forming galaxies, and, in galaxies where it is observed, the place where the photon is originally emitted and where it is observed are two very different things. We discuss here how the Lyman-Alpha Reference Sample (LARS) provides a unique sample of 14 nearby ($0.02 < z < 0.2$) galaxies in which we investigate the role of scattering, both on the global scale of the galaxies and down to scales of ~ 50 parsecs using *Hubble Space Telescope* imaging. We compare the Lyα/Hα ratios with those expected from pure dust attenuation models, finding that in some cases significant positive departures are found on small scales, consistent with geometrical effects being important on sizes comparable to the HII regions. We then develop a simple scattering model in which we are able to estimate the average path length a Lyα photon travels with respect to non-resonant radiation, and quantifiy the excess dust optical depth to which Lyα radiation may be susceptible.

Author(s): Joanna Bridge[1], Matthew Hayes[2], Jens Melinder[2], Göran Östlin[2], Caryl Gronwall[1]
Institution(s): *1. Pennsylvania State University, 2. Stockholm University*

222.02 – Green Peas emit X-rays: Extreme Star Formation in Early Universe Analog Galaxies

Luminous compact galaxies (LCGs), Lyman Alpha Emitters

(LAEs), and Lyman Break Analog galaxies (LBAs) are all used as proxies for star-forming galaxies in the early Universe (z ≥ 6). The X-ray emission from such galaxies has been found to be elevated compared to other star-forming galaxies in our local Universe. It has been suggested that this may be due to the lower metallicity seen in these proxies to high-redshift galaxies and the elevated X-ray emission may affect the heating and Reionization evolution of the early Universe. Our previous studies have suggested the existence of an L_X-SFR-metallicity plane for all star-forming galaxies. We present these results in the context of our newest Joint *Chandra/HST* study containing the first X-ray detection of the Green Pea galaxies, a population of compact starburst galaxies discovered by volunteers in the Galaxy Zoo Project (Cardamone+2009). The galaxies were given the name Green Peas due to their compact size and green appearance in the *gri* composite images from SDSS. The green color is caused by a strong [OIII]λ5007Å emission line, an indicator of recent star formation. We observed a few of the most promising candidates with joint *Chandra/HST* observation and discuss our findings here.

Author(s): Matthew Brorby[1], Philip Kaaret[1]
Institution(s): *1. University of Iowa*

222.03 – The Dense Molecular Gas and Nuclear Activity in the Local ULIRG IRAS 13120-5453

Ultraluminous infrared galaxies (ULIRGs) are the most luminous and concentrated star-forming galaxies in the local Universe. With a galaxy's worth of gas in the central kiloparsec and star formation rates in excess of 100 solar masses per year, these systems can have infrared surface densities that approach predictions for radiation pressure-limited starbursts. We will present a case study of a local ULIRG, IRAS 13120-5453, using ALMA observations of dense gas tracers HCN and HCO+, and the 330 GHz continuum emission. We find the HCN/HCO+ ratio to be elevated above typical values for star-forming galaxies and suggest the enhancement can be explained by increased HCN abundance driven by mechanical heating from supernovae in the starburst. The 330 GHz continuum size is resolved, with a size of ~500 pc. Using this as a measure of the starburst size, we show the IR luminosity surface density is below that for a radiation pressure-limited starburst. We also find tentative evidence for non-virial motions of HCN, suggesting dense molecular gas may be entrained the molecular wind (previously detected in OH).

Author(s): George C. Privon[6], Susanne Aalto[2], Niklas Falstad[2], Sebastien Muller[2], Eduardo González-Alfonso[8], Kazimierz Sliwa4, Ezequiel Treister[6], Francesco Costagliola[2], Lee Armus7, Aaron S. Evans[10], Santiago Garcia-Burillo5, Takuma Izumi9, Kazushi Sakamoto[1], Paul van der Werf3
Institution(s): *1. Academia Sinica, 2. Chalmers University of Technology, 3. Leiden University, 4. Max Planck Institute for Astronomy, 5. Observatorio de Madrid, 6. Pontificia Universidad Católica de Chile, 7. SSC/Caltech, 8. Universidad de Alcalá, 9. University of Tokyo, 10. University of Virginia*

222.04 – Scaling Relations of Galactic Winds with Star Formation Rate

The galactic scale outflows generated by nuclear starbursts consist of a multiphase medium where each phase has a distinct velocity depending on the characteristics of the starburst. Using synthetic absorption lines generated from 3D hydrodynamical simulations we probe the outflow velocity of the hot, warm, and neutral gas entrained in a galactic wind. By varying the star formation rate (SFR) in our simulations, we find no correlation between the outflow velocity of the hot gas with the SFR, but we do find a correlation between the outflow velocity of both warm and neutral gas with the SFR. The scaling relation between outflow velocity and SFR only holds for low SFR until the scaling relation abruptly flattens at a SFR determined by the mass loading of the starburst. The outflow velocity of the hot gas only depends on the mass loading of the starburst and not the SFR. For low SFRs the difference between the velocity of cold gas, as measured by absorption lines of neutral or low ionized gas, may be 5-7 times lower than the velocity of the hot, highly ionized gas. The difference in velocity between the cold and hot gas for higher SFRs depends on the mass loading factor of the starburst. Thus the measured velocities of neutral or low ionized gas cannot be used to estimate the outflow velocity of the hot gas without determining the mass loading of the starburst.

Author(s): Ryan Tanner[1], Gerald Cecil[2], Fabian Heitsch[2]
Institution(s): *1. Augusta University, 2. University of North Carolina at Chapel Hill*

222.05D – Simulating Galactic Winds on Supercomputers

Galactic winds are a ubiquitous feature of rapidly star-forming galaxies. Observations of nearby galaxies have shown that winds are complex, multiphase phenomena, comprised of outflowing gas at a large range of densities, temperatures, and velocities. Describing how starburst-driven outflows originate, evolve, and affect the circumgalactic medium and gas supply of galaxies is an important challenge for theories of galaxy evolution. In this talk, I will discuss how we are using a new hydrodynamics code, *Cholla,* to improve our understanding of galactic winds. *Cholla* is a massively parallel, GPU-based code that takes advantage of specialized hardware on the newest generation of supercomputers. With *Cholla,* we can perform large, three-dimensional simulations of multiphase outflows, allowing us to track the coupling of mass and momentum between gas phases across hundreds of parsecs at sub-parsec resolution. The results of our recent simulations demonstrate that the evolution of cool gas in galactic winds is highly dependent on the initial structure of embedded clouds. In particular, we find that turbulent density structures lead to more efficient mass transfer from cool to hot phases of the wind. I will discuss the implications of our results both for the incorporation of winds into cosmological simulations, and for interpretations of observed multiphase winds and the circumgalatic medium of nearby galaxies.

Author(s): Evan Schneider[1]
Institution(s): *1. University of Arizona*

222.06 – Photometric Redshifts for High Resolution Radio Galaxies in the SuperCLASS Field

SuperCLASS (the Super-Cluster Assisted Shear Survey) is a deep, wide-area (~2 square degrees) extragalactic field with high resolution (0.1”) radio continuum coverage from e-MERLIN (Multi-Element Radio Linked Interferometer Network.) The combination of sensitivity and spatial resolution make e-MERLIN an ideal tool to trace spatially resolved star-formation in heavily obscured, dusty star-forming galaxies (DSFGs). Plus, thanks to the tight relationship between radio continuum and far-IR observations we have an observationally inexpensive and accurate method of mapping star formation density in distant galaxies. We present a photometric redshift catalog for DSFGs located in the SuperCLASS field. Multiwavelength photometric data was obtained with Subaru SuprimeCam (B,V,r,i,z) and photometric redshifts were generated using the public photometric redshift code, EAZY. With these redshifts we aim to conduct the first large sample morphological analysis of z~1-3 obscured galaxies. We plan to address two important questions: 1) Are the majority of obscured SFR>50 M_{solar}/yr galaxies driven by major collisions? and 2) do luminous active galactic nuclei (AGN) play a crucial role in the quenching of highly obscured star-formation? These photometric redshifts are crucial in determining the physical origins of our DSFG sample and to also conduct radio weak lensing experiments with the e-MERLIN dataset.

Author(s): Sinclaire Manning[1], Caitlin Casey[1], Richard Battye4, Christopher A. Hales5, Scott Chapman[2], Ian Smail3
Institution(s): *1. Department of Astronomy, University of Texas at Austin, 2. Department of Physics and Atmospheric Science, Dalhousie University, 3. Institute for Computational Cosmology, Durham University, 4. Jodrell Bank Centre for Astrophysics, University of Manchester, 5. National Radio Astronomy Observatory*
Contributing team(s): SuperCLASS Team

222.07 – Probing the Circumgalactic Medium of Submillimeter Galaxies with QSO Absorption Line Spectroscopy

We present first results from an ongoing survey to characterize the circumgalactic medium (CGM) of the massive high-redshift galaxieds detected as submillimeter galaxies (SMGs). By cross-matching far-infrared-selected galaxies from *Herschel* with spectroscopically confirmed quasars, we constructed a sample of 163 SMG-QSO pairs with separations less than 36". We observed 62 SMG-QSO pairs with the Very Large Array (VLA) and the Atacama Large Millimeter Array (ALMA). These observations obtained sub-arcsecond positions of 31 SMGs and identified seven previously-thought SMG-QSO pairs as submillimeter-luminous QSOs. We are currently conducting a redshift survey of the VLA/ALMA-confirmed SMGs and acquiring high S/N UV-optical specrtoscopy of the background QSOs. For the small sample of three VLA-confirmed SMG-QSO pairs that we have the complete data set, absorption line spectra of the background QSOs allow us to analyze the CGM of SMGs for the first time, providing insight into the fuel-supply ultimately powering their tremendous starbursts. Our observations reveal strong HI Ly-alpha absorption (rest-frame equivalent widths about 2-3 A) around all three SMGs; however, none exhibit compelling evidence for strong neutral absorbers ($N_{HI} > 10^{17.2}$ cm^{-2}) or metal absorption, allowing us to place an 1-sigma upper limit on the covering factor of optically thick HI gas around SMGs of $f_C < 36.9\%$. This is significantly lower than the covering factor around the co-eval population of luminous QSOs. Theoretical models predict that the structure of the CGM is entirely determined by dark matter halo mass. Given that that SMGs are believed to inhabit massive dark matter halos comparable to those hosting quasars, this difference in covering factor is unexpected. Therefore, our results tentatively indicate that SMGs may not have substantial cool gas reservoirs in their halos and that they may inhabit much less massive halos than previously thought.

Author(s): Hai Fu[6], Joseph F Hennawi[1], Jason X. Prochaska4, Alan N. Stockton5, Robert Lucien Mutel[6], Caitlin Casey7, Asantha R. Cooray[2], Dusan Keres3
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223 – Surveys & Data - From the Ground

223.01 – The Dynamic Infrared Sky

The dynamic infrared sky is hitherto largely unexplored. I will present the SPitzer InfraRed Intensive Transients Survey (SPIRITS) ––– a systematic search of 194 nearby galaxies within 30 Mpc, on timescales ranging between a week to a year, to a depth of 20 mag with Spitzer's IRAC camera. SPIRITS has already uncovered over 95 explosive transients and over 1200 strong variables. Of these, 37 infrared transients are especially interesting as they have no optical counterparts whatsoever even with deep limits from Keck and HST. Interpretation of these new discoveries may include (i) the birth of massive binaries that drive shocks in their molecular cloud, (ii) stellar mergers with dusty winds, (iii) 8--10 solar mass stars experiencing e-capture induced collapse in their cores, (iv) enshrouded supernovae, or (v) formation of stellar mass black holes. SPIRITS reveals that the infrared sky is not just as dynamic as the optical sky; it also provides access to unique, elusive signatures in stellar astrophysics.

Author(s): Mansi M. Kasliwal[1]
Institution(s): *1. Caltech*
Contributing team(s): SPIRITS (Spitzer InfraRed Intensive Transients Survey) Team

223.02 – Guard Earth, but Monitor the Universe: ATLAS and the Variable Sky

The Asteroid Terrestrial-Impact Last Alert Survey uses custom-built 0.5 meter telescopes to scan the whole accessible sky with a cadence optimized to detect small asteroids on their 'final plunge' toward impact with Earth. In the process, ATLAS produces calibrated images and photometry of two hundred million point source detections per night to 19th magnitude -- a rich data set for analysis of variable stars and transients with a huge range of timescales. We report our early results, including the discoveries of several hundred supernovae and several new variables stars, and we explore the potential of ATLAS data to contribute to the science of astronomical transients and variables.

Author(s): Aren Heinze[1], John Tonry[1], Larry Denneau[1], Brian Stalder[1], Andrei Sherstyuk[1], Armin Rest[2], Ken Smith[2], Steven Smartt[2]
Institution(s): *1. Institute for Astronomy, University of Hawaii, 2. Queen's University Belfast*

223.03 – The Pan-STARRS1 Survey Data Release

The first Pan-STARRS1 Science Mission is complete and an initial Data Release 1, or DR1, including a database of measured attributes, stacked images, and metadata of the 3PI Survey, will be available from the STScI MAST archive. This release will contain all stationary objects with mean and stack photometry registered on the GAIA astrometric frame.

The characteristics of the Pan-STARRS1 Surveys will be presented, including image quality, depth, cadence, and coverage. Measured attributes include PSF model magnitudes, aperture magnitudes, Kron Magnitudes, radial moments, Petrosian magnitudes, DeVaucoulers, Exponential, and Sersic magnitudes for extended objects. Images include total intensity, variance, and masks.

An overview of both DR1 and the second data release DR2, to follow in the spring of 2017, will be presented. DR2 will add all time domain data and individual warped images. We will also report on the status of the Pan-STARRS2 Observatory and ongoing science with Pan-STARRS. The science from the PS1 surveys has included results in many t fields of astronomy from Near Earth Objects to cosmology.

The Pan-STARRS1 Surveys have been made possible through contributions of the Institute for Astronomy of the University of Hawaii; the Pan-STARRS Project Office; the Max-Planck Society and its participating institutes: the Max Planck Institute for Astronomy, Heidelberg and the Max Planck Institute for Extraterrestrial Physics, Garching; The Johns Hopkins University; Durham University; the University of Edinburgh; Queen's University Belfast; the Harvard-Smithsonian Center for Astrophysics, the Las Cumbres Observatory Global Telescope Network Incorporated; the National Central University of Taiwan; the Space Telescope Science Institute; the National Aeronautics and Space Administration under Grants No. NNX08AR22G, NNX12AR65G, NNX14AM74G issued through the Planetary Science Division of the NASA Science Mission Directorate; the National Science Foundation under Grant No. AST-1238877; the University of Maryland; the Eotvos Lorand University; and the Los Alamos National Laboratory.

Author(s): Kenneth C. Chambers[1]
Institution(s): *1. Univ. of Hawaii*
Contributing team(s): Pan-STARRS Team

223.04D – Late-Time Follow-up of ASAS-SN Tidal Disruption Events

Humanity should have a continuous record of the sky, and for the past 3.5 years, the All-Sky Automated Survey for SuperNovae (ASAS-SN or "Assassin") has been working to provide that record. ASAS-SN is a long-term project to monitor the entire sky with a rapid cadence using a global array of small telescopes in both hemispheres, searching for new bright transients that can be studied in detail by the world's astronomers. By focusing only on the brightest objects, ASAS-SN limits its discoveries to only those that can be studied in the greatest detail, and it is unique among professional surveys in this respect.

While the primary goal of ASAS-SN is a complete survey of bright, nearby supernovae, ASAS-SN also finds many other interesting transients. ASAS-SN has discovered 3 of the brightest tidal disruption events (TDEs) ever found at optical wavelengths, and we have performed extensive follow-up studies of these objects since discovery. I will present the results of late-time follow-up studies of the ASAS-SN TDEs and discuss the deeper insight into TDE physics that can be gained from this work.

Author(s): Thomas Warren-Son Holoien[1]
Institution(s): *1. The Ohio State University*
Contributing team(s): The ASAS-SN Team

223.05 – Selected First Results from the 7 Ms Chandra Deep Field-South Survey

The exposure on the Chandra Deep Field-South (CDF-S) has recently been increased to 7 Ms, making it the most sensitive extragalactic X-ray survey by a wide margin. About 1050 X-ray sources have been detected, primarily distant active galactic nuclei (AGNs) and starburst/normal galaxies. The unmatched deep multiwavelength coverage for these sources allows superb follow-up investigations; e.g., 98.4% of the X-ray sources have multiwavelength counterparts, and 97.8% have spectroscopic/photometric redshifts. I will briefly describe the source catalog for the 7 Ms CDF-S and some exciting first science results. The latter will likely include (1) constraints on SMBH growth in the first galaxies as revealed by direct detection and stacking; (2) long-term variability studies of the AGNs producing most of cosmic accretion power; (3) AGN/galaxy interactions as investigated via the host properties of X-ray AGNs; and (4) measurements of the evolving X-ray binary populations of normal and starburst galaxies.

Author(s): W. Niel Brandt[1]
Institution(s): *1. Penn State Univ.*
Contributing team(s): Chandra Deep Field-South Team

223.06 – A Numerical Study on the Streams of Star Debris after Tidal Disruption

Lurking at the centers of most galaxies are gigantic star and gas devouring monsters. These monsters are supermassive black holes (SMBHs), some of which are larger than our solar system and ten billion times as massive as our own Sun. The vast majority of stars in the universe live for tens of billions of years, eventually dying from old age as the nuclear
reactions that power them become progressively less effective. But for every ten thousand stars that die peacefully, one star will be brutally torn apart by the extreme tidal forces present as it passes near a SMBH. My recent work has been to develop computational tools necessary to study the fates of stars disrupted by SMBHs. In this research project I present
the results of my numerical study aimed at understanding the streams of star debris that result after disruption.

Author(s): Priscila Camacho Olachea[1], Enrico Ramirez-Ruiz[1], Jamie Law-Smith[1]
Institution(s): *1. University of California Santa Cruz*

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224 – Large Scale Structure, Cosmic Distance Scale

224.01 – Where does cosmic far-infrared background come from? Interpreting the Planck and Herschel results using physical and empirical models

Cosmic far-infrared background (CFIRB) originates from dusty star-forming galaxies across cosmic time. It contains a wealth of information about star formation history and the connection between galaxies and dark matter halos. I will present two complementary approaches for interpreting the intensity and anisotropy of CFIRB observed by Planck and Herschel, as well as other far-infrared/submillimeter results. The first approach applies a physical model based on the continuity equations of gas, stars, and metal. The second approach uses empirical scaling relations from optical surveys. I demonstrate how CFIRB constrains star formation rate as a function of halo mass and redshift, dust attenuation, and the contribution of quiescent and starburst galaxies. This work presents a highly self-consistent picture of cosmic star formation history. It also motivates the design and the priority of the Far-IR Surveyor planned by NASA.

Author(s): Hao-Yi Wu[1], Olivier Doré[1]
Institution(s): *1. California Institute of Technology.*

224.02D – Methods for accurate analysis of galaxy clustering on non-linear scales

Measurements of galaxy clustering with the low-redshift galaxy surveys provide sensitive probe of cosmology and growth of structure. Parameter inference with galaxy clustering relies on computation of likelihood functions which requires estimation of the covariance matrix of the observables used in our analyses. Therefore, accurate estimation of the covariance matrices serves as one of the key ingredients in precise cosmological parameter inference. This requires generation of a large number of independent galaxy mock catalogs that accurately describe the statistical distribution of galaxies in a wide range of physical scales. We present a fast method based on low-resolution N-body simulations and approximate galaxy biasing technique for generating mock catalogs. Using a reference catalog that was created using the high resolution Big-MultiDark N-body simulation, we show that our method is able to produce catalogs that describe galaxy clustering at a percentage-level accuracy down to highly non-linear scales in both real-space and redshift-space.

In most large-scale structure analyses, modeling of galaxy bias on non-linear scales is performed assuming a halo model. Clustering of dark matter halos has been shown to depend on halo properties beyond mass such as halo concentration, a phenomenon referred to as assembly bias. Standard large-scale structure studies assume that halo mass alone is sufficient in characterizing the connection between galaxies and halos. However, modeling of galaxy bias can face systematic effects if the number of galaxies are correlated with other halo properties. Using the Small MultiDark-Planck high resolution N-body simulation and the clustering measurements of Sloan Digital Sky Survey DR7 main galaxy sample, we investigate the extent to which the dependence of galaxy bias on halo concentration can improve our modeling of galaxy clustering.

Author(s): Mohammadjavad Vakili[1]
Institution(s): *1. New York University*

224.03 – Redshift-Independent Distances in the NASA/IPAC Extragalactic Database Surpass 166,000 Estimates for 77,000 Galaxies

Redshift-independent extragalactic distance estimates are used by researchers to establish the extragalactic distance scale, to underpin estimates of the Hubble constant, and to study peculiar velocities induced by gravitational attractions that perturb the motions of galaxies with respect to the “Hubble flow” of universal expansion. In 2006, the NASA/IPAC Extragalactic Database (NED) began providing users with a comprehensive tabulation of the redshift-independent extragalactic distance estimates published in the astronomical literature since 1980. A decade later, this compendium of distances (NED-D) surpassed 100,000 estimates for 28,000 galaxies, as reported in our recent journal article (Steer et al. 2016). Here, we are pleased to report NED-D has surpassed 166,000 distance estimates for 77,000 galaxies. Visualizations of the growth in data and of the statistical distributions of the most used distance indicators will be presented, along with an overview of the new data responsible for the most recent growth. We conclude with an outline of NED’s current plans to facilitate extragalactic research further by making greater use of redshift-independent distances. Additional information about other extensive updates to NED is presented at this meeting by Mazzarella et al. (2017). NED is operated by and this research is funded by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Author(s): Ian Steer[1]
Institution(s): *1. NED*

224.04D – Galaxy-galaxy and galaxy-CMB Lensing with SDSS-III BOSS galaxies

Weak lensing has emerged as an important cosmological probe for our understanding of dark matter and dark energy. The low redshift spectroscopic sample of SDSS-III BOSS survey, with a well-understood galaxy population is ideal to probe cosmology using galaxy-galaxy lensing and galaxy-CMB lensing. I will present results from two methods that combine information from lensing and galaxy clustering. The first involves combining lensing and galaxy clustering to directly measure galaxy bias and thus recover the matter correlation function, which is directly predicted from theory. Using scales where linear perturbation theory is valid, we carry out a joint analysis of galaxy-galaxy clustering, galaxy-galaxy lensing, and CMB-galaxy lensing, and constrain linear galaxy bias b=1.80+/-0.06, Omega_m=0.284+/-0.024, and relative calibration bias between CMB and galaxy lensing, b_l=0.82+/-0.15. The second method involves including information about redshift-space distortions to measure the E_G statistic to test gravitational physics at cosmological scales. This statistic is independent of galaxy bias and the amplitude of the matter power spectrum. Different theories of gravity predict a different E_G value, making it a clean and stringent test of GR at cosmological scales. Using the BOSS low redshift sample, we have measured E_G at z=0.27 with ~10% (15%) accuracy using galaxy (CMB) lensing, with results consistent with LCDM predictions.

Author(s): Sukhdeep Singh[1], Rachel Mandelbaum[1]
Institution(s): *1. Carnegie Mellon University*

224.05 – Efficient Cosmological Perturbation Theory with FAST-PT

Cosmological perturbation theory is a powerful tool to model observations of large-scale structure in the weakly non-linear regime. However, even at next-to-leading order, it results in computationally expensive mode-coupling integrals. In this talk, I will focus on the physics behind our extremely efficient algorithm, FAST-PT. I will show how the algorithm can be applied to calculate 1-loop power spectra for several cosmological observables, including the matter density, galaxy bias, galaxy intrinsic alignments, the Ostriker-Vishniac effect, the secondary CMB polarization due to baryon flows, and redshift-space distortions. Our public code is written in Python and is easy to use and adapt to additional applications.

Author(s): Xiao Fang[1], Jonathan Blazek[1], Joseph McEwen[1], Christopher M. Hirata[1]
Institution(s): *1. The Ohio State University*

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225 – Extremes of Time Domain Astrophysics: Stellar Mergers to Black Hole Outbursts

Time Domain Astrophysics (TDA) covers an enormous landscape of timescales and energies: from stellar birth to death; and from mergers of stars, to stellar mass black holes, to supermassive black hole mergers -- to list but a few. We propose a Special Session to to focus on the extremes of TDA phenomena, with duration timescales from months to milliseconds and currently observed (or inferred) rates (if recurrent) of <~10^-2 -- >~10^+3 per year. The Session will deal not only with extreme phenomena, but the current and planned surveys and analysis methods to study them. Both observation and analysis techniques will be paramount to the session organization. An accompanying Poster session will be solicited. This session is also designed to promote the newly formed (2014) Working Group on Time Domain Astronomy (WGTDA) and enlist new members to work in and promote this now major field of Astronomy/Astrophysics as well as to consider its future needs and plans for the coming 2020 Decadal Survey.

225.01 – Stellar Mergers and Common Envelope Episodes in the Transient Night Sky

Recent evidence is revealing that the many massive stars are not single, but are, in fact, in binary systems so tight that they will interact during the stars' lifetimes. Mass transfer episodes, stellar mergers, and common envelope phases – which occur when one star in a binary pair evolves to engulf its companion – are therefore critical processes which regulate the lives of many stars. In particular, the formation of compact binaries which can merge under the influence of gravitational radiation depends heavily on phases of orbital transformation regulated by binary interaction. These phases of merger and common envelope interaction also imprint themselves on the transient night sky. This talk discusses the growing class of luminous red novae transients and their strong association with a stellar merger origin. I focus the discussion on two recent extragalactic transients with pre-outburst detections of their progenitor systems, M31 LRN 2015 and M101 OT2015-1. Pre-outburst detections make these systems particularly valuable in understanding the link between progenitor systems and the transients they produce. Study of this class of transients offers a pathway to directly constrain the properties and outcomes of crucial but long-uncertain phases of binary evolution like common envelope episodes.

Author(s): Morgan MacLeod[1]
Institution(s): *1. Institute for Advanced Study*

225.02 – Fast Radio Bursts

Fast Radio Bursts (FRBs) are a recently discovered phenomenon consisting of short (few ms) bursts of radio waves that have dispersion measures that strongly suggest an extragalactic and possibly cosmological origin. Current best estimates for the rate of FRBs is several thousand per sky per day at radio frequencies near 1.4 GHz. Even with so high a rate, to date, fewer than 20 FRBs have been reported, with one source showing repeated bursts. In this talk I will describe known FRB properties including what is known about the lone repeating source, as well as models for the origin of these mysterious events. I will also describe the CHIME radio telescope, currently under construction in Canada. Thanks to its great sensitivity and unprecedented field-of-view, CHIME promises major progress on FRBs.

Author(s): Victoria M. Kaspi[1]
Institution(s): *1. McGill Univ.*

225.03 – Changing Look Quasars

Accretion onto black holes (BH) illuminates fascinating physics from the stellar mass BHs in Galactic X-ray binaries (XRBs) to the supermassive black holes (SMBH) in Seyferts and quasars. Alas, BH accretion regions are too compact to be spatially resolved. Temporal changes in XRB spectral states have gone a long way to unravel the accretion physics in XRBs, and suggest powerful theoretical and observational analogies to quasars. However, simple mass scaling to SMBHs suggests impractically long timescales (millenia) for accretion state transitions in quasars. However, large spectral state changes in quasars have now been detected that both inform and invigorate debates about accretion theory and the nature of historical quasar classes (e.g., Type 1 vs Type 2). In the last couple of years, a dozen luminous "changing-look quasars" (CLQs) were discovered to exhibit strong, persistent changes in luminosity, accompanied by the dramatic emergence or disappearance of broad emission-line (BEL) components. The availability of repeat spectroscopy for large samples of quasars provided by Sloan Digital Sky Survey (SDSS) and its ongoing Time Domain Spectroscopic Survey (TDSS) now extend this rare and remarkable phenomenon to regimes of luminosity and redshift that overlap the huge cosmological samples of quasars in the SDSS. We review the current understanding of these events, and upcoming possibilities for their detection, characterization and modeling.

Author(s): Paul J. Green[2], Chelsea MacLeod[2], Scott F. Anderson[5], Michael Eracleous[3], John J. Ruan[5], Jessie C. Runnoe[4], Matthew J. Graham[1]
Institution(s): *1. California Institute of Technology, 2. Harvard-Smithsonian CfA, 3. Penn State University, 4. University of Michigan, 5. University of Washington*

225.04 – Exciting Developments in Tidal Disruption Event Observations

In the past decade, there has been a steady rate of tidal disruption event (TDE) detections from wide-field surveys across the electromagnetic spectrum of a couple per year. I will highlight recent real-time TDE discoveries by optical time domain surveys that have enabled the detailed characterization of TDE light curves, broad-line emission, dust echoes, and outflows. In the next decade, ZTF and LSST will dramatically increase the survey capabilities in the optical time domain, potentially yielding tens to thousands of TDE detections per year. I will conclude with thoughts on how to achieve efficient and prompt classification of TDEs among the future deluge of optical transients, in order that they may be used as effective probes of supermassive black hole demographics and accretion physics.

Author(s): Suvi Gezari[1]
Institution(s): *1. University of Maryland*

225.05 – Electromagnetic Counterparts to Gravitational Waves

The direct detection of gravitational waves from merging black holes marks the dawn of a new era. I will present ongoing efforts and prospects
to identify and characterize the electromagnetic counterpart. Among the various models for electromagnetic emission from binary neutron
star mergers, free neutron decay gives the most luminous and fast-evolving optical counterpart. I will describe a co-ordinated global effort, the GROWTH (Global Relay of Observatories Watching Transients Happen) network working in tandem with the Zwicky Transient Facility.

Author(s): Mansi M. Kasliwal[1]
Institution(s): *1. Caltech*
Contributing team(s): GROWTH collaboration, iPTF/ZTF collaboration

225.06 – Harvesting Extremes of Time Domain Astrophysics in the 2020s and Beyond

In this session we have touched on several examples of Extreme Transients -- Stellar Mergers, Fast Radio Bursts, Changing Look Quasars, Tidal Disruption Events, and Gravitational Wave Counterparts. Other key examples of the Extremes of Time Domain Astrophysics are, of course, Gamma Ray Bursts (both Short and Long), Super-luminous Supernovae, Black Hole X-ray Binary Outbursts (every ~50y?), Extreme Flares of Blazars, PeV Neutrinos, and many more. For all of these the ability for rapid followup with Gamma-ray, X-ray, optical, IR, radio imaging and spectroscopy is needed for exploring and understanding the underlying physics that extreme transients represent. We introduce two concepts for space-borne observatories that can do this: 1) a Time-domain Spectroscopic Observatory (TSO), proposed as Concept for a Probe-class mission devoted to TDA followup. TSO would be a 1.5-2m cold telescope in Geosynch orbit over LSST for imaging and spectroscopy (R = 5, 100, 3000) over the 0.4 - 5 micron band to finally enable use of GRBs as probes of the Early Universe and EoR out to z >10-12, as well as measures of the M-sigma relation from reverberation mapping of AGN flares for the growth of SMBHs in AGN out to z ~8 (and many other key projects); and 2) a 4pi (simultaneous) X-ray Imaging Observatory (4piXIO), as a Swarm of ~30 CubeSats (36U) each with 0.4sr FoV coded aperture telescopes with ~1arcmin resolution and ~10arcsec source positions to monitor all classes of transients and variable sources (0.3 - 200 keV) as well as provide 4pi coverage for GRBs to a TSO, for followup on a sample >10X that of Swift. We also introduce the newly-formed (2014) AAS Working Group on Time Domain Astronomy (WGTDA) and invite all with interests in this exciting and growing field to join and consider how TDA can best advance in the next Decade.

Author(s): Jonathan E. Grindlay[1]
Institution(s): *1. Harvard-Smithsonian, CfA*

226 – Science with the Hyper Suprime-Cam (HSC) Survey

This goal of this session, including both talks and poster contributions, is to present a selection of initial science results from the first year of the HSC survey, including exciting results in the fields of weak gravitational lensing, strong lensing, galaxy clusters including SZ-selected ACT clusters, galaxy evolution, and high-redshift quasars. The Hyper Suprime-Cam (HSC) Subaru Strategic Program is an ongoing 300 night survey at the 8.2m Subaru telescope using the wide-field HSC imager over a period of five years. The survey has three layers — wide, deep, and ultra-deep — covering 1400 deg^2, 27 deg^2, and 3.5 deg^2, respectively; observations are being taken in five broadband filters and several narrow-band filters. The survey depth (r~26 for the wide layer) and the excellent imaging quality (median seeing of 0.6 arcsec in the i band), combined with the overlap with many ancillary multi-wavelength datasets like SDSS/BOSS and ACTPol, makes this survey very powerful for a wide range of scientific goals, from weak lensing cosmology, to studies of galaxies at low and high redshift, to quasars (with many additional investigations in other areas enabled by the dataset). The first dataset from the survey will be released in early 2017. For more information about the HSC survey, see http://hsc.mtk.nao.ac.jp/ssp/.

226.01 – The Subaru Hyper Suprime-Cam Survey

High-latitude wide-field optical imaging surveys allow us to address scientific questions ranging from the properties of asteroids in the Solar System, to the structure of the Milky Way halo, to galaxy evolution, to the distribution of dark matter in the universe and the properties and evolution of dark energy. Hyper Suprime-Cam (HSC) is an imaging camera with a 1.77 deg^2 field of view, mounted at the Prime Focus of the Subaru 8.2-m telescope operated by the National Astronomical Observatory of Japan on the summit of Maunakea in Hawaii. A consortium of astronomers from Japan, Taiwan and Princeton University is carrying out a three-layer, 300-night, multiband survey with this instrument. The Wide Layer will cover 1400 deg^2 in five broad bands (grizy), to a 5 sigma point-source depth of r~26. The Deep Layer will cover 28 deg^2 in four separate fields, going a magnitude deeper, and including narrow-band imaging to identify Lyman-alpha emitters at high redshift. The Ultradeep Layer will go a magnitude deeper still in two pointings (3.5 deg^2), allowing studies of supernovae and other variable phenomenae.

The survey started in 2014, and will continue through 2019. We have covered 240 deg^2 of the Wide Layer in all five bands, and the median seeing in the i band is 0.60 arcseconds. In this introductory talk to the HSC special session, I will describe the quality of the data, plans for public data release, and touch upon some of the early science results, which range from the discovery of an ultrafaint dwarf galaxy in the Milky Way halo, to significant numbers of quasars and galaxies with redshifts between 5.7 and 7, to measurements of gravitational weak lensing around clusters.

Author(s): Michael A. Strauss[1]
Institution(s): *1. Princeton Univ.*
Contributing team(s): the Hyper Suprime-Cam team

226.02 – Weak gravitational lensing with the Hyper Suprime-Cam survey

Data from the Hyper Suprime-Cam (HSC) survey on the Subaru telescope show great promise for weak gravitational lensing science. The unprecedented combination of area, depth, and imaging quality of this survey (with median i-band seeing of 0.6 arcsec) will enable a wide array of weak lensing measurements, with significant contributions from lenses up to redshift z~1.

Applications include cosmological weak lensing measurements from shear-shear and galaxy-shear correlations, which will be especially powerful when combined with the overlapping SDSS-III spectroscopic datasets; and studies of the dark matter halos of galaxies and galaxy clusters. In this talk, I will demonstrate the imaging quality and the tests used to validate the weak lensing measurements. These include null tests internal to the data, comparisons with external datasets, and image simulation-based tests. I will also show the lensing mass profiles of spectroscopic galaxies from the SDSS-III, illustrating the current signal-to-noise ratio on small and large scales and demonstrating the potential for innovative galaxy and cosmological science with the complete survey area.

Author(s): Rachel Mandelbaum[1]
Institution(s): *1. Carnegie Mellon University*
Contributing team(s): The Hyper Suprime-Cam (HSC) collaboration

226.03 – Weak Lensing with the Hyper Suprime-Cam Survey: Connecting the Mass Profiles of Massive Galaxies with their Dark Matter Halos

The HSC survey is an ambitious multi-wavelength (g,r,i,z,y) weak-lensing program to map out 1400 square degrees of the sky with the 8.2m Subaru Telescope to a 5 sigma point-source depth of $i\sim26$ mag. This is a truly unique combination of deep imaging over a wide area which makes this a well suited data-set for studying the mass profiles and assembly histories of the most rare and massive galaxies in the universe. Furthermore, the lensing capabilities of HSC means that we can tie the luminous properties of massive galaxies to the properties of their dark matter halos. With 240 deg^2 of excellent quality imaging data already in hand, I will show that HSC can simultaneously map the light profiles of massive galaxies out to 100 kpc and characterize the profiles of their host dark matter halos to radii greater than 10 Mpc. By comparing with modern hydrodynamic simulations of galaxy formation, I will show that the combination of these two measurements provides strong observational constraints on the strength of feedback mechanisms in massive galaxies.

Author(s): Alexie Leauthaud[1]
Institution(s): *1. UCSC*
Contributing team(s): HSC Survey Collaboration

226.04 – HSC Weak Lensing Measurement of ACTPol SZ-selected Galaxy Clusters

Although the abundance of galaxy clusters is one of the most powerful cosmological probes, the precision of abundance measurement is currently limited by systematic uncertainties in cluster mass calibration. Weak gravitational lensing is a valuable tool to calibrate cluster mass, since it directly probes the dark matter distribution without physical assumptions such as hydrostatic equilibrium. In this talk, combining the cutting-edge optical and microwave data from Subaru Hyper Suprime-Cam (HSC) and ACTPol, we report the weak lensing mass measurement of galaxy clusters selected based on thermal Sunyaev–Zel'dovich (SZ) effect. Thanks to the high number density of source galaxies, we obtain a stacked weak lensing signal with a signal to noise ratio of ~20. We present detailed systematic tests such as background galaxy selection as well as a comparison of our mass calibration to previous results in the literature.

Author(s): Hironao Miyatake[1]
Institution(s): *1. Jet Propulsion Laboratory/California Institute of Technology*
Contributing team(s): HSC collaboration, ACTPol collaboration

226.05 – One survey to find them all: detecting and studying galaxy clusters from infancy to maturity with Subaru HyperSuprimeCam Survey

With its unprecedented combination of depth and area, the Subaru HSC survey opens up a unique window to probe the formation and evolution of galaxy clusters from infancy (proto-clusters) to maturity based on one single dataset. Furthermore, the superb imaging quality and the combination of broad and narrow band filters offer several complementary ways in detecting clusters, including total-mass selection (via weak shear), red sequence selection, and concentration of line-emitting galaxies (for clusters at $z>1$). I will present the efforts of the HSC cluster working group in detecting clusters and proto-clusters, and the studies of galaxy population evolution in clusters. In particular, for the latter topic, I will summarize results based on the Camira cluster sample (Oguri et al.), which is constructed from concentrations of red galaxies in multi-color space. Using cross correlation techniques, we have examined the stellar mass assembly history of brightest cluster galaxies, inferred the details of dynamical friction and mechanisms of quenching of star formation from the radial profile of quiescent galaxies, quantified the evolution of stellar mass function of both red and blue galaxies, and made the first measurement of the radio luminosity function of radio-loud galaxies in clusters out to $z\sim1$.

Author(s): Yen-Ting Lin[1]
Institution(s): *1. Academia Sinica*
Contributing team(s): HSC collaboration

226.06 – Exciting discoveries of strong gravitational lenses from the HSC Survey

Strong gravitational lenses have numerous applications in astrophysics and cosmology. We expect to discover thousands of strong gravitational lenses from the Hyper Suprime-Cam (HSC) Survey, thanks to its unique combination of deep and wide imaging. I will give highlights on a few interesting gravitational lenses that were discovered recently from early HSC data, for example, the first spectroscopically confirmed double source plane (DSP) lens system dubbed "Eye of Horus" and the highest-redshift quadruply-lensed low-luminosity Active Galactic Nucleus (LLAGN).

DSP lenses such as "Eye of Horus" are even more rare than ordinary lenses but provide tighter constraints on the lens mass distribution and can also be useful to measure cosmological parameters such as Dark Energy and Matter density parameter. The lensed LLAGN discovered recently from HSC is only the second such lens system in our knowledge. LLAGNs are thought to have differentmechanisms driving their nuclear activity compared to their brighter counterparts i.e. quasars. Our knowledge about this abundant but faint population of AGNs is limited to the local universe so far. But lensing magnification will allow studies of distant LLAGNs which should be discovered in large numbers from a deep survey like HSC for the first time. Also, owing to the variable nature of LLAGNs, they could potentially be used as a cosmological probe similar to the lensed quasars.

Author(s): Anupreeta More[1]
Institution(s): *1. Kavli IPMU, U. of Tokyo*
Contributing team(s): Team 1: Masayuki Tanaka, Kenneth Wong, et al.; Team 2: Chien-Hsiu Lee, Masamune Oguri, et al.

226.07 – Environment and Structure of Massive Central Galaxies through the Eye of Hyper Suprime-Cam

Although the environmental dependence of structures for massive central galaxies is predicted by the promising hierarchical assembly model, observations at low redshift seem to find no convincing evidence of that. With the help of deep i-band images of a large sample of massive central galaxies at $0.3 < z < 0.5$ from the Subaru Hyper Suprime-Cam (HSC) survey, we map their stellar mass distributions out to radius larger than 100 kpc, and discover subtle, but systematic and robust structural differences that depend on halo mass. At fixed stellar mass within 100 kpc, the massive central galaxies in more massive ($M_{200,c} > 1.6\times10^{14} M_{sun}$) halos have a slightly flattened inner profile within ~15-20 kpc, and a more prominent outer envelope compared to ones in less massive ($M_{200,c} < 8.7\times10^{13} M_{sun}$) halos. For centrals with $M_* > 10^{11.5} M_{sun}$, the ones in more massive halos show very significant excess of mass in the outskirt when the two samples are matched using proxies of mass assembled at $z > 1$. Such differences are broadly consistent with richer recent merging history for more massive halos. We suggest that the relation between total stellar mass and mass within inner 5 or 10 kpc is potentially interesting for diagnosing the role played by host halo in shaping the structures of massive central galaxies. These results also highlight the importance of deep photometry and the usage of detailed structural information in the study of the assembly history of galaxies. We also show that the radial profiles of ellipticity and optical color, along with the preliminary weak lensing signals will enable us gain more insights about the evolution of massive galaxies.

Author(s): Song Huang[1]
Institution(s): *1. Kavli-IPMU, University of Tokyo*
Contributing team(s): The HSC Survey Collaboration

226.08 – Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs): New z > 6 Quasar Survey with Subaru/HSC

Quasars at high redshift are an important and unique probe of the distant Universe, for understanding the origin and progress of cosmic reionization, the early growth of supermassive black holes, and the evolution of quasar host galaxies and their dark matter halos, among other topics. We are currently carrying out a new spectroscopic survey, called SHELLQs (Subaru High-z Exploration of Low-Luminosity Quasars), to search for low-luminosity quasars at z > 6. By exploiting the exquisite imaging data produced by the Subaru Hyper Suprime-Cam (HSC) survey, we aim to probe quasar luminosities down to M_{1450} ~ -22 mag, i.e., below the classical threshold between quasars and Seyfert galaxies. Candidate selection is performed by combining several photometric approaches including a Bayesian probabilistic algorithm. A large spectroscopic observing program is underway, using Subaru/FOCAS, GTC/OSIRIS, and Gemini/GMOS; in particular, SHELLQs has been approved as a Subaru intensive program to use 20 nights in the coming four semesters. As of August 2016, we have discovered ~40 quasars and bright galaxies at z ~ 6 and beyond, from the first 100 deg^2 of the HSC survey (Matsuoka et al. 2016, ApJ, 828, 26). Surprisingly, we are starting to see the steep rise of the luminosity function of high-z galaxies, compared with that of quasars, at magnitudes fainter than M_{1450} ~ -22 mag or z_{AB} ~ 24 mag. Multi-wavelength follow-up studies of the discovered objects as well as further survey observations are ongoing.

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Institution(s): *1. National Astronomical Observatory of Japan*
Contributing team(s): The SHELLQs collaboration

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227 – W. M. Keck Observatory: A Resource for NASA and the Entire US Community

This 90 minute session will feature 6 speakers, presenting a broad array of science highlighting the scientific complementarity between NASA missions and Keck Observations. The session will include such scientific milestones as: 1) The confirmation of planets from the Kepler and K2 missions to establish the demography and physical properties of planetary systems; 2) Spectroscopy of exoplanets revealing the presence of various molecular species; 3) Spectroscopic measurements of Pluto's surface and atmosphere to provide context for the New Horizon's encounter; 4) Spectroscopy of brown dwarf candidates identified by WISE, allowing astronomers to establish new spectroscopic classes T and Y; 5) The validation and characterization of extremely high redshift galaxies first located by NASA space observatories Spitzer and HST; 6) The ongoing effort to observe a large number of high redshift galaxies to determine their spectroscopic redshifts in preparation for Euclid and WFIRST. The session will also inform the attendees on how the broad US community can apply for Keck time through the NASA Exoplanet Science Institute (NExScI), as well as how to access public Keck data through the NASA-Keck joint Keck Observatory Archive (KOA).

227.01 – Andrew Howard

227.01 – Direct spectroscopy of exoplanets revealing the presence of various molecular species

In the past decade, several new jovian exoplanets at wide separations have been revealed using ground based telescopes equipped with adaptive optics systems. These planets, with masses between ~2-14 MJup, remain a puzzle for both major planet formation models – core accretion and gravitational instability. At the same time, they offer a powerful tool in the hunt for observational constraints of formation, as they can be characterized with both imaging and spectroscopy. I will describe our recent efforts to push beyond the discovery phase into the realm of detailed characterization of these planetary systems. Using Keck, we have been targeting the HR 8799 multiplanet system. OSIRIS observations of HR 8799b and c have yielded the best-ever spectra for any exoplanet. These observations have allowed us to resolve molecular lines for species such as water, carbon monoxide and methane. Using these observations, we have measured the C/O ratio in these planets, which can be used as a diagnostic for planet formation. Our observations demonstrate the power of the Keck adaptive optics instrument suite to offer a new window into planet formation and evolution.

Author(s): Quinn M. Konopacky[1]
Institution(s): *1. University of California, San Diego*

227.02 – Every Member of the U.S. Astronomical Community Can Apply for NASA Keck Time

NASA time on the W. M. Keck telescopes is open to every member of the U.S. astronomical community. In fact, it is the only way for PIs from non Keck partner institutions to gain access to these two 10 meter telescopes. I will provide information and tips on how to apply for NASA Keck time through the NASA Exoplanet Science Institute (NExScI), as well as how to access public Keck data through the NASA-Keck joint Keck Observatory Archive (KOA).

Author(s): Dawn M. Gelino[1]
Institution(s): *1. NASA Exoplanet Science Institute*

227.03 – Spectroscopic constraints on Pluto's coupled surface and atmosphere: context for the New Horizons encounter

Pluto's bright surface is a direct result of the transport of volatiles on seasonal timescales. Over the course of a Pluto year (248 years), nitrogen, CO and methane frosts migrate over different parts of Pluto's surface. Pluto's atmosphere is predominantly N_2 gas, supported by the vapor pressure of nitrogen frost -- the most volatile of Pluto's surface constituents. New Horizons obtained spectral image cubes of Pluto's surface in the 2 - 2.5 µm range, where N_2, CO, CH_4 and other frosts have diagnostic features. Some of the surprising results from New Horizons were the inhomogeneity of N_2 frost distribution (why is there "Tombaugh Regio," a concentration of bright N_2 frost?) and CH_4 frost features on certain topographic locations. Given that the vapor pressure of N_2 frost is about five orders of magnitude higher than that of CH_4 at a given temperature, one might expect Pluto's seasonal warming and cooling cycles to act as a massive distillery and separate N_2 and CH_4 frosts. Ground-based spectroscopy from Keck using NIRSPEC extends our spectroscopy of Pluto to the 2.8 - 3.5 µm range, beyond New Horizon's limit. We see that the 3.3 µm band of methane frost is nearly zero, ruling out any N_2 frost on Pluto that does not have CH_4 frost mixed in. Furthermore, the edge of the 3.3 µm feature is diagnostic of pure CH_4 ice vs. CH_4 that is mixed in an N_2 matrix. The mixed state of N_2 and CH_4 ices, a surprise given their drastically different vapor pressures, has changed the paradigm of how Pluto's surface frosts and atmosphere are coupled. In particular, Keck spectra help us extend the snapshot of the New Horizons flyby to models of volatile transport that span an entire Pluto orbit. Certain scenarios are prohibited, such as the case where Pluto's atmosphere freezes out during aphelion. Some of the lessons learned for Pluto's seasonal atmospheric behavior can be applied to other frost-covered TNOs in highly eccentric orbits, like Eris or Makemake.

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Institution(s): *1. Southwest Research Inst.*

227.04 – Exploring Substellar Evolution with the Coldest Brown Dwarfs

The coldest brown dwarfs are our best analogs to extrasolar gas-giant planets, representing the lowest mass products of star formation. Our view of such objects has been transformed over the last few years as new observations have revealed that the solar neighborhood is populated by much colder objects than previously recognized. At the center of efforts to discover and characterize these coldest substellar objects have been observations from NASA missions (WISE, Spitzer, HST) and the Keck Telescopes. I will review the tremendous progress made in this field over just the last few years thanks to major community efforts to overcome observational challenges in obtaining spectroscopy, photometry, and astrometry of these infrared-faint, optically invisible objects. Spectra from HST and Keck were key in establishing the much anticipated "Y" spectral type, extending the classic stellar classification scheme to atmospheres as cool as 300–400 K. Parallaxes and photometry from Spitzer and Keck have provided absolute fluxes, enabling robust temperature determinations and critical tests of model atmopheres. High-resolution imaging with Keck laser guide star adaptive optics (LGS AO) has been the most prolific resource for revealing tight companions among the coldest brown dwarfs. In fact, with continued orbit monitoring with Keck LGS AO and HST, these binary systems will ultimately provide dynamical masses that will allow the strongest tests of models and reveal if the coldest brown dwarfs are indeed "planetary mass" (less than about 13 Jupiter masses) as is currently thought.

Author(s): Trent J. Dupuy[1]
Institution(s): *1. University of Texas at Austin*

227.05 – The Confirmation and Characterization of the Highest Redshift Galaxies: The Power of Complementary Observations by Keck, Spitzer and Hubble.

Extraordinary numbers of high-redshift galaxies have been detected in deep Hubble imaging over the last ~20-yrs. While much is learned from the images, spectroscopy holds the key to both confirming their redshifts and to characterizing their astrophysical properties. The faintness of the galaxies requires our biggest telescopes and high-throughput instruments to do such spectroscopy, and many such combinations are now available on 8-10 m class telescopes. This talk will largely concentrate on Keck's role given the focus of this special session. Since the HDF in 1995 and the HUDF and GOODS in 2003-4, Keck and its powerful optical instruments such as LRIS and DEIMOS have played a major role in spectroscopic studies. With the advent of the WFC3/IR in 2009 and near-IR imaging of fields such as HUDF09, CANDELS and HUDF12 between 2009-and 2012, not only were greater insights for $z\sim1$-6 galaxies enabled, but whole new opportunities were opened up for the detection of large samples of galaxies in the first billion years at $z>6$. The recognition that Spitzer could measure galaxies in the IR well into the confusion-limited regime also resulted in much enhanced datasets on the most distant galaxies. Keck soon was positioned to take advantage of these new higher redshift sources with instruments such as MOSFIRE. The result was a series of detections of the highest redshift galaxies. I will discuss the role that Keck spectroscopy has played in pushing the spectroscopic frontiers for high-redshift galaxies and highlight the synergies that have resulted from Hubble, Spitzer and Keck observations.

Author(s): Garth D. Illingworth[1]
Institution(s): *1. UC, Santa Cruz*

227.06 – C3R2 - Complete Calibration of the Color-Redshift Relation: Keck spectroscopy to train photometric redshifts for Euclid and WFIRST

A primary objective of both WFIRST and Euclid is to provide a 3D map of the distribution of matter across a significant fraction of the universe from the weak lensing shear field, but to do so requires robust distances to billions of galaxies. I will report on a multi-semester program, expected to total approximately 40 nights with Keck over the next two years. This program, supporting both the NASA PCOS and COR science goals, will obtain the necessary galaxy spectroscopy to calibrate the color-redshift relation for the Euclid mission, and make significant progress towards the WFIRST requirements. The program, called C3R2 or Complete Calibration of the Color-Redshift Relation, already encompasses 10 allocated nights of NASA Keck Key Strategic Mission Support (PI D. Stern), 12 allocated nights from Caltech (PI J. Cohen), 3 allocated nights from the University of Hawaii (PI D. Sanders), and 1.5 allocated nights from UC-Riverside (PI B. Mobasher). We are also pursuing opportunities at additional 8- to 10-meter class telescopes, including Magellan, VLT and GCT. I will present the motivation for this program, the plans, and current results.

Author(s): Daniel Stern[1]
Institution(s): *1. JPL/ Caltech*
Contributing team(s): C3R2 Team

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228 – White Dwarfs

228.01 – White Dwarf Pulsational Constraints on Stellar Evolution

The complex processes that convert a protostellar cloud into a carbon/oxygen-core white dwarf star are distilled and modeled in state of the art stellar evolution codes. Many of these processes are well-constrained, but several are uncertain or must be parameterized in the models because a complete treatment would be computationally prohibitive—turbulent motions such as convective overshoot cannot, for example, be modeled in 1D. Various free parameters in the models must therefore be calibrated. We will discuss how white dwarf pulsations can inform such calibrations. The results of all prior evolution are cemented into the interiors of white dwarf stars and, so, hidden from view. However, during certain phases of their cooling, pulsations translate the star's evolutionary history into observable surface phenomena. Because the periods of a pulsating white dwarf star depend on an internal structure assembled as it evolved to its final state, white dwarf pulsation periods can be viewed as observable endpoints of stellar evolution. For example, the thickness of the helium layer in a white dwarf directly affects its pulsations; the observed periods are, therefore, a function of the number of thermal pulses during which the star converts helium into core material on the asymptotic giant branch. Because they are also a function of several other significant evolutionary processes, several pulsation modes are necessary to tease all of these apart. Unfortunately, white dwarf pulsators typically do not display enough oscillation modes to constrain stellar evolution. To avoid this limitation, we consider the pulsations of the entire collection of hot pulsating hydrogen-atmosphere white dwarf stars (DAVs). Though any one star may not have sufficient information to place interesting constraints on its evolutionary history, taken together, the stars show a pattern of modes that allows us to test evolutionary models. For an example set of published evolutionary models, we show a mismatch between this observed pattern and the one resulting from the model evolutionary history. Finally, we discuss the most likely parameters that can be tweaked to bring the theory in line with the observations.

Author(s): Bart H. Dunlap[1], J. Christopher Clemens[1], Patrick C. O'Brien[1], J. J. Hermes[1], Joshua T Fuchs[1]
Institution(s): *1. University of North Carolina at Chapel Hill*

228.02D – Outbursts from Cool Pulsating White Dwarfs in Kepler and K2

Data from the Kepler and K2 missions have captured the signatures of a new pulsation-related phenomenon in hydrogen atmosphere white dwarfs. Some pulsating white dwarfs within 500 K of the empirical cool edge of the ZZ Ceti instability strip exhibit outburst-like brightness enhancements of up to 15% that last many hours and recur irregularly on timescales on days. In this thesis talk, I summarize the observational characteristics of this new outbursting class of ZZ Ceti.

Author(s): Keaton J. Bell[2], J. J. Hermes[1], Michael H. Montgomery[2], Donald E. Winget[2]
Institution(s): *1. University of North Carolina-Chapel Hill, 2. University of Texas-Austin*

228.03 – Evolution of double white dwarf binaries undergoing direct-impact accretion: Implications for gravitational wave astronomy

For close double white dwarf binaries, the mass-transfer phenomenon known as direct-impact accretion (when the mass transfer stream impacts the accretor directly rather than forming a disc) may play a pivotal role in the long-term evolution of the systems. In this analysis, we explore the long-term evolution of white dwarf binaries accreting through direct-impact and explore implications of such systems to gravitational wave astronomy. We cover a broad range of parameter space which includes initial component masses and the strength of tidal coupling, and show that these systems, which lie firmly within the *LISA* frequency range, show strong negative chirps which can last as long as several million years. Detections of double white dwarf systems in the direct-impact phase by detectors such as *LISA* would provide astronomers with unique ways of probing the physics governing close compact object binaries.

Author(s): Kyle Kremer[1], Katelyn Breivik[1], Shane L. Larson[1], Vassiliki Kalogera[1]
Institution(s): *1. CIERA-Northwestern University*

228.04 – When flux standards go wild: white dwarfs in the age of *Kepler*

White dwarfs have been used as flux standards for decades, thanks to their staid simplicity. We have tested their photometric stability by analyzing the light curves of several hundred spectroscopically confirmed white dwarfs, through *K2* Campaign 8. We find that the vast majority (>90%) are <1% stable in the *Kepler* bandpass on 0.04-d to 10-d timescales, confirming that these stellar remnants are generally excellent flux standards. From the cases that do exhibit significant (several percent) variability, we caution that binarity and magnetism are two extremely important attributes to rule out when establishing a white dwarf as a photometric standard.

Author(s): JJ Hermes[1]
Institution(s): *1. University of North Carolina at Chapel Hill*

228.05D – A Uniform Set of DAV Atmospheric Parameters to Enable Differential Seismology

We have observed over 130 hydrogen-atmosphere pulsating white dwarfs (DAVs) using the Goodman Spectrograph on the SOAR Telescope. This includes all known DAVs south of +10° declination as well as those observed by the K2 mission. Because it employs a single instrument, our sample allows us to carefully explore systematics in the determination of atmospheric parameters, T_{eff} and log(g). While some systematics show changes of up to 300 K in T_{eff} and 0.06 in log(g), the relative position of each star in the T_{eff}-log(g) plane is more secure. These relative positions, combined with differences in pulsation spectra, will allow us to investigate relative differences in the structure and composition of over 130 DAVs through differential seismology.

Author(s): Joshua T Fuchs[1], Bart H. Dunlap[1], J. Christopher Clemens[1], Jesus Meza[1], Erik Dennihy[1]
Institution(s): *1. University of North Carolina at Chapel Hill*

228.06D – Compact binaries in the globular cluster 47 Tucanae

The high stellar interaction rates in globular clusters are ideal for studying the formation and evolution of compact binary stars. For this purpose, we have carried out a study of the cataclysmic variables (CVs) and millisecond pulsar (MSP) companions in the non core collapsed globular cluster 47 Tucanae. We used near-ultraviolet and optical (including H-alpha) images of the cluster obtained with the Hubble Space Telescope (HST), in combination with Chandra X-ray data.
From this study we obtained the deepest measurements of the cluster CV luminosity function. We found that this luminosity function is different from those of core collapsed clusters. This result will help understanding how the stellar interactions affect the creation and destruction of CVs. I will discuss our results with respect to the models of formation and evolution of CVs, focusing on the predicted number of these binaries and their radial distribution in the cluster.

I will also present the discovery of 2 likely He white dwarf (WD) companions to MSPs in the same cluster, as well as the confirmation of 2 tentative identifications. This represents a significant contribution to the total number of optical counterparts known in Galactic globular clusters so far. Based on our UV photometry and He WD cooling models we derived the ages, the masses and the bolometric luminosities for all the He WD companions. I will discuss these results and their implications in the context of the standard MSP formation scenario.

Author(s): Lilliana Rivera Sandoval[7], Maureen Van Den Berg[7], Craig O. Heinke[6], Haldan N. Cohn[2], Phyllis M. Lugger[2], Paulo Freire[3], Jay Anderson[5], Adrienne Cool[4], Jonanthan Grindlay[1], Peter Edmonds[1], Rudy Wijnands[7], Natalia Ivanova[6]
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229 – Star-forming Galaxies at z~2

229.01D – A Multi-Wavelength Census of Dust and Star Formation in Galaxies at z ~ 2

Redshift of z ~ 2 is an important era in the history of the universe, as it contains the peak of star formation rate density and quasar activity. We study the galaxy properties during this era from two different, yet complementary, aspects: by studying formation of stars and mass assembly, and exploring the properties of galactic dust. We use a wealth of multi-wavelength data, from UV to far-IR, to obtain a complete census of obscured and unobscured star formation in galaxies. Our data consists of rest-frame optical spectra from the MOSDEF survey, rest-frame UV and optical photometric data from the 3D-HST survey, and mid- and far-IR data obtained by the Spitzer and Herschel telescopes. In the MOSDEF survey, we acquired rest-frame optical spectra of ~ 1500 galaxies with the MOSFIRE spectrograph on the Keck I telescope. MOSDEF is currently the largest survey of the rest-frame optical properties of galaxies at $1.37 \le z \le 3.80$. Using the multi-wavelength data sets, we show that Hα SFRs, corrected for dust attenuation using the Hβ line, accurately trace SFRs up to ~ 300 $M_{\odot}\ yr^{-1}$, when compared with panchromatic (UV-to-far-IR) SED models. Using Hα SFRs for a large sample of ~ 200 galaxies at z ~ 2, we explore the SFR-M* relation and show that the slope of this relation is shallower than previously measured. We conclude that the scatter in the SFR-M* relation is dominated by uncertainties in dust correction and cannot be used to measure the star formation stochasticity. Furthermore, we investigate the robustness of Spitzer/MIPS 24 micron flux as an SFR indicator and its variation with ISM physical parameters. We find that 24 micron flux, which at z ~ 2 traces the emission from the PAH grains, significantly depends on metallicity, such that there is a PAH deficiency in metal-poor galaxies. We demonstrate that commonly-used conversions of 24 micron flux to IR luminosity underestimate the IR luminosity of low-mass galaxies by more than a factor of 2. Our results suggest a higher specific SFR (i.e., SFR/M*) at M* ~ $10^{9.5} M_{\odot}$ and a higher IR luminosity density at z ~ 2 than previously measured. The latter corresponds to a ~ 30% increase in the SFR density.

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Contributing team(s): MOSDEF collaboration

229.02 – ZFIRE: Similar Stellar Growth in Halpha-emitting Cluster and Field Galaxies at z~2

We compare galaxy scaling relations as a function of environment at z~2 with our ZFIRE survey where we have measured Halpha fluxes for 90 galaxies selected from a mass-limited sample based on ZFOURGE. The cluster galaxies (37) are part of a spectroscopically confirmed system at z=2.095 and the field galaxies (53) have redshifts of 1.9<z<2.4. There is no statistical difference between Halpha-emitting cluster and field populations when comparing their star formation rate (SFR), stellar mass, galaxy size, star formation rate surface density, and stellar age distributions. Approximately 20-25% of Halpha-emitting galaxies in both the cluster and field are IR-luminous. In our combined cluster and field sample, IR-luminous galaxies have ~5 times more stellar mass and radii that are ~70% larger than the low-IR galaxies. To track stellar growth, we separate galaxies into those that lie above, on, and below the Halpha star-forming main sequence (SFMS) using delta[SFR]=+/-0.2 dex. Galaxies above the SFMS (starbursts) tend to have higher Halpha SFR surface densities and younger stellar ages compared to galaxies below the SFMS. Our results indicate that starbursts (+SFMS) in the cluster and field at z~2 are growing their stellar cores. Lastly, we compare to the (SFR-stellar mass) relation predicted by the RHAPSODY galaxy cluster simulations and find that the predicted slope is nominally consistent with the observations. However, the predicted cluster SFRs tend to be too low by a factor of ~2 which suggests that simulations may be over-predicting how efficient environment is at quenching star formation.

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229.03D – The Physical Properties of z ~ 2 Lyman-alpha Emitters and their Use as Tracers of the Star Forming Galaxy Population

Lyman-alpha emitting galaxies (LAEs) provide a unique way to sample low-mass galaxies at high redshift, and are complementary to various photometric selection techniques that generally identify massive high-redshift galaxies. We discuss the physical and morphological properties of z~2 LAEs found photometrically in narrow-band studies and spectroscopically via the HETDEX Pilot Survey. We use spectral energy distribution (SED) fitting of HST broad-band photometry and morphological analyses of HST rest-frame UV and optical imaging to show that LAEs exhibit a wide range of physical properties. We find that z~2 LAEs extend over a range of 2.5 dex in stellar mass, that Lyman-alpha luminosity is not correlated with stellar mass, and that not all LAEs are dust-poor objects. Furthermore, when we compare the properties of our LAEs to those of z~2 galaxies selected via their their rest-frame optical emission lines, we find no significant differences between the two samples. This suggests that LAEs are simply pulled from the epoch's general star forming galaxy population. Finally, we comment on the potential of HETDEX for transformative studies of LAEs and the general z~2 population

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Contributing team(s): HETDEX Team

229.04D – The MOSDEF Survey: Outflows from Broadened Emission Lines at z=[1.3 - 3.8]

We present results from the MOSFIRE Deep Evolution Field (MOSDEF) survey on broad emission from the nebular emission lines H-alpha, [NII], [OIII], H-beta, and [SII]. After removing known AGN, the sample consists of 171 galaxies with 1.37 < z < 2.61 and 84 galaxies with 2.95 < z < 3.80. We study broad flux by decomposing the emission lines using narrow and broad components for individual galaxies and stacks. For the z~2 sample, the broad flux accounts for 20-50% of the flux in nebular emission lines and in the z~3.3 sample the broad component comprises 30-60% of the flux. We estimate the mass loading factor (mass outflow rate/SFR), assuming the outflow is photoionized, as a function of SFR, mass, sSFR, and star formation surface density and compare to recent simulations. We find our galaxies are compatible with simulations only if a large fraction of the outflowing material is <300 km/s for galaxies below 10^10 stellar mass. We calculate [SII]/H-alpha, [NII]/H-alpha, and [OIII]/H-beta line ratios for the narrow components and broad components. When placed on the BPT diagram ([OIII]/H-beta vs. [NII]/H-alpha) the broad components are shifted towards the higher [OIII]/H-beta and [NII]/H-alpha ratios. This is likely the results of shocks or low luminosity AGN. The narrow component line ratios are closer to local measurements than other studies at z~2 but are still slightly offset. Outflows and shocks may significantly alter measurements made from emission lines and line ratios.

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229.05 – Low Gas Fractions Connect Compact Star-Forming Galaxies to their z~2 Quiescent Descendants

Early quiescent galaxies at z ~ 2 are known to be remarkably compact compared to their nearby counterparts. Possible progenitors of these systems include galaxies that are structurally similar, but are still rapidly forming stars. I will present Karl G. Jansky Very Large Array (VLA) observations of the CO(1–0) line towards three such compact, star-forming galaxies at z ~ 2.3, significantly detecting one. The VLA observations indicate baryonic gas fractions 5 times lower and gas depletion times 10 times shorter than normal, extended massive star-forming galaxies at these redshifts. At their current star formation rates, all three objects will deplete their gas reservoirs within 100Myr. These objects are among the most gas-poor objects observed at z > 2 and are outliers from standard gas scaling relations, a result which remains true regardless of assumptions about the CO-H2 conversion factor. Our observations are consistent with the idea that compact, star-forming galaxies are in a rapid state of transition to quiescence in tandem with the build-up of the z ~ 2 quenched population. In the detected compact galaxy, we see no evidence of rotation or that the CO-emitting gas is spatially extended relative to the stellar light. This casts doubt on recent suggestions that the gas in these compact galaxies is rotating and significantly extended compared to the stars. Instead, we suggest that, at least for this object, the gas is centrally concentrated, and only traces a small fraction of the total galaxy dynamical mass. I will conclude by discussing my ongoing efforts to characterize the gas and star forming properties of this unusual population of galaxies.

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230 – Cool Stars II

230.01 – An X-ray and Optical Spectroscopic Study of the Perplexing Star RZ Piscium

The evolutionary status of the "anti-flare" variable star RZ Psc is ambiguous; both pre- and post-main sequence models have been proposed. RZ Psc shows evidence for gaseous and dusty circumstellar material in the form of emission lines and an infrared excess; its space velocities suggest that it is young, but it does not appear to be a member of a known association of young stars. We report the results of X-ray observations of RZ Psc with XMM-Newton, as well as high-resolution optical spectroscopy of the star obtained at the Lick and Keck observatories. The XMM-Newton imaging spectroscopy establishes that RZ Psc is highly X-ray-luminous, while the optical spectroscopy confirms that the star is G-type and has low surface gravity. The nearly saturated stellar activity and X-ray plasma properties of RZ Psc are indicative of pre-main sequence status, but are also consistent with those of rapidly rotating first-ascent giants. The optical spectroscopy yields evidence for radial velocity variability, hinting at the possibility that RZ Psc is a spectroscopic binary system. Further observations of RZ Psc and its field are necessary to break the age degeneracy and to confirm its close binary status. This research is supported in part by NASA Astrophysics Data Analysis program grant NNX16AG13G to RIT.

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230.02 – Flares of Nearby, Mid-to-late M-dwarfs Characterized by the MEarth Project

Stellar flares are both a curse and a blessing: Transit and radial velocity searches for exoplanets are hindered by the variability caused by flares, while the characteristics of this variability offer valuable insight into the magnetic properties of the star. We present an analysis of flare events of nearby, mid-to-late M-dwarfs from the MEarth Project. MEarth consists of a northern and a southern array of 8 telescopes each that photometrically monitors most mid-to-late M-dwarfs within 30 parsecs. Although the initial motivation was to search for exoplanet transits, the cadence of approximately 20 minutes is well-suited to capturing long-lived flares. However, MEarth employs a single, wide, red bandpass, which poses challenges to the robust detection of flare events, which are typically bluer in color. Using MEarth data, our team has recently published trigonometric parallaxes and estimates of rotation periods for an unprecedented number of nearby low-mass stars. We also gathered supplementary optical and near infrared spectra of a subset of these stars. We describe here the properties of the flares detected by MEarth, and explore the relation of the presence of flares on individual stars with stellar parameters such as rotational period, mass, and H-alpha equivalent width. We also provide an estimate of flare rate for individual stars by injecting flares into our pipeline.

The MEarth project acknowledges funding from the National Science Foundation and the David and Lucile Packard Foundation Fellowship for Science and Engineering. This work was made possible through the support of a grant from the John Templeton Foundation.

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230.03D – Companions and Environments of Low-Mass Stars: From Star-Forming Regions to the Field

We present results from two studies probing the multiplicity and environmental properties of low-mass stars: (1) The MinMs (M-dwarfs in Multiples) Survey, a large, volume-limited survey of 245 field M-dwarfs within 15 pc, and (2) the TBOSS (Taurus Boundary of Stellar/Substellar) Survey, an ongoing study of disk properties for the lowest-mass members within the Taurus star-forming region. The MinMs Survey provides new measurements of the companion star fraction, separation distribution, and mass ratio distribution for the nearest K7-M6 dwarfs, utilizing a combination of high-resolution adaptive optics imaging and digitized widefield archival plates to cover an unprecedented separation range of ~1-10,000 AU. Within these data, we also identify companions below the stellar/brown dwarf boundary, enabling characterization of the substellar companion population to low-mass field stars. For the much younger population in Taurus, we present results from ALMA Band 7 continuum observations of low-mass stellar and substellar Class II objects, spanning spectral types from M4-M7.75. The sub-millimeter detections of these disks provide key estimates of the dust mass in small grains, which is then assessed within the context of region age, environment, and viability for planet formation. This young population also includes a number of interesting young binary systems. Covering both young (1-2 Myr) and old (>5 Gyr) populations of low-mass stars, the results from these studies provide benchmark measurements on the population statistics of low-mass field stars, and on the early protoplanetary environments of their younger M-star counterparts.

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230.04D – Elucidating the True Binary Fraction of VLM Stars and Brown Dwarfs with Spectral Binaries

The very lowest-mass (VLM) stars and brown dwarfs are found in abundance in nearly all Galactic environments, yet their formation mechanism(s) remain an open question. One means of testing current formation theories is to use multiplicity statistics. The majority of VLM binaries have been discovered through direct imaging, and current angular resolution limits (0.05”-0.1") are coincident with the 1-4 AU peak in the projected separation distribution of known systems, suggesting an observational bias. I have developed a separation-independent method to detect T dwarf companions to late-M/early-L dwarfs by identifying methane absorption in their unresolved, low-resolution, near-infrared spectra using spectral indices and template fitting. Over 60 spectral binary candidates have been identified with this and comparable methods. I discuss follow-up observations, including laser-guide star adaptive optics imaging with Keck/NIRC2, which have confirmed 9 systems; and radial velocity and astrometric monitoring observations that have confirmed 7 others. The direct imaging results indicate a resolved binary fraction of 18%, coincident with current estimates of the VLM binary fraction; however, our sample contained 5 previously confirmed binaries, raising its true binary fraction to 47%. To more accurately measure the true VLM binary fraction, I describe the construction of an unbiased, volume-limited, near-infrared spectral sample of M7-L5 dwarfs within 25 pc, of which 4 (1%) are found to be spectral binary candidates. I model the complex selection biases of this method through a population simulation, set constraints on the true binary fraction as traced by these systems, and compare to the predictions of current formation theories. I also describe how this method may be applied to conduct a separation-unbiased search for giant exoplanets orbiting young VLM stars and brown dwarfs.

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230.05 – The Active Latitudes of HAT-P-11

Transiting planets map the brightness of their host stars, as the flux lost during exoplanet transits is proportional to the integrated flux occulted by the planet. We analyze four years of Kepler short-cadence photometry of HAT-P-11 – an active K4 dwarf with a 29 day rotation period, orbited by a hot-Neptune. Due to its highly-misaligned orbit, the planet occults most stellar latitudes during each transit, and the latitude distribution of spots is encoded in the transit light curves. We model each spot occultation in transit to create a spot map of HAT-P-11, which reveals two active latitudes near ±17 degrees. We investigate whether the spot distribution changes in time, and we compare the spot latitude distributions of HAT-P-11 and the Sun throughout the solar activity cycle.

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230.06 – About K Dwarfs - Investigating the Goldilocks Stars of Exobiology

In this study, we argue that stars between spectral type late-G and mid-K (with a maximum at early-K), i.e., orange dwarfs, are expected to provide the best conditions for the development and sustainability of life, including advanced life forms. Though our study is mostly theoretical, observational data are considered as fit. Our analysis considers a variety of stellar properties, including (1) the frequency of the various types of stars, (2) the speed of stellar evolution their lifetimes, (3) the size of the stellar climatological habitable zones (CLI-HZs), (4) the strengths and persistence of their magnetic dynamo generated X-ray--UV emissions, and (5) the frequency and severity of (super-)flares; both (4) and (5) greatly reduce the suitability of M-type dwarfs to host life-bearing planets. M-type dwarfs are numerous, having long lifetimes, but their narrow CLI-HZs and hazards from magnetic activity make them less suitable for hosting exolife. Therefore, we argue that K-dwarfs should be rightfully considered "Goldilocks" stars, thus deserving heightened attention in future observational and theoretical studies.

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231 – Galaxy Clusters & Local Environment

231.01 – Probing the mass distribution at the outskirts of galaxy clusters using weak lensing

Galaxy clusters are often described by NFW (Navarro, Frenk & White) profiles which are a good description of cluster scale halos formed in cosmological dark matter simulations. Here we discuss the lensing signals of high-resolution clusters extracted from cosmological dark matter and hydrodynamic simulations, and determine on what scales the clusters' average weak lensing shear is best described by the shear of the Diemer-Kravtsov (DK) or NFW profile. In particular, we assess the number of clusters and the type of observations (e.g. number of galaxies available for the weak lensing analysis) that must be stacked in order to distinguish between these and other profiles, focusing on the larger scales where the best-fit shear profiles differ.

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231.02 – Unusually gas-rich central galaxies in small groups

Observations of gas in galaxies have shown dramatic differences between rich clusters and isolated field environments. However, pre-processing in intermediate group environments is expected to be responsible for much of the transformation between gas-rich blue and gas-poor red galaxies. We investigate this by taking advantage of the deepest observations to date of atomic and molecular gas in local galaxies from the GASS and COLD GASS surveys and their extensions to low stellar masses. This sample is uniquely suited to quantify gas and star formation properties of galaxies across environments, reaching the gas-poor regime of groups and clusters. We find that central galaxies in small groups are unusually gas rich and star-forming, compared to isolated galaxies. Below log Mst/Msun = 10, gas-poor group central galaxies are rare. We suggest that these central galaxies are being fed by the filaments of the cosmic web.

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Contributing team(s): xGASS team

231.03 – The Massive and Distant Clusters of WISE Survey (MaDCoWS): Stellar mass fractions in a sample of infrared-selected galaxy clusters at z~1

Galaxy clusters are the largest gravitationally bound objects in the universe. In addition to being interesting objects in their own right, they are excellent laboratories in which to study galaxy evolution and the properties and abundance of galaxy clusters provide important tests for cosmology. The Massive and Distant Clusters of WISE Survey (MaDCoWS) is a high-redshift (z~1) survey that selects galaxy clusters in the infrared over nearly the full extragalactic sky using the Wide-field Infrared Survey Explorer (WISE) AllWISE data release. We have measured Sunyaev-Zel'dovich (SZ) masses for twelve of the MaDCoWS clusters lying in the range $0.9 < z < 1.3$ using the Combined Array for Research in Millimeter-wave Astronomy (CARMA) and used follow-up Spitzer/IRAC rest-frame near-infrared observations to measure the stellar mass of these clusters. With these data, we have measured the stellar mass fraction, f_star, and it's relation to total mass for a sample of infrared-selected clusters at z~1. We repeated our analysis of stellar mass fraction on a sample of SZ-selected clusters from the South Pole Telescope (SPT)-SZ survey that lie in a comparable range of mass and redshift to our MaDCoWS clusters to compare the selection methods. We found no significant difference in the trend of stellar mass fraction-to-total mass between infrared and radio selections. Comparing to similar measurements in the local Universe, we find no evidence of strong evolution in the trend over the last 8 Gyr.

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231.04 – Low star formation efficiencies in z=1.62 star-forming proto-cluster galaxies as seen in CO(1-0).

I will present JVLA CO imaging in the 1-0 transition of a z=1.62 galaxy cluster located in the UKIDSS/UDS and covered by the 3D-HST data. These are the deepest existing data in CO(1-0), corresponding to nearly 100 hours of JVLA observations, and are giving us the powerful ability to study the molecular gas contents of massive cluster galaxies when they were in the last throes of their star formation. The 3D-HST data are crucial to this endeavor as they 1) give us accurate redshifts with which to confirm membership, 2) give us the ability to reject cluster interlopers, and 3) serve as a strong redshift prior to search for weak CO lines. We securely detect two cluster members in CO(1-0) at the expected frequency given the grism redshifts. This nearly doubles the number of published CO(1-0) detections of normal star-forming galaxies at high redshift. These two galaxies are massive, with log(Mstar~11) and extremely gas rich (Mgas/Mbaryon~0.5-0.6). Despite their very large gas reservoirs they are forming stars at a sedate pace for their stellar mass and lie on or below the main star formation sequence. I will discuss potential reasons for the apparent high CO luminosities (and correspondingly low star formation efficiencies) of these objects, e.g. stablization of the gas by a compact stellar configuration or abnormally low conversion factors from CO to molecular hydrogen. I will also comment on the implications of this interesting finding for understanding the truncation of gas accretion onto distant cluster galaxies.

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231.05D – Faint Submillimeter Galaxies Behind Lensing Clusters

Faint submillimeter galaxies are the major contributors to the submillimeter extragalactic background light and hence the dominant star-forming population in the dusty universe. Determining how much these galaxies overlap the optically selected samples is critical to fully account for the cosmic star formation history. Observations of massive cluster fields are the best way to explore this faint submillimeter population, thanks to gravitational lensing effects. We have been undertaking a lensing cluster survey with the SCUBA-2 camera on the James Clerk Maxwell Telescope to map nine galaxy clusters, including the northern five clusters in the HST Frontier Fields program. We have also been using the Submillimeter Array and the Very Large Array to determine the accurate positions of our detected sources. Our observations have discovered high-redshift dusty galaxies with far-infrared luminosities similar to that of the Milky Way or luminous infrared galaxies. Some of these galaxies are still undetected in deep optical and near-infrared images. These results suggest that a substantial amount of star formation in even the faint submillimeter population may be hidden from rest-frame optical surveys.

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231.06 – The ALMA Frontier Fields

The Frontier Fields Legacy Program targets six strong lensing clusters with deep HST and Spitzer imaging to detect and characterize the faint background galaxy population, particularly the first galaxies at z~6-10. We initiated an ALMA survey to produce “shallow” ~2'x2' maps of the Frontier Field cluster fields at 1.1mm to study intrinsically faint dusty star-forming galaxies (DSFGs) and place constraints on the star formation from a variety of interesting extragalactic source populations. Five of the six clusters have now been completed, yielding relatively uniform maps that pinpoint cool dust emission from powerful DSFGs at z>1. I will present a census of the detected objects thus far, as well as some stacking constraints on the average emission from undetected source populations.

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Contributing team(s): The ALMA Frontier Fields Team

231.07 – CANDELS Sheds Light on the Environmental Quenching of Low-mass Galaxies

We use a simple method to investigate the environmental quenching of low-mass galaxies beyond the local universe. Essentially all local low-mass quenched galaxies are believed to live in massive dark matter halos and hence close to the massive central galaxies. We use CANDELS data to test up to which redshift and stellar mass is this statement still true. By investigating *whether or not* this quenched dwarf--massive central galaxy connection, a manifestation of environmental quenching, exists, we only need a statistically representative, rather than complete, sample of low-mass galaxies. Such a sample enables extending environment studies of low-mass galaxies up to z=2. For each detected quenched low-mass galaxy, we measure the projected distance (θmin) to its nearest massive neighbor (stellar mass > 10^{10.5} solar mass) within a projected volume. In a given redshift and stellar mass bin, we compare the distribution of the projected distances (θmin) of quenched galaxies to that of star-forming galaxies. At z<~1 and stellar mass between 10^{8} and 10^{10} solar masses, the θmin distributions of quenched galaxies are significantly different from and skewed toward lower values than those of star-forming galaxies, thereby demonstrating that quenching is strongly related to low-mass galaxy distances to massive central galaxies. Such a difference between the two populations disappears at z>1.2. This transition around z=1 places a constraint on the environmental quenching timescale (T_Q). We find that T_Q gradually increases from 4 Gyr at 10^{8.5} solar mass to 6 Gyr at 10^{10.5} solar mass. Our method provides a uniform way to measure T_Q over 2 dex of satellite stellar masses.

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231.08 – Effect of local environment and stellar mass on galaxy quenching at 0.3 < z < 2.5 in ZFOURGE

We study the effects of stellar mass and local environment on the star-formation activity of galaxies at 0.3 < z < 2.5 with $\log(M/M_{Sun}) > 8.8$ using the data from the FourStar Galaxy Evolution Survey (ZFOURGE), which is a deep near-infrared survey with the FourStar camera on Magellan. The medium-band filters from ZFOURGE provide well-constrained photometric redshifts at 1 < z < 4. This accurate photometric redshift measurement allows us to estimate the environmental densities around galaxies. We apply two local projected density estimators -- a Bayesian local density estimator and the traditional *N*th nearest neighbor -- on a mock galaxy catalog to demonstrate that the Bayesian local density estimator with *N* = 3, where distances to the first, second, and third near neighbors are all incorporated, is better correlated with the spectroscopic density estimator in comparison with the traditional 3th nearest neighbor. We find a higher quiescent fraction of galaxies in denser environments even at fixed mass out to at least z ~ 2, but the effect is weaker than at z < 1. We quantify environmental quenching by comparing the quiescent fractions at fixed stellar mass and redshift in low-density environment to those in high-density environment. Similarly, we quantify mass quenching by comparing the quiescent fractions of our lowest-mass galaxy sample in high-density environment to those of more massive galaxies in the same environment. At all redshifts, mass-quenching is a dominant quenching mechanism for massive galaxies ($\log(M/M_{Sun}) >10.2$). At z < 1.0, in the high-density environment, an environmental quenching process increases its contribution to suppress the star-formation, and eventually it is a dominant quenching mechanism for lowest-mass galaxies relative to mass-quenching process. We do not find any difference in the morphologies of quiescent galaxies in high- and low-density environments, suggesting that quiescent galaxies in high-density region have been quenched due to some environmental process that leaves their morphologies intact. We discuss scenarios to explain the trends we observed, including constraints on the timescales and physical processes of environmental quenching allowed by our data.

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Contributing team(s): the ZFOURGE team

232 – Stellar Evolution, Stellar Populations

232.01 – Seeing Stars Like Never Before: A Multi-Year Interferometric Imaging Study of Red Supergiants in the H-Band.

As some of the largest stars, red supergiants (RSG) are ideal candidates for interferometric imaging. 3D radiative hydrodynamic (RHD) models suggest that RSG have large convection cells with lifetimes on the order of 1000s of days. Many imaging projects have hinted at the existence of these features but, until recently, we have lacked the angular resolution to directly compare models to observations. In this presentation, we discuss early results from a multi-year survey of red supergiants using the Michigan InfraRed Combinber (MIRC) on the Center for High Angular Resolution Astronomy (CHARA Array), which has a maximum baseline of 330 m. We will present H-band images of RSG spanning several years developed using a new machine learning based image reconstruction tool for interferometric data. We will also present fundamental parameters for the targets, and discuss the implications of these results on 1D model atmospheres and 3D

RHD models of RSG.

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232.02D – Bayesian Analysis and Characterization of Multiple Populations in Galactic Globular Clusters

Globular clusters have long been important tools to unlock the early history of galaxies. Thus, it is crucial we understand the formation and characteristics of the globular clusters (GCs) themselves. Historically, GCs were thought to be simple and largely homogeneous populations, formed via collapse of a single molecular cloud. However, this classical view has been overwhelmingly invalidated by recent work. It is now clear that the vast majority of globular clusters in our Galaxy host two or more chemically distinct populations of stars, with variations in helium and light elements at discrete abundance levels. No coherent story has arisen that is able to fully explain the formation of multiple populations in globular clusters nor the mechanisms that drive stochastic variations from cluster to cluster.

We use Cycle 21 Hubble Space Telescope (HST) observations and HST archival ACS Treasury observations of 30 Galactic Globular Clusters to characterize two distinct stellar populations. A sophisticated Bayesian technique is employed to simultaneously sample the joint posterior distribution of age, distance, and extinction for each cluster, as well as unique helium values for two populations within each cluster and the relative proportion of those populations. We find the helium differences among the two populations in the clusters fall in the range of 0.04 to 0.11. Because adequate models varying in CNO are not presently available, we view these spreads as upper limits and present them with statistical rather than observational uncertainties. Evidence supports previous studies suggesting an increase in helium content concurrent with increasing mass of the cluster. We also find that the proportion of the first population of stars increases with mass. Our results are examined in the context of proposed globular cluster formation scenarios.

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Institution(s): *1. Argiope Technical Solutions, 2. Embry Riddle Aeronautical University, 3. Imperial College London, 4. Statistical and Applied Mathematical Sciences Institute, 5. The Wharton School, University of Pennsylvania, 6. University of Florida , 7. University of Texas*
Contributing team(s): BASE-9, HST UVIS Globular Cluster Treasury Program

232.03 – Searching for New Highly *r*-Process-Enhanced Stars in the Halo of the Milky Way

Great progress has been made in recent years concerning understanding and constraining the nature of the astrophysical *r*-process, and on obtaining evidence for the likely astrophysical site(s) of its production. One of the keys to this progress was the identification, over 20 years ago, of a rare class of VMP stars ([Fe/H] < -2.0), which in spite of their very low metallicity, exhibit *r*-process-element enhancements relative to iron from 10 to over 100 times the Solar ratio (the *r*-II stars). These stars provide us with the best probes of the production of the *r*-process elements in the early Universe. Furthermore, knowledge of their metallicity distribution and frequency in the halo field provides potentially tight constraints on the origin of the *r*-process. However, due to their rarity (~3% of VMP stars), only a total of ~25 *r*-II stars have been found to date.

We provide an update on our new survey effort to quadruple the numbers of recognized *r*-II stars over the next few years, based on "snapshot" high-resolution spectroscopy of a sample of some 2500 bright (V < 13.5) VMP stars, using the Echelle spectrograph on the du Pont 2.5m telescope. To date, some 1000 targets have been identified, based on medium-resolution follow-up of stars from the RAVE survey, the Best & Brightest survey, and a variety of other sources. Over 100 of these targets have been observed at high resolution in the first run with the du Pont telscope; we expect this number to grow rapidly, as observations continue.

This work received partial support from PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

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232.04 – Kinematics and chemistry of faint high latitude dwarf carbon stars

The diffuse halo system of the Milky Way is complex, and has been shown to comprise at least two main components: a near-zero net rotation inner-halo and a more rapidly rotating outer-halo component. Studies of the ancient, very metal-poor stars in the Galactic halo system are crucial for understanding its early formation history. The so-called carbon-enhanced metal-poor (CEMP) stars are an important subset of the stars in the halo system, which exhibit distinctive kinematic and chemical signatures that can be used to constrain the star-formation histories and assembly of the various Galactic components.

We have examined the sample of main-sequence dwarf and other faint high Galactic latitude carbon-enhanced stars from the Sloan Digital Sky Survey studied by Green (2013). As noted by Green, many of these stars
exhibit high proper motions, which have been later claimed to be related to possible binary ejection models Plant et al. (2016). By use of the CEMP sub-classification approach of Yoon et al. (2016), we investigate whether the kinematics of these stars might instead result from their membership in the inner/outer halo populations of the Galaxy.

References
Green, P. 2013, ApJ, 765, 12
Plant, K. et al. 2016, AAS 227.34115
Yoon, J. et al. 2016, ApJ, in press

Acknowledgement
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232.05D – Testing the Wind-Shock Paradigm for B-Type Star X-Ray Production with θ Carinae

We present *Chandra* X-ray grating spectroscopy of the B0.2V star, θ Carina. θ Car is in a critical transition region between the latest O-type and earliest B-type stars, where some stars are observed to have UV-determined wind densities much lower than theoretically expected. In general, X-ray emission in this low-density wind regime should be less prominent than O-star winds, but observations have shown a higher than expected production of X-ray emission from the winds of these stars; this hotter wind could explain the weak UV wind signature, but this might severely challenge predictions of radiatively driven wind theory. We measured the *f/i* ratio of several He-like ions and the widths of several He-like, H-like and Fe ions in the X-ray spectrum. The *f/i* ratio is a diagnostic of the radial location of the X-ray emitting plasma, which is modified by the distance to the UV-emitting stellar photosphere.

Low flow velocity measured from the widths of the X-ray lines agree with a slower and lower density wind as compared to what is theoretically predicted from strong O-star wind theory. The measured widths are also consistent with other stars in the weak wind regime, β Cru, for example. The location of the X-ray emitting plasma is measured to be relatively close to the star, also consistent with a low-density wind and with other weak wind stars. We use θ Car to determine how low-density winds with a higher than expected X-ray production agrees or disagrees with the theory for radiatively-driven winds.

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232.06 – Using a Weak CN Spectral Feature as a Marker for Massive AGB Stars in the Andromeda Galaxy

The Panchromatic Hubble Andromeda Treasury (PHAT) survey has produced six-filter photometry at near-ultraviolet, optical and nearly infrared wavelengths (F275W, F336W, F475W, F814W, F110W and F160W) for over 100 million stars in the disk of the of the Andromeda galaxy (M31). As part of the Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo (SPLASH) survey, medium resolution (R ~ 2000) spectra covering the wavelength range 4500–9500A were obtained for over 5000 relatively bright stars from the PHAT source catalog using the Keck II 10-meter telescope and DEIMOS spectrograph. While searching for carbon stars in the spectroscopic data set, we discovered a rare population of stars that show a weak CN spectral absorption feature at ~7900A (much weaker than the CN feature in typical carbon stars) along with other spectral absorption features like TiO and the Ca triplet that are generally *not* present/visible in carbon star spectra but that are typical for normal stars with oxygen rich atmospheres. These 150 or so "weak CN" stars appear to be fairly localized in six-filter space (i.e., in various color-color and color-magnitude diagrams) but are generally offset from carbon stars. Comparison to PARSEC model stellar tracks indicates that these weak CN stars are probably massive (5–10 $M_{\rm sun}$) asymptotic giant branch (AGB) stars in a relatively short-lived core helium burning phase of their evolution. Careful spectroscopic analysis indicates that the details of the CN spectral feature are about 3–4x weaker in weak CN stars than in carbon stars. The kinematics of weak CN stars are similar to those of other young stars (e.g., massive main sequence stars) and reflect the well ordered rotation of M31's disk.

This research project is funded in part by NASA/STScI and the National Science Foundation. Much of this work was carried out by high school students and undergraduates under the auspices of the Science Internship Program and LAMAT program at the University of California Santa Cruz.

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Contributing team(s): PHAT collaboration, SPLASH collaboration

232.07 – Variable Polarization from Co-Rotating Interaction Regions in Massive Star Winds

Co-rotating Interaction Regions (CIRs) are a well-known phenomenon in the solar wind, and is a favored culprit for certain cyclical behavior observed in the spectra of some massive stars. A prime example are the discrete absorption components (DACs) seen in the UV wind lines of many O stars. Here we report on modeling for the variable continuum polarization that could arise from the presence of CIR structures. Considerations are limited to optically thin scattering. Using a core-halo approach for winds that are thick to electron scattering, an application to observed variable polarization of WR6 (EZ CMa; HD 50896) is presented.

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233 – Neutron Stars (Pulsars, Magnetars, Pulsar Wind Nebulae) I

233.01D – Polarized X-ray Scattering and Birefringence in Magnetars

Interest in radiative processes in the super-strong magnetic regime germane to magnetars has grown over the last two decades. These processes have an inherently anisotropic and polarization-dependent character. Of particular interest is the resonant cyclotron scattering domain, where the Compton cross section is enhanced by orders of magnitude very near the cyclotron frequency -- for electrons in magnetar atmospheres, this is above 10 MeV in energy, and for protons this can be at 1-10 keV. The Compton process is dominant in the highly optically thick environs of magnetar atmospheres, and also in the magnetospheric locales for the production of the hard X-ray bursts. The detailed forms of X-ray spectra will depend intimately on the character of the Compton cross section and the emission zone geometry. The practical determination of the rate of Compton scattering depends on the polarization configuration of incoming photons. This in turn is sensitive to the details of radiation dispersion and transport in hot plasmaspheres near neutron stars. This birefringent dispersion present in strongly-magnetized plasmas can profoundly influence the determination of scattering probabilities. Such polarization transfer is usually addressed by simplifying to the transfer two normal mode intensities. The assumptions involved in this simplification such as orthonormality and "large Faraday depolarization" are valid for a wide range of parameter space, but are known to break down in important cases, such as near a cyclotron resonance. We explore the polarization transfer problem for Compton scattering including the regime where Faraday depolarization is not large. Accordingly, plasma birefringence and the generalized Faraday effect are considered explicitly as part of the transfer problem. Spectra generated from two Monte Carlo models of the transfer problem are presented, one treating isothermal atmospheres in the normal X-ray band, and the other addressing hard X-ray flares in magnetar magnetospheres.

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233.02 – Testing the electron-capture supernova scenario using universal relations between neutron star properties

8-10 solar mass stars may end their lives in electron-capture supernovae (ECSNe), in which ONeMg cores are destabilized by electron captures onto Neon and Magnesium. Strong circumstantial evidence exists that the Crab pulsar and PSR J0737-3039b were formed in ECSNe. Evidence for the existence of the ECSN mechanism has important implications for the rate of production of Be/X-ray binaries and the rate of binary neutron star mergers.

I will discuss how supernova modeling suggests that neutron stars formed via the electron-capture mechanism have a specific gravitational binding energy. Recently, universal relations between neutron star properties including their binding energy, moment of inertia, quadrupole moments and tidal polarizability have been carefully examined. I will show how these relations, coupled with measurements of the post-Newtonian parameters of the PSR J0737-3039 system and of the acceleration of the Crab supernova remnant, can provide evidence for or against the electron-capture supernova formation scenario.

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233.03 – A Model for Axions Producing Extended

gamma-ray Emission from Neutron Star J0108-1431

Axions are hypothetical particles proposed to solve the strong CP problem in QCD and may constitute a significant fraction of the dark matter in the Universe. Axions are expected to be produced in neutron stars and subsequently decay, producing gamma-rays detectable by the Fermi Large Area Telescope (Fermi-LAT). Considering that light axions may travel a long range before they decay into gamma rays, neutron stars may appear as a spatially-extended source of gamma rays. We extend our previous search for gamma rays from axions, based on a point source model, to consider the neutron star as an extended source of gamma rays. We investigate the spatial emission of gamma rays using phenomenological models. We present models including the fundamental astrophysics and relativistic, extended gamma-ray emission from axions around neutron stars. A Monte Carlo simulation of the LAT gives us an expectation for the extended angular profile and spectrum. We predict a mean angular spread of 0.8 degrees with energies in the range 30-200 MeV. We consider projected sensitivities for mass limits on axions from J0108-1431, a neutron star at a distance of 240 pc. We demonstrate the feasibility of setting more stringent limits for axions in this mass range, excluding a range not probed by observations before. Based on the extended angular profile of the source, the expected sensitivity of the 95% CL upper limit on the axion mass from J0108-1431 is >10 meV. We also consider observational strategies in the search for axions from J0108-1431 with the Fermi-LAT.

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Contributing team(s): Fermi LAT Collaboration

233.04D – An Analytic Particle Acceleration Model in Pulsar Wind Termination Shocks Applied to the Crab Nebula Gamma-Ray Flares

The Crab nebula is a persistent source of gamma-rays up to about 100 MeV due to synchrotron radiation from electrons/positrons emitting in an ambient magnetic field thought to be of magnitude B~200 μG. The radiating electrons are limited by radiation-reaction forces which place an upper limit of about 100 MeV on the gamma-ray photons it can produce. This normally quiescent nebula has been observed by AGILE and *Fermi* to undergo bright transients lasting about a week and characterized by a significant increase in gamma-ray flux far above the classical radiation-reaction limit, with energies often reaching 3 GeV. The flares imply a population of PeV electrons accelerated on sub-day timescales. The very short acceleration timescales and the observed emission above the radiation-reaction limit place severe constraints on contemporary shock acceleration models such as diffusive shock acceleration which cannot account for the temporal and energetic properties of the gamma-ray flares. In this component of my dissertation research, I revisit the problem and find an analytic solution to the Fokker-Planck equation which incorporates a variety of acceleration and loss terms. I find that the model can reproduce the various *Fermi*-LAT flare spectra well and that electrostatic acceleration is the most significant contributor to the underlying mechanisms responsible for the most energetic astrophysical particle population ever observed. I find that the spectra of all the *Fermi*-LAT flares from the Crab nebula can be reproduced with this model using magnetic fields that are in agreement with multi-wavelength observations.

Author(s): John J. Kroon[2], Peter A. Becker[1], Finke Justin[2], Charles D. Dermer[2]
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233.05 – A Library of known X-ray Pulsars in the Small Magellanic Cloud: Time Evolution of their Luminosities and Spin Periods

We have collected and analyzed 116 {\itshape XMM-Newton\/}, 151 {\itshape Chandra\/}, and 952 {\itshape RXTE\/} observations of the Small Magellanic Cloud (SMC), spanning 1997-2014. The resulting observational library provides a comprehensive view of the physical, temporal and statistical properties of the SMC pulsar population across the luminosity range of $L_X= 10^{31.5}-10^{38}$~erg~s^{-1}. We report $\sim$1600 individual pulsar detections, yielding $\sim$1300 pulse period measurements. Our pipeline generates a suite of products for each pulsar detection: period, flux, event list, high time-resolution light-curve, pulse-profile, periodogram and X-ray spectrum. Upper-limits are estimated for all non-detections bringing the combined database to $\sim$37,000 observations of 67 pulsars. Combining all three satellites, we generated complete histories of the spin periods, pulse amplitudes, pulse fractions and X-ray luminosities. Many of the pulsars show variations in pulse period due to the combination of orbital motion and accretion torques. Long-term spin-up/down trends are seen in 27/25 pulsars respectively, pointing to sustained transfer of mass and angular momentum to the neutron star on decadal timescales. The distributions of pulse-detection and flux as functions of spin-period provide interesting findings: mapping boundaries of accretion-driven X-ray luminosity, and showing that fast pulsars ($P<$10 s) are rarely detected, yet are more prone to giant outburst. Accompanying this paper is an initial public release of the library so that it can be used by other researchers. We intend the database and pulse profile library to be useful in driving improved models of neutron star magnetospheres and accretion physics.

Author(s): Jun Yang[2], Silas Laycock[2], Dimitris Christodoulou[2], Jeremy J. Drake[1], Jaesub Hong[1], Vallia Antoniou[1], Andreas Zezas[1], Malcolm Coe3, Wynn Ho3
Institution(s): *1. Harvard-Smithsonian CfA, 2. University of Massachusetts, 3. University of Southampton*

233.06D – Characterization of a Precision Pulsar Timing Gravitational Wave Detector

We aim to construct a Galactic-scale detector comprised of an array of pulsars distributed across the sky in an effort to detect low-frequency (nanohertz) gravitational waves. Even without a detection, observations of pulsar timing arrays have allowed us to begin to place impactful astrophysical constraints on dynamical processes occurring during galaxy mergers. Understanding the detector is necessary for improving our sensitivity to gravitational waves and making a detection. Therefore, our goal is to characterize the entire propagation path through the pulsar timing array detector. To do so, we must understand: what intrinsic noise processes occur at the pulsar, what effects the interstellar medium has on pulsed radio emission, and what errors we introduce when measuring the incident electromagnetic radiation at our observatories.

In this work, we observed of one of the most spin-stable objects known for 24 hours to understand the fundamental limits of precision pulsar timing. We investigated the effect of non-simultaneous, multi-frequency sampling of pulsar dispersion measures on timing and analyzed the cause of deterministic and stochastic temporal variations seen in dispersion measure time series. We analyzed errors in pulse arrival times and determined the white noise budget for pulsars on the timescale of a single observation. Finally, we measured the excess noise beyond the white noise model in pulsar timing residuals and incorporated our results into a global model over all pulsar populations to improve excess noise scaling relations.

Author(s): Michael T. Lam[1]
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234 – Dannie Heineman Prize for Astrophysics: Increasing Accuracy and Increasing Tension in H_0, Wendy Freedman (University of Chicago)

234.01 – Increasing Accuracy and Increasing Tension in H_0

The Hubble Constant, H_0, provides a measure of the current expansion rate of the universe. In recent decades, there has been a huge increase in the accuracy with which extragalactic distances, and hence H_0, can be measured. While the historical factor-of-two uncertainty in H_0 has been resolved, a new discrepancy has arisen between the values of H_0 measured in the local universe, and that estimated from cosmic microwave background measurements, assuming a Lambda cold dark matter model. I will review the advances that have led to the increase in accuracy in measurements of H_0, as well as describe exciting future prospects with the James Webb Space Telescope (JWST) and Gaia, which will make it feasible to measure extragalactic distances at percent-level accuracy in the next decade.

Author(s): Wendy L. Freedman[1]
Institution(s): *1. The University of Chicago*

235 – HEAD Bruno Rossi Prize: A Good Hard Look at Growing Supermassive Black Holes in the Distant Universe, W. Neil Brandt (Pennsylvania State University)

235.01 – A Good Hard Look at Growing Supermassive Black Holes in the Distant Universe

Sensitive cosmic X-ray surveys with the Chandra, XMM-Newton, and now NuSTAR observatories have revolutionized our ability to find and study distant active galactic nuclei (AGNs), the main sites of supermassive black hole growth in the Universe. I will describe some of the resulting discoveries about the demographics, physics, and ecology of distant AGNs with an emphasis on the deepest Chandra surveys, the Chandra Deep Fields. Some specific topics covered will include (1) robust X-ray spectral and variability characterization of the AGNs producing most of cosmic accretion power; (2) the demographics of AGNs in the first galaxies as revealed by direct detection and stacking; (3) AGN/galaxy interactions as investigated via the host properties of X-ray AGNs; and (4) the cosmic balance of power between supermassive black holes and stars. I will also briefly describe other remarkable discoveries coming from the deepest X-ray surveys; e.g., measurements of the evolving X-ray binary populations of normal and starburst galaxies. I will end by discussing some key outstanding questions and new observations and missions aiming to answer them.

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Contributing team(s): The Chandra Deep Fields Team

236 – Computation, Data Handling, Image Analysis & Light Pollution Poster Session

236.01 – When Will It Be ...?: U.S. Naval Observatory Sidereal Time and Julian Date Calculators

Sidereal time and Julian date are two values often used in observational astronomy that can be tedious to calculate. Fortunately, the U.S. Naval Observatory (USNO) has redesigned its on-line Sidereal Time and Julian Date (JD) calculators to provide data through an Application Programming Interface (API). This flexible interface returns dates and times in JavaScript Object Notation (JSON) that can be incorporated into third-party websites or applications.
Via the API, Sidereal Time can be obtained for any location on Earth for any date occurring in the current, previous, or subsequent year. Up to 9999 iterations of sidereal time data with intervals from 1 second to 1095 days can be generated, as long as the data doesn't extend past the date limits. The API provides the Gregorian calendar date and time (in UT1), Greenwich Mean Sidereal Time, Greenwich Apparent Sidereal Time, Local Mean Sidereal Time, Local Apparent Sidereal Time, and the Equation of the Equinoxes.
Julian Date can be converted to calendar date, either Julian or Gregorian as appropriate, for any date between JD 0 (January 1, 4713 BCE proleptic Julian) and JD 5373484 (December 31, 9999 CE Gregorian); the reverse calendar date to Julian Date conversion is also available. The calendar date and Julian Date are returned for all API requests; the day of the week is also returned for Julian Date to calendar date conversions.
On-line documentation for using all USNO API-enabled calculators, including sample calls, is available (http://aa.usno.navy.mil/data/docs/api.php).
For those who prefer using traditional data input forms, Sidereal Time can still be accessed at http://aa.usno.navy.mil/data/docs /siderealtime.php, and the Julian Date Converter at http://aa.usno.navy.mil/data/docs/JulianDate.php.

Author(s): Malynda R. Chizek Frouard[1], Michael V. Lesniak[1], Jennifer L. Bartlett[1]
Institution(s): *1. US Naval Observatory*

236.02 – Automated Approaches to RFI Flagging

It is known that Radio Frequency Interference (RFI) is a major issue in centimeter wavelength radio astronomy. Radio astronomy software packages include tools to excise RFI; both manual and automated utilizing the visibilities (the uv data). Here we present results on an automated RFI flagging approach that utilizes a uv-grid, which is the intermediate product when converting uv data points to an image. It is a well known fact that any signal that appears widespread in a given domain (e.g., image domain) is compact in the Fourier domain (uv-grid domain), i.e., RFI sources that appear as large scale structures (e.g., stripes) in images can be located and flagged using the uv-grid data set. We developed several automated uv-grid based flagging algorithms to detect and excise RFI. These algorithms will be discussed, and results of applying them to measurement sets will be presented.

Author(s): Karthik Garimella[1], Emmanuel Momjian[2]
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236.03 – First Science Verification of the VLA Sky Survey Pilot

My research involved analyzing test images by Steve Myers for the upcoming VLA Sky Survey. This survey will cover the entire sky visible from the VLA site in S band (2-4 GHz). The VLA will be in B configuration for the survey, as it was when the test images were produced, meaning a resolution of approximately 2.5 arcseconds. Conducted using On-the-Fly mode, the survey will have a speed of approximately 20 deg^2 hr^{-1} (including overhead). New Python imaging scripts are being developed and improved to process the VLASS images. My research consisted of comparing a continuum test image over S band (from the new imaging scripts) to two previous images of the same region of the sky (from the CNSS and FIRST surveys), as well as comparing the continuum image to single spectral windows (from the new imaging scripts and of the same sky region). By comparing our continuum test image to images from CNSS and FIRST, we tested on-the-Fly mode and the imaging script used to produce our images. Another goal was to test whether individual spectral windows could be used in combination to calculate spectral indices close to those produced over S band (based only on our continuum image). Our continuum image contained 64 sources as opposed to the 99 sources found in the CNSS image. The CNSS image also had lower noise level (0.095 mJy/beam compared to 0.119 mJy/beam). Additionally, when our continuum image was compared to the CNSS image, separation showed no dependence on total flux density (in our continuum image). At lower flux densities, sources in our image were brighter than the same ones in the CNSS image. When our continuum image was compared to the FIRST catalog, the spectral index difference showed no dependence on total flux (in our continuum image). In conclusion, the quality of our images did not completely match the quality of the CNSS and FIRST images. More work is needed in developing the new imaging scripts.

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236.04 – Image-based query-by-example for big databases of galaxy images

Very large astronomical databases containing millions or even billions of galaxy images have been becoming increasingly important tools in astronomy research. However, in many cases the very large size makes it more difficult to analyze these data manually, reinforcing the need for computer algorithms that can automate the data analysis process. An example of such task is the identification of galaxies of a certain morphology of interest. For instance, if a rare galaxy is identified it is reasonable to expect that more galaxies of similar morphology exist in the database, but it is virtually impossible to manually search these databases to identify such galaxies. Here we describe computer vision and pattern recognition methodology that receives a galaxy image as an input, and searches automatically a large dataset of galaxies to return a list of galaxies that are visually similar to the query galaxy. The returned list is not necessarily complete or clean, but it provides a substantial reduction of the original database into a smaller dataset, in which the frequency of objects visually similar to the query galaxy is much higher. Experimental results show that the algorithm can identify rare galaxies such as ring galaxies among datasets of 10,000 astronomical objects.

Author(s): Lior Shamir[1], Evan Kuminski[1]
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236.05 – Bifrost: a Modular Python/C++ Framework for Development of High-Throughput Data Analysis Pipelines

Large radio interferometers have data rates that render long-term storage of raw correlator data infeasible, thus motivating development of real-time processing software. For high-throughput applications, processing pipelines are challenging to design and implement. Motivated by science efforts with the Long Wavelength Array, we have developed Bifrost, a novel Python/C++ framework that eases the development of high-throughput data analysis software by packaging algorithms as black box processes in a directed graph. This strategy to modularize code allows astronomers to create parallelism without code adjustment. Bifrost uses CPU/GPU 'circular memory' data buffers that enable ready introduction of arbitrary functions into the processing path for 'streams' of data, and allow pipelines to automatically reconfigure in response to astrophysical transient detection or input of new observing settings. We have deployed and tested Bifrost at the latest Long Wavelength Array station, in Sevilleta National Wildlife Refuge, NM, where it handles throughput exceeding 10 Gbps per CPU core.

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236.06 – photPARTY: Python automated square-aperture photometry

As CCD's have drastically increased the amount of information recorded per frame, so too have they increased the time and effort needed to sift through the data. For observations of a single star, information from millions of pixels needs to be distilled into one number: the magnitude. Various computer systems have been used to streamline this process over the years. The CCDPhot photometer, in use at the Kitt Peak 0.9-m telescope in the 1990's, allowed for user settings and provided real time magnitudes during observation of single stars. It is this level of speed and convenience that inspired the development of the Python-based software analysis system photPARTY, which can quickly and efficiently produce magnitudes for a set of single-star or un-crowded field CCD frames. Seeking to remove the need for manual interaction after initial settings for a group of images, photPARTY automatically locates stars, subtracts the background, and performs square-aperture photometry. Rather than being a package of available functions, it is essentially a self-contained, one-click analysis system, with the capability to process several hundred frames in just a couple of minutes. Results of comparisons against present systems such as IRAF will be presented. The support of the National Science Foundation through grant AST-1211621 is gratefully acknowledged.

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Institution(s): *1. University of Kansas*

236.07 – A Modified Bootstrap Monte Carlo Method to Investigate the Impact of Systematic Effects on Calibrated Optical Interferometry Data

We describe a modified bootstrap Monte Carlo method that was developed to assess quantitatively the impact of systematic residual errors on calibrated optical interferometry data from the Navy Precision Optical Interferometer. A variety of atmospheric and instrumental effects represent the sources of residual systematic errors that remain in the data after calibration, for example when there are atmospheric fluctuations with shorter time scales than the time scale between the observations of calibrator-target pairs. The modified bootstrap Monte Carlo method retains the inherent structure of how the underlying data set was acquired, by accounting for the fact that groups of data points are obtained simultaneously instead of individual data points. When telescope pairs (baselines) and spectral channels corresponding to a specific output beam from a beam combiner are treated as groups, this method provides a more realistic (and typically larger) uncertainties associated with the fitted model parameters, such as angular diameters of resolved stars, than the standard method based solely on formal errors.
This work has been supported by NSF grant AST-1614983.

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Institution(s): *1. Central Michigan University, 2. The University of Western Ontario, 3. US Naval Observatory, Flagstaff Station*

236.08 – DRAGraces: An open source pipeline to extract your GRACES data!

Written in IDL, the DRAGraces pipeline is designed to reduce and extract data from the Gemini high-resolution spectrograph GRACES*. It is barely more than a thousand lines long, and everyone is invited to download, use and modify it as needed (https://github.com/AndreNicolasChene/DRAGRACES/releases/tag/1.0.1).

This poster details how to retrieve observed GRACES data from the Gemini Observatory Archive, and explains how to run DRAGraces. It also describes the pipeline's steps, capability and performances. It is recommended to use this code and/or the other open soure pipeline, OPERA, to obtain an optimized extraction of GRACES data, before publication. It is the best way to keep control on all the reduction steps, most importantly calibration.

****G**emini **R**emote **A**ccess to **C**FHT **E**SPaDOnS **S**pectrograph **(GRACES)** is the result of a cooperation between the Canada-France-Hawaii Telescope (CFHT), Gemini, and NRC-Herzberg (Canada). It combines the large collecting area of the Gemini North telescope with the high resolving power and high efficiency of the ESPaDOnS spectrograph at CFHT, to deliver high resolution spectroscopy across the optical region. This is achieved through a 270 m fiber optics feed from the Gemini North telescope to ESPaDOnS.

Author(s): André-Nicolas Chené[1]
Institution(s): *1. Gemini Observatory*

236.09 – TOASTing Your Images With Montage

The Montage image mosaic engine is a scalable toolkit for creating science-grade mosaics of FITS files, according to the user's specifications of coordinates, projection, sampling, and image rotation. It is written in ANSI-C and runs on all common *nix-based platforms. The code is freely available and is released with a BSD 3-clause license.

Version 5 is a major upgrade to Montage, and provides support for creating images that can be consumed by the World Wide Telescope (WWT). Montage treats the TOAST sky tessellation scheme, used by the WWT, as a spherical projection like those in the WCStools library. Thus images in any projection can be converted to the TOAST projection by Montage's reprojection services. These reprojections can be performed at scale on high-performance platforms and on desktops. WWT consumes PNG or JPEG files, organized according to WWT's tiling and naming scheme. Montage therefore provides a set of dedicated modules to create the required files from FITS images that contain the TOAST projection.

There are two other major features of Version 5. It supports processing of HEALPix files to any projection in the WCS tools library. And it can be built as a library that can be called from other languages, primarily Python.

http://montage.ipac.caltech.edu.
GitHub download page: https://github.com/Caltech-IPAC/Montage.
ASCL record: ascl:1010.036. DOI: dx.doi.org/10.5281/zenodo.49418

Montage is funded by the National Science Foundation under Grant Number ACI-1440620,

Author(s): G. Bruce Berriman[1], John Good[1]
Institution(s): *1. Caltech*

236.10 – Galaxy Classification using Machine Learning

We present our current research into the use of machine learning to classify galaxy imaging data with various convolutional neural network configurations in TensorFlow. We are investigating how five-band Sloan Digital Sky Survey imaging data can be used to train on physical properties such as redshift, star formation rate, mass and morphology. We also investigate the performance of artificially redshifted images in recovering physical properties as image quality degrades.

Author(s): Lucas Fowler[1], Kevin Schawinski[1], Ben-Elias Brandt[1], Nicole widmer[1]
Institution(s): *1. ETH Zürich*

236.11 – Gemini Observatory Operations and Software for the 2020s

Gemini Observatory is planning several major software upgrades to improve usability and maintenance and to help prepare Gemini for the LSST, ELT, and JWST era. Gemini is currently a leader in target-of-opportunity (ToO) observing (e.g. SNe and GRB follow-up, solar system objects, eclipses, occultations) due to the dominant queue mode of observing. In the era of large transient surveys (e.g. iPTF, Catalina, Pan-STARRS, and especially LSST) and other transient surveys we expect that the follow-up of faint transient sources will become a very significant, if not dominant, use of Gemini. The next Gemini instrument, Gen4#3, is being designed for transient follow-up. However, much of Gemini's software infrastructure is now more than 15 years old is not sufficiently user-friendly, scalable, or maintainable. Therefore, we are embarking on a series of upgrade projects with the goals of making Gemini easier to use, making the system more scalable and flexible, and ensuring that the system is maintainable for the next 15 years. This poster will describe the ongoing projects and future plans to upgrade the real-time control systems, develop a new Observatory Control System (including a potential rewrite of the Observing Tool and an automated scheduling capability), and integrate into future ToO networks. Feedback on requirements for new user software, in particular, is requested.

Author(s): Bryan W. Miller[2], Andrew W. Stephens[1], Arturo Nunez[2], Mischa Schirmer[2]
Institution(s): *1. Gemini Observatory - North, 2. Gemini Observatory - South*

236.12 – Maestro and Castro: Simulation Codes for Astrophysical Flows

Stellar explosions are multiphysics problems—modeling them requires the coordinated input of gravity solvers, reaction networks, radiation transport, and hydrodynamics together with microphysics recipes to describe the physics of matter under extreme conditions. Furthermore, these models involve following a wide range of spatial and temporal scales, which puts tough demands on simulation codes. We developed the codes Maestro and Castro to meet the computational challenges of these problems. Maestro uses a low Mach number formulation of the hydrodynamics to efficiently model convection. Castro solves the fully compressible radiation hydrodynamics equations to capture the explosive phases of stellar phenomena. Both codes are built upon the BoxLib adaptive mesh refinement library, which prepares them for next-generation exascale computers. Common microphysics shared between the codes allows us to transfer a problem from the low Mach number regime in Maestro to the explosive regime in Castro. Importantly, both codes are freely available (https://github.com/BoxLib-Codes). We will describe the design of the codes and some of their science applications, as well as future development directions.

Support for development was provided by NSF award AST-1211563 and DOE/Office of Nuclear Physics grant DE-FG02-87ER40317 to Stony Brook and by the Applied Mathematics Program of the DOE Office of Advance Scientific Computing Research under US DOE contract DE-AC02-05CH11231 to LBNL.

Author(s): Michael Zingale4, Ann Almgren[2], Vince Beckner[2], John Bell[2], Brian Friesen[2], Adam Jacobs3, Maximilian P. Katz4, Christopher Malone[1], Andrew Nonaka[2], Weiqun Zhang[2]
Institution(s): *1. LANL, 2. LBNL, 3. MSU, 4. Stony Brook University*

236.13 – Top ten reasons to register your code with the Astrophysics Source Code Library

With 1,400 codes, the Astrophysics Source Code Library (ASCL, ascl.net) is the largest indexed resource for codes used in astronomy research in existence. This free online registry was established in 1999, is indexed by Web of Science and ADS, and is citable, with citations to its entries tracked by ADS. Registering your code with the ASCL is easy with our online submissions system. Making your software available for examination shows confidence in your research and makes your research more transparent, reproducible, and falsifiable. ASCL registration allows your software to be cited on its own merits and provides a citation that is trackable and accepted by all astronomy journals and journals such as *Science* and *Nature*. Registration also allows others to find your code more easily. This presentation covers the benefits of registering astronomy research software with the ASCL.

Author(s): Alice Allen[1], Kimberly DuPrie[10], G. Bruce Berriman4, Jessica D. Mink9, Robert J. Nemiroff7, Thomas Robitaille3, Judy Schmidt[1], Lior Shamir[6], Keith Shortridge5, Peter J. Teuben[11], John F. Wallin[8], Rein Warmels[2]
Institution(s): *1. Astrophysics Source Code Library, 2. European Southern Observatory, 3. Freelance, 4. IPAC, Caltech, 5. Knave and Varlet, 6. Lawrence Technological University, 7. Michigan Technological Univ., 8. Middle Tennessee State University, 9. Smithsonian Astrophysical Observatory, 10. STScI, 11. University of Maryland*

236.14 – 3D Immersive Visualization with Astrophysical Data

We present the refinement of a new 3D immersion technique for astrophysical data visualization.
Methodology to create 360 degree spherical panoramas is reviewed. The 3D software package Blender coupled with Python

and the Google Spatial Media module are used together to create the final data products. Data can be viewed interactively with a mobile phone or tablet or in a web browser. The technique can apply to different kinds of astronomical data including 3D stellar and galaxy catalogs, images, and planetary maps.

Author(s): Brian R. Kent[1]
Institution(s): *1. NRAO*

236.15 – SciServer: An Online Collaborative Environment for Big Data in Research and Education

For the past year, SciServer Compute (http://compute.sciserver.org) has offered access to big data resources running within server-side Docker containers. Compute has allowed thousands of researchers to bring advanced analysis to big datasets like the Sloan Digital Sky Survey and others, while keeping the analysis close to the data for better performance and easier read/write access. SciServer Compute is just one part of the SciServer system being developed at Johns Hopkins University, which provides an easy-to-use collaborative research environment for astronomy and many other sciences.

SciServer enables these collaborative research strategies using Jupyter notebooks, in which users can write their own Python and R scripts and execute them on the same server as the data. We have written special-purpose libraries for querying, reading, and writing data. Intermediate results can be stored in large scratch space (hundreds of TBs) and analyzed directly from within Python or R with state-of-the-art visualization and machine learning libraries. Users can store science-ready results in their permanent allocation on SciDrive, a Dropbox-like system for sharing and publishing files.

SciServer Compute's virtual research environment has grown with the addition of task management and access control functions, allowing collaborators to share both data and analysis scripts securely across the world. These features also open up new possibilities for education, allowing instructors to share datasets with students and students to write analysis scripts to share with their instructors. We are leveraging these features into a new system called "SciServer Courseware," which will allow instructors to share assignments with their students, allowing students to engage with big data in new ways.

SciServer has also expanded to include more datasets beyond the Sloan Digital Sky Survey. A part of that growth has been the addition of the SkyQuery component, which allows for simple, fast cross-matching between very large astronomical datasets.

Demos, documentation, and more information about all these resources can be found at www.sciserver.org.

Author(s): Jordan Raddick[1], Barbara Souter[1], Gerard Lemson[1], Manuchehr Taghizadeh-Popp[1]
Institution(s): *1. Johns Hopkins University*

236.16 – Understanding and Using the Fermi Science Tools

The Fermi Science Support Center (FSSC) provides information, documentation, and tools for the analysis of Fermi science data, including both the Large-Area Telescope (LAT) and the Gamma-ray Burst Monitor (GBM). Source and binary versions of the Fermi Science Tools can be downloaded from the FSSC website, and are supported on multiple platforms. An overview document, the Cicerone, provides details of the Fermi mission, the science instruments and their response functions, the science data preparation and analysis process, and interpretation of the results. Analysis Threads and a reference manual available on the FSSC website provide the user with step-by-step instructions for many different types of data analysis: point source analysis - generating maps, spectra, and light curves, pulsar timing analysis, source identification, and the use of python for scripting customized analysis chains. We present an overview of the structure of the Fermi science tools and documentation, and how to acquire them. We also provide examples of standard analyses, including tips and tricks for improving Fermi science analysis.

Author(s): Joseph Asercion[1]
Institution(s): *1. Fermi Science Support Center*
Contributing team(s): Fermi Science Support Center

236.17 – Secondary Standard Sequence and BVRI-H-alpha Light Curves for NGC 4151

We present data for the Seyfert 1 galaxy NGC 4151 secured at the BYU West Mountain Observatory on 36 nights between 2016 April 2 and 2016 August 14. Observations were made using standard BVRI filters as well as a 20 nm filter centered on the rest wavelength of the H-alpha line of hydrogen. Standardized data are presented for 15 stars in the field of NGC 4151 in each of the BVRI magnitudes. The V magnitude range for the extended sequence is between 11.480 and 16.100. Additionally, we have found light curves for NGC 4151 in each of the five colors using both traditional photometric analysis and image subtraction routines. representative examples of light curves are presented for each of the techniques we have tested. We acknowledge the Brigham Young University Department of Physics and Astronomy for continued support of student research experiences at the West Mountain Observatory.

Author(s): Melissa Hallum[1], Micheal Joner[1]
Institution(s): *1. Brigham Young University*

236.18 – Improving Photometric Redshifts for Hyper Suprime-Cam

Deriving accurate photometric redshift (photo-z) probability distribution functions (PDFs) are crucial science components for current and upcoming large-scale surveys. We outline how rigorous Bayesian inference and machine learning can be combined to quickly derive joint photo-z PDFs to individual galaxies and their parent populations. Using the first 170 deg^2 of data from the ongoing Hyper Suprime-Cam survey, we demonstrate our method is able to generate accurate predictions and reliable credible intervals over ~370k high-quality redshifts. We then use galaxy-galaxy lensing to empirically validate our predicted photo-z's over ~14M objects, finding a robust signal.

Author(s): Josh S Speagle[1], Alexie Leauthaud5, Daniel Eisenstein[1], Kevin Bundy5, Peter L. Capak3, Boris Leistedt4, Daniel C. Masters3, Daniel Mortlock[2], Hiranya Peiris[6]
Institution(s): *1. Harvard University, 2. Imperial College London, 3. IPAC, 4. NYU, 5. UCSC, 6. University College London*
Contributing team(s): HSC Photo-z Team, HSC Weak Lensing Team

236.19 – Comparing High-redshift Galaxy Dropouts in GOODS-S from SelfCal and MultiDrizzle Maps

A subset of the multi-wavelength CANDELS survey is utilized to compare results of high-redshift photometric dropout galaxies from two different image processing techniques in the GOODS-S region. The maps used are the publicly available CANDELS mosaics and SelfCal, which is a self-calibration method that removes anisotropy offsets that are introduced from combining frames taken at different times. The identified dropout sources for redshifts 4 and larger from each dataset are compared to Lyman-break galaxy catalogs. Preliminary results indicate a low match rate for sources between the SelfCal maps and published catalogs, which could be attributed to differing map depth and processing techniques.

Author(s): Jennifer Cooper[1], Asantha R. Cooray[2], Hooshang Nayyeri[2]
Institution(s): *1. California State University Los Angeles, 2. UC Irvine*

236.20 – Measuring the color and brightness of artificial sky glow from cities using an all-sky imaging system calibrated with astronomical methods in the Johnson-Cousins B and V photometric systems

Artificial light at night, when observed at some distance from a city, results in a dome of sky glow, brightest at the horizon. The spectral power distribution of electric light utilized will determine its color of the light dome and the amount of light will determine its brightness. Recent outdoor lighting technologies have included blue-rich light emitting diode (LED) sources that may increase the relative amount of blue to green light in sky glow compared to typical high pressure sodium (HPS) sources with warmer spectra. Measuring and monitoring this effect is important to the preservation of night sky visual quality as seen from undeveloped areas outside the city, such as parks or other protected areas, since the dark-adapted human eye is more sensitive to blue and green. We present a method using a wide field CCD camera which images the entire sky in both Johnson V and B photometric bands. Standard stars within the images are used for calibration. The resulting all-sky brightness maps, and a derived B-V color index map, provide a means to assess and track the impact of specific outdoor lighting practices. We also present example data from several cities, including Las Vegas, Nevada, Flagstaff, Arizona, and Cheyenne, Wyoming.

Author(s): Ashley Pipkin[2], Dan M Duriscoe[2], Christian Lughinbuhl[1]
Institution(s): *1. Flagstaff Dark Skies Coalition, 2. National Park Service*

236.21 – Studying the Light Pollution around Urban Observatories: Columbus State University's WestRock Observatory

Light pollution plays an ever increasing role in the operations of observatories across the world. This is especially true in urban environments like Columbus, GA, where Columbus State University's WestRock Observatory is located. Light pollution's effects on an observatory include high background levels, which results in a lower signal to noise ratio. Overall, this will limit what the telescope can detect, and therefore limit the capabilities of the observatory as a whole.

Light pollution has been mapped in Columbus before using VIIRS DNB composites. However, this approach did not provide the detailed resolution required to narrow down the problem areas around the vicinity of the observatory. The purpose of this study is to assess the current state of light pollution surrounding the WestRock observatory by measuring and mapping the brightness of the sky due to light pollution using light meters and geographic information system (GIS) software.

Compared to VIIRS data this study allows for an improved spatial resolution and a direct measurement of the sky background. This assessment will enable future studies to compare their results to the baseline established here, ensuring that any changes to the way the outdoors are illuminated and their effects can be accurately measured, and counterbalanced.

Author(s): Brendon Andrew O'Keeffe[1], Michael Johnson[1]
Institution(s): *1. Columbus State University*

237 – Surveys & Large Programs Poster Session

237.01 – A methodology to address mixed AGN and starlight contributions in emission line galaxies found in the RESOLVE survey and ECO catalog

We present a novel methodology for modeling emission line galaxy samples that span the entire BPT diagram. Our methodology has several advantages over current modeling schemes: the free variables in the model are identical for both AGN and SF galaxies; these free variables are more closely linked to observable galaxy properties; and the ionizing spectra including an AGN and starlight are handled self-consistently rather than empirically. We show that our methodology is capable of fitting the vast majority of SDSS galaxies that fall within the traditional regions of galaxy classification on the BPT diagram. We also present current results for relaxing classification boundaries and extending our galaxies into the dwarf regime, using the REsolved Spectroscopy of a Local VolumE (RESOLVE) survey and the Environmental COntext (ECO) catalog, with special attention to compact blue E/S0s. We compare this methodology to PCA decomposition of the spectra. This work is supported by National Science Foundation awards AST-0955368 and CISE/ACI-1156614.

Author(s): Chris T. Richardson[1], Sheila Kannappan[2], Ashley Bittner[2], Rohan Isaac[2]
Institution(s): *1. Elon University, 2. University of North Carolina*
Contributing team(s): RESOLVE

237.02 – Structure and Morphology of RESOLVE Galaxies in Relation to Environment, Gas, and Star Formation

We examine the structure and morphology of galaxies in the RESOLVE (REsolved Spectroscopy Of a Local VolumE) survey, a census of >1500 galaxies with baryonic mass >~10^9 Msun spanning multiple environments across >50,000 cubic Mpc of the nearby cosmic web. We investigate the statistical distribution of basic structural parameters as well as tidal streams and compact cores identified by image decomposition. Our results offer clues to the drivers of diversity in star formation and gas properties, particularly the unexpected phenomenon of red, gas depleted dwarf galaxies that are not satellites. RESOLVE was supported by NSF award AST-0955368.

Author(s): Sheila Kannappan[1], Callie Hood[1], Elaine M. Snyder[1], Kathleen D. Eckert[1], David Stark[1]
Institution(s): *1. Univ. of North Carolina*
Contributing team(s): RESOLVE team

237.03 – The Environmental Dependence of the Galaxy Stellar Mass Function in the ECO Survey

We study the environmental dependence of the galaxy stellar mass function in the ECO survey and compare it with models that associate galaxies with dark matter halos. Specifically, we quantify the environment of each galaxy in the ECO survey using an Nth nearest neighbor distance metric, and we measure how the galaxy stellar mass distribution varies from low density to high density environments. As expected, we find that massive galaxies preferentially populate high density regions, while low mass galaxies preferentially populate lower density environments. We investigate whether this trend can be explained simply by the stellar-to-halo mass relation combined with the environmental dependence of the halo mass function. In other words, we test the hypothesis that the stellar mass of a galaxy depends solely on the mass of its dark matter halo and does not exhibit a residual dependence on the halo's larger environment. To test this hypothesis, we first construct mock ECO catalogs by populating dark matter halos in an N-body simulation with galaxies using a model that preserves the overall clustering strength of the galaxy population. We then assign stellar masses to the mock galaxies using physically motivated models that connect stellar mass to halo mass and are constrained to match the global ECO stellar mass function. Finally, we impose the radial and angular selection functions of the ECO survey and repeat our environmental analysis on the mock catalogs. We find that the environmental dependence of stellar mass in the mock catalogs is in agreement with that observed in the ECO survey. Our results are thus consistent with the simple hypothesis that galaxy stellar mass only depends on halo mass. The RESOLVE/ECO surveys were supported by NSF award AST-0955368.

Author(s): Hannah Richstein[2], Andreas A. Berlind5, Victor Calderon5, Kathleen D. Eckert3, Sheila Kannappan3, Amanda J. Moffett4, David Stark[1]
Institution(s): *1. Kavli IPMU, 2. Texas Christian University, 3. University of North Carolina, Chapel Hill, 4. University of Western Australia, 5. Vanderbilt University*

237.04 – An Automated Census Of Variable X-Ray Objects in the Direction of Clusters of Galaxies

Since the launch of the Chandra X-ray Observatory in 1999, broad x-ray surveys have been the primary means of discovering new objects in the sky. We present the results of one such survey, examining variable x-ray sources in archival Chandra data. Our survey maximizes the possibility of finding novel and interesting sources by searching for all x-ray variable sources and manually categorizing variable objects. This allows for the identification of interesting objects with common classifications, like a typical galaxy with unusual fluctuations. To further increase the probability of finding sources we focused on galaxy clusters, allowing us to look at over a thousand galaxies per observation. Our analysis was based on a previously compiled database of source fluxes, over all available observations and across energies from 0.2 keV to 12 keV. We converted the soft x-ray flux (0.5 to 2 keV) to count rate, then fit it to the average count rate using least squares regression. Variable sources are defined as those with $c^2 > 50$ over the total observed time. We then categorized variable objects and found optical counterparts. Our criteria identified 49 variable sources from a total of 58,000 sources in our database, though we estimate up to 20% of the database is extraneous double sources. Of these variable sources, 9 had not been previously identified in the SIMBAD database and 28 had not been previously categorized as variable. A majority of the objects found were expected, such as various classes of active galactic nuclei and variable red dwarfs. Other more interesting objects include a variable A-type star and an ultraluminous galaxy.

Author(s): Lupe MacIntosh[1], Elizabeth Cunningham[2], Melville P. Ulmer3
Institution(s): *1. Harvey Mudd College, 2. Loyola University, 3. Northwestern University*

237.05 – Point and Condensed Hα Sources in the Interior of M33

A variety of interesting objects such as Wolf-Rayet stars, tight OB associations, planetary nebula, x-ray binaries, etc. can be discovered as point or condensed sources in Hα surveys. How these objects distribute through a galaxy sheds light on the galaxy star formation rate and history, mass distribution, and dynamics. The nearby galaxy M33 is an excellent place to study the distribution of Hα-bright point sources in a flocculant spiral galaxy. We have reprocessed an archived WIYN continuum-subtracted Hα image of the inner 6.5' of the nearby galaxy M33 and, employing both eye and machine searches, have tabulated sources with a flux greater than 1×10^{-15} erg cm^{-2}sec^{-1}. We have identified 152 unresolved point sources and 122 marginally resolved condensed sources, 38 of which have not been previously cataloged. We present a map of these sources and discuss their probable identifications.

Author(s): J. Ward Moody[1], Eric G. Hintz[1], Peter Roming[1], Michael D. Joner[1], Brian Bucklein[2]
Institution(s): *1. Brigham Young Univ., 2. Missouri Western*

237.06 – Pan-STARRS1 Medium Deep Survey

The Panoramic Survey Telescope And Rapid Response System 1 (Pan-STARRS1, PS1) has been in full science operation since Spring 2010 with the PS1 Science Consortium (PS1SC) observational program concluding in early 2014. The Medium Deep Survey (MDS) component of the program, allocated 25% of the time, regularly visited 10 fields (~7 sq. deg. each) with significant multi-wavelength overlap from previous and concurrent surveys (e.g. SDSS, DEEP2, CDFS, COSMOS, GALEX). The cadence generally includes the g & r, i, z filters in a 3 day cycle with nightly 5-sigma point source stack depths of r,i~23.5 mag and switching to the y filter primarily during bright time over the 6-8 month season a MDS field is visible. While nightly processing was regularly producing data for the transient event discovery and other science consortium programs with incremental improvements during the survey, the entire MDS dataset has now been uniformly reprocessed for the upcoming public data release. The MDS data products, to be made available after the full release of the 3PI dataset, will be summarily presented.

For details on PS1 and the Science Consortium, visit http://ps1sc.org/

Author(s): Mark Huber[1]
Institution(s): *1. Institute for Astronomy, University of Hawaii*
Contributing team(s): PS1 Science Consortium, Pan-STARRS IPP Team

237.07 – Pan-STARRS Data Release 1

We present an overview of the first and second Pan-STARRS data release (DR1 and DR2), and how to use the Published Science Products Subsystem (PSPS) and the Pan-STARRS Science Interface (PSI) to access the images and the catalogs. The data will be available from the STScI MAST archive. The PSPS is an SQLServer database that can be queried via script or web interface. This database has relative photometry and astrometry and object associations, making it easy to do searches across the entire sky as well as tools to generate lightcurves of individual objects as a function of time. Both releases of data use the 3pi survey, which has 5 filters (g,r,i,z,y), roughly 60 epochs (12 per filter) and covers 3/4 of the sky and everything north of -30 degrees declination. The first release of data (DR1) will contain stack images, mean attribute catalogs and static sky catalogs based off of the stacks. The second release of data (DR2) will contain the time domain data. For the images, this will include single exposures that have been detrended and warped. For the catalogs, this will include catalogs of all exposures as well as forced photometry.

Author(s): Heather Flewelling[1]
Institution(s): *1. University of Hawaii*

237.08 – Census of the Local Universe (CLU) Galaxy Survey: Results Within Preliminary Fields

We present an analysis of galaxy candidates in 15 (out of ~3600) preliminary fields of the Census of the Local Universe (CLU) galaxy survey. The intermediate Palomar Transient Factory (iPTF) is undertaking the CLU project to complete our survey of galaxies out to 200 Mpc (z ~ 0.05) and deploys 4 wavelength-adjacent, narrowband filters to search for emission line (Hα) sources across 3π (~28,000 deg^2) of the sky. Using the Palomar 200-inch Hale telescope, we have obtained spectroscopic follow-up observations with which we can verify each candidate's redshift and derive galaxy properties. In addition, we present some interesting galaxies in our candidate list (e.g., green peas) whose extreme properties (e.g., low metallicity and high star formation rate) are similar to those of higher redshift galaxies (z>2). We will expand our analysis to all ~3600 fields and anticipate finding tens-of-thousands of new galaxies in the local Universe over the next year.

Author(s): David O. Cook[1], Mansi M. Kasliwal[1], Angela Van Sistine[2], Daniel A. Dale3, Jessica Sutter3, Jordan Turner3, Ryan Parziale3
Institution(s): *1. Caltech, 2. University of Wisconsin - Milwaukee, 3. University of Wyoming*
Contributing team(s): iPTF Team

237.09 – Highlights from the La Silla QUEST Variability Survey

The recently completely QUEST supernova survey ran for 6 years on the ESO 1m Schmidt telescope in La Silla Chile using a large CCD array to replace the photographic plate of the Schmidt. The survey covered ~1000 degres twice per night, for a total survey coverage area of ~20,000 square degrees from declination ~ -40 to +20. The survey magnitude limit is V~21. The average number of visits on a given patch of sky was ~150, although over a thousand squares more than 1000 visits. Although the survey cadence was driven by supernova science, it turns out to be provide good logarithmic coverage on a broad range of timescales, from ~hours to ~year, Much more time domain science can thus be done than a simple supernova search. Here we present highlights from La Silla QUEST non-supernova science, especially for AGN and RR Lyrae stars. Lessons learned from the La Silla QUEST survey should prove useful in preparing for LSST.

Author(s): Paolo S. Coppi[1]
Institution(s): *1. Yale Univ.*
Contributing team(s): The La Silla QUEST Survey Team

237.10 – Transients Discovered by the All-Sky Automated Survey for Supernovae

Even in the modern era, only human eyes are able to scan the entire optical sky for the violent, variable, and transient events that shape our universe. The "All Sky Automated Survey for Supernovae" (ASAS-SN or "Assassin") is changing this by monitoring the night sky down to V~17 mag every 2-3 days using multiple telescopes, hosted by Las Cumbres Observatory Global Telescope Network, in the northern and southern hemispheres. The primary goal of ASAS-SN is to discover bright, nearby supernovae (SNe); we currently discover more than 50% of SNe with V<17. Since June 2013 our SNe discovery rate has averaged one every three days, resulting in approximately 400 discoveries in total. ASAS-SN has also discovered many other interesting transients, including tidal disruption events, superluminous SNe, and Galactic novae. The nearby nature of ASASSN discoveries allows detailed follow-up across a wide wavelength coverage; here we present some of these data on recent ASAS-SN transients.

Author(s): Jonathan Brown[1], Thomas Warren-Son Holoien[1]
Institution(s): *1. The Ohio State University*
Contributing team(s): The ASAS-SN Team

237.11 – The Expansion of the Astronomical Photographic Data Archive at PARI

A diverse set of photometric, astrometric, spectral and surface brightness data exist on decades of photographic glass plates. The Astronomical Photographic Data Archive (APDA) at the Pisgah Astronomical Research Institute (PARI) was established in November 2007 and is dedicated to the task of collecting, restoring, preserving and storing astronomical photographic data and PARI continues to accept collections. APDA is also tasked with scanning each image and establishing a database of images that can be accessed via the Internet by the global community of scientists, researchers and students. APDA is a new type of astronomical observatory – one that harnesses analog data of the night sky taken for more than a century and making that data available in a digital format.

In 2016, APDA expanded from 50 collections with about 220,000 plates to more than 55 collections and more than 340,000 plates and films. These account for more than 30% of all astronomical photographic data in the United States. The largest of the new acquisitions are the astronomical photographic plates in the Yale University collection. We present details of the newly added collections and review of other collections in APDA.

Author(s): J. Donald Cline[1], Thurburn Barker[1], Michael Castelaz[1]
Institution(s): *1. Pisgah Astronomical Research Institute*

237.12 – The first two years of the Gemini Fast Turnaround Proposal Program

Gemini Observatory has since February 2015 offered telescope time monthly through the Fast Turnaround observing route. A fast review process by the proposers themselves coupled with rapid scheduling allow the proposals to go from submission to part of the queue in a month and the observations are then active for 3 months, much faster than the traditional semester based proposal scheme.
Both telescopes are included and around 10% of the available telescope time is allocated each month.
Here we present the early results and lessons learned from the program. We discuss the over-subscription, the review process and the selection of proposals as well as the scheduling. The completion rates is further discussed. Finally we highlight some of the science results coming out of the program.

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237.13 – The Formation of COINS: Equity and Inclusion in SDSS

In the era of large surveys, collaborations like the Sloan Digital Sky Survey (SDSS) are becoming a new normal for many scientists, and collaboration policies and climate have a considerable affect on scientific careers. As such, it is essential that collaborations actively strive to include all scientists regardless of gender, gender identity, race, ethnicity, sexual orientation, disability, career stage, geographic location, economic background, social and cultural backgrounds, and all possible intersections thereof. We report on the formation and progress of the Committee On INclusiveness in the SDSS (COINS). COINS was formed to assess the SDSS-IV project and collaboration's climate and demographics, to recommend new policies or practices with regard to increasing inclusiveness, and to assist in the implementation of these new activities where necessary. We report on our current activities, which include ongoing support for the SDSS Research Experience for Undergraduates program, support for the SDSS Faculty and Student Teams initiative, administering and analyzing the SDSS demographic surveys, working towards collaboration meeting inclusiveness and accessibility, and adopting strategies for integrating and mentoring new members. We welcome input from SDSS members and non-members about how to work towards a more equitable and inclusive collaboration.

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238 – Space Missions & Instrumentation Poster Session

238.01 – NASA Astrophysics Prioritizes Technology Development Funding for Strategic Missions

The Cosmic Origins (COR) and Physics of the Cosmos (PCOS) Program Offices (POs) reside at NASA GSFC and implement priorities for the NASA HQ Astrophysics Division (APD). One major aspect of the POs' activities is managing our Strategic Astrophysics Technology (SAT) program to mature technologies for future strategic missions. The Programs follow APD guidance on which missions are strategic, currently informed by the NRC's 2010 Decadal Survey report, as well as APD's Implementation Plan and the Astrophysics Roadmap.
In preparation for the upcoming 2020 Decadal Survey, the APD has established Science and Technology Definition Teams (STDTs) to study four large-mission concepts: the Origins Space Telescope, Habitable Exoplanet Imaging Mission, Large UV/Optical/IR Surveyor, and X-ray Surveyor. The STDTs will develop the science case and design reference mission, assess technology development needs, and estimate the cost of their concept. A fifth team, the L3 Study Team (L3ST), was charged to study potential US contributions to ESA's planned L3 gravitational-wave observatory.
The POs use a rigorous and transparent process to solicit technology gaps from the scientific and technical communities, and prioritize those entries based on strategic alignment, expected impact, cross-cutting applicability, and urgency. Starting in 2016, the technology-gap assessments of the four STDTs and the L3ST

are included in our process. Until a study team submits its final report, community-proposed changes to gaps submitted or adopted by a study team are forwarded to that study team for consideration. We discuss our technology development process, with strategic prioritization informing calls for SAT proposals and informing investment decisions. We also present results of this year's technology gap prioritization and showcase our current portfolio of technology development projects. To date, 77 COR and 80 PCOS SAT proposals have been received, of which 18 COR and 22 PCOS projects were funded (PCOS awards starting in 2017 have yet to be announced). For more information, see the respective Program Annual Technology Reports under the technology tabs of the COR website at cor.gsfc.nasa.gov and the PCOS website at pcos.gsfc.nasa.gov.

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238.02 – Ensuring the Enduring Viability of the Space Science Enterprise: New Questions, New Thinking, New Paradigms

Pursuing ground breaking science in a highly cost and funding constrained environment presents new challenges to the development of future space astrophysics missions. Within the conventional cost models for large observatories, executing a flagship "mission after next" appears to be unstainable. To achieve our nation's space astrophysics ambitions requires new paradigms in system design, development and manufacture. Implementation of this new paradigm requires that the space astrophysics community adopt new answers to a new set of questions. This paper will discuss the origins of these new questions and the steps to their answers.

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238.03 – Determination of the STIS CCD Gain

The Space Telescope Imaging Spectrograph (STIS) has been aboard the Hubble Space Telescope (HST) for almost 20 years. The STIS instrument team at Space Telescope Science Institute has continuously endeavored to provide high quality scientific data to the astronomical community, in part by monitoring the health and stability of the instrument. Because the change in gain value over time is a proxy for detector health, we measured the gain of the STIS CCD for amplifiers A, C and D using the mean-variance method, which has not been used to measure the CCD gain on STIS since before it was installed on HST. Here we present our methodology and results using data from the HST program 14424, which indicate a <3.5% change in the gain for amplifier D from when it was originally calculated pre-flight. We compare the various CCD gain measurements made over the history of STIS and discuss the extent to which the data and the different measurement techniques allow real changes to be distinguished from small systematic measurement errors. For the time being, we recommend the continued use of the currently adopted calibration pipeline values of 1.000 and 4.016 e-/DN for amplifier D at the nominal gain settings 1 and 4 e-/DN, respectively, as these are the values that were adopted when determining the other instrument calibrations.

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238.04 – HST Wide Field Camera 3: Instrument Status and Advice for Cycle 25 Proposers

The Wide Field Camera 3 on-board of the Hubble Space Telescope provides astronomers with powerful imaging and slitless spectroscopic capabilities from the near-ultraviolet (200 nm) to the near-infrared (1700 nm). We summarize the basic characteristics and performances of WFC3, highlight changes in the calibration pipeline, summarize the calibration program for Cycle 24, and provide new information useful for observers planning to apply for future science investigations.

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Contributing team(s): WFC3 Instrument Team

238.05 – Charge transfer efficiency in HST WFC3/UVIS: monitoring and mitigation

The UVIS channel of the Wide Field Camera 3 (WFC3) on the Hubble Space Telescope (HST) contains a 4096x4096 pixel e2v CCD array. The detectors have been performing well on-orbit but as expected, are exhibiting the cumulative effects of radiation damage. The result is a growing hot pixel population and declining charge transfer efficiency. We summarize the progression of the CTE losses, their effects on science data, and discuss two of the primary mitigation options: post-flash and a pixel-based CTE correction. The latter is now part of the automated WFC3 calibration pipeline in the Mikulski Archive for Space Telescopes (MAST), providing observers with both standard and CTE-corrected data products.

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Contributing team(s): WFC3 Team

238.06 – Low Frequency Flats for Imaging Cameras on the Hubble Space Telescope

We created a revamped Low Frequency Flat (L-Flat) algorithm for the Hubble Space Telescope (HST) and all of its imaging cameras. The current program that makes these calibration files does not compile on modern computer systems and it requires translation to Python. We took the opportunity to explore various methods that reduce the scatter of photometric observations using chi-squared optimizers along with Markov Chain Monte Carlo (MCMC). We created simulations to validate the algorithms and then worked with the UV photometry of the globular cluster NGC6681 to update the calibration files for the Advanced Camera for Surveys (ACS) and Solar Blind Channel (SBC). The new software was made for general usage and therefore can be applied to any of the current imaging cameras on HST.

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238.07 – Fermi Science Support Center Data Servers and Archive

The Fermi Science Support Center (FSSC) provides the scientific community with access to Fermi data and other products. The Gamma-Ray Burst Monitor (GBM) data is stored at NASA's High Energy Astrophysics Science Archive Research Center (HEASARC) and is accessible through their searchable Browse web interface. The Large Area Telescope (LAT) data is distributed through a custom FSSC interface where users can request all photons detected from a region on the sky over a specified time and energy range. Through its website the FSSC also provides planning and scheduling products, such as long and short term observing timelines, spacecraft position and attitude histories, and exposure maps. We present an overview of the different data products provided by the FSSC, how they can be accessed, and statistics on the archive usage since launch.

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Contributing team(s): FSSC, LAT Collaboration

238.08 – Wide Field Lyman alpha Geocoronal Simulator (WFLaGS) for the Far-uv Off Rowland-circle Telescope for Imaging and Spectroscopy (FORTIS)

At 23:52 on 17 December 2015 FORTIS (36.312 UG) was launched from the White Sands Missile Range in New Mexico on a mission to observe hydrogen emission and absorption features superimposed on the stellar continua of hot star formation regions in the spiral galaxy NGC 1365. Unfortunately scattered geocoronal Lyα from well outside our nominal (1/2 degree)^2 field-of-view (FOV) overwhelmed the signal from the target. Post-flight analysis of the observed scattered light levels, in comparison to a wide-FOV model of the light scattered from various surfaces in the optical train, produced good agreement. Suppression of this scatter is the highest priority for the FORTIS return to flight effort. Our analysis pointed to the need for development of a Wide Field Lyα Geocoronal Simulator (WFLaGS) with a 10° FOV to fully characterize the end-to-end response of FORTIS to off-axis illumination. Previous end-to-end testing was performed with a vacuum UV collimator with only a limited FOV, ≈ 100". The development of WFLaGS will allow us to validate our scattered light model and verify our mitigation strategies, which will incorporate low scatter materials, and possibly 3-d printed light traps, covering exposed scatter centers. The design of WFLaGs, consisting of a 50mm diameter F/1 aluminum parabolic collimator and a hydrogen discharge lamp with an ~ 80mm clear MgF_2 window is described, along with our initial turn-on tests. This work is supported by NASA grants to John Hopkins University, NNX11AG54G and NNX14AI78G.

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238.09 – LISA Pathfinder: A Summary of results to date

The LISA Pathfinder mission is an ESA-led mission with contributions from several European member states and NASA which has the primary purpose of validating technologies for a future space-based observatory of gravitational waves. Launched on Dec. 3rd, 2015, LPF has been conducting science operations since March 1st, 2016 and is now entering an extended mission phase that is expected to last unitl June 2016.
This poster will present an overview of the LPF results, the highlight of which is the exquiste measurement of differential acceleration at the femto-g level and interferometry at the femtometer level. In addition, I will describe auxilliary analyses that have been applied to the LPF data to search for impacts from micrometeorites and interactions with the Solar environment.

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Contributing team(s): LISA Pathfinder Team, LTP Team, DRS Team

238.10 – Build up and integration of the rocket-borne Cosmic Infrared Background ExpeRiment-2

The Cosmic Infrared Background ExpeRiment, CIBER-2, is a near-infrared rocket-borne instrument designed to conduct comprehensive multi-band measurements of extragalactic background light anisotropy on arcsecond to degree angular scales. Recent measurements of the near-infrared Extragalactic Background Light (EBL) anisotropy find excess spatial power above the level predicted by known galaxy populations at large angular scales. CIBER-2 is designed to make measurements of the EBL anisotropy with the sensitivity, spectral range, and spectral resolution required to disentangle the contributions to the EBL from various sources throughout cosmic history.

CIBER-2 consists of a 28.5 cm Cassegrain telescope assembly, imaging optics, and cryogenics mounted aboard a sounding rocket. Two dichroic beam-splitters spectrally subdivide the incident radiation into three optical paths, which are further subdivided in two wavelength bands per path, for a total of six observational wavelength bands that span the optical to the near-infrared and produce six 1.2 by 2.4 degree images recorded by three 2048 x 2048 HAWAII-2RG detector arrays. A small portion of each detector is also dedicated to absolute spectrophotometric imaging provided by a linear-variable filter. The instrument has several novel cryogenic mechanisms, a cryogenically-cooled pop-up baffle that extends during observations to provide radiative shielding and an electromagnetic cold shutter. We provide an overview of the instrument and current integration.

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238.11 – Near Ultraviolet Spectrograph for Cubesats

We have designed a near ultraviolet (200 - 400 nm) spectrograph to fit into a 2U CubeSat and planned for flight in mid-2017 with a scientific goal of obtaining NUV spectra of bright sources (< 6th magnitude) with a spectral resolution of 10 Å. The aggressive timeline drives the design to include only off-the-shelf items to minimize procurement delays and cost. Our baseline optical design consists of a collecting mirror with a 70 mm diameter which reflects light onto a concave reflection grating with a spacing of 1200 lines per mm. The grating focuses the light onto a linear array back-thinned FFT CCD with a pixel size of 14-µm × 14-µm.
We will present the design of the payload and the choices forced on us by the restrictive CubeSat environment and the short lead times. This payload is a part of our program to build payloads that will address limited scientific goals but making full use of the opportunities that are arising for CubeSat class missions.

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238.12 – The James Webb Space Telescope: Observatory Status Update

The James Webb Space Telescope (JWST) is a large (6.5 m) segmented aperture telescope equipped with near- and mid-infrared instruments (0.6-28 microns), all of which are passively cooled to ~40 K by a 5-layer sunshield while the mid-infrared instrument is actively cooled to 7 K. JWST is currently in the integration and test phase, with parallel activities on-going across the project. The current estimated JWST performance metrics will be presented, such as the image quality, pointing stability, sensitivity, and stray light backgrounds. The JWST development status and future schedule will be described for the full integration, launch, and commissioning.

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238.13 – WebbPSF for JWST and WFIRST

Modeling a telescope's point spread function accurately is key to predicting its performance and extracting information from observations. WebbPSF is a flexible Python-based PSF simulation tool for JWST and WFIRST, developed at STScI. The WebbPSF-WFIRST module implements a model for the proposed Wide Field Instrument, as well as a proof-of-concept model for the Coronagraph Instrument. Since its announcement and public release at the Winter 2016 AAS, WebbPSF-WFIRST has been enhanced with the Cycle 6 design updates to the wide field instrument model. Additionally, the JupyterHub-based WFIRST Tools Server effort at STScI has provided access to these tools for dozens of users without the overhead of installing the software locally. For JWST, the optical models have been updated based on the latest test data and metrology for the instruments and the telescope flight hardware, including as-built mirror surface figures, variation between different field points, and updated optical budgets for in flight performance. WebbPSF has been checked against instrument test data from previous campaigns, and analysis of the PSF images taken during the JWST CV3 cryo-vac test campaign is currently underway.

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238.14 – Cryo-Vacuum Testing of JWST's Integrated Telescope & Scientific Instrument Suite

A very exciting milestone in the development of the James Webb Space Telescope (JWST) is coming up this year: the eagerly-awaited cryo-vacuum test of the combination of the Optical Telescope Element (OTE) and the Integrated Science Instrument Module (ISIM). This combination, known as the OTIS (= OTE + ISIM) is soon to complete its ambient integration and test program at NASA's Goddard Space Flight Center. The cryo-vacuum test of this level of assembly will take place in historic Chamber A (a landmark from the Apollo era, refurbished and upgraded for JWST) at NASA's Johnson Space Center. We report here on the optical, thermal, and operational goals of the upcoming cryo-vacuum test program. We also highlight the results of the precursor "Pathfinder" test program, which in three extensive tests over the past two years has thoroughly validated the test equipment and procedures that will be needed for testing of the flight payload. These Pathfinder tests have provided invaluable experience to prepare the team for successful execution of the flight test program.

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238.15 – Starshade Orbital Maneuver Study for WFIRST

The Wide Field Infrared Survey Telescope (WFIRST) mission, scheduled for launch in the mid-2020s will perform exoplanet science via both microlensing surveys and direct imaging. Currently, an internal coronagraph is planned to perform starlight suppression for exoplanet imaging. Alternatively, an external starshade could be used to achieve the required high contrasts. A starshade could potentially have higher throughput than an equivalent coronagraph, would also have the benefit of a wavelength-independent inner working angle (IWA), and would remove the requirement of deformable mirrors in the telescope optics. The starshade approach would require a separately-launched occulter spacecraft to be positioned at exact distances from the telescope along the line of sight to a target star system. We perform a detailed study to quantify the Δv requirements and feasibility of deploying this additional spacecraft as a means of exoplanet imaging. The fuel use of the occulter can be categorized into two phases: station-keeping during imaging and repositioning between different targets. WFIRST is assumed to be in a halo orbit about the Sun-Earth L2 point with an out of plane amplitude of 250,000km. Based on its designed IWA, the occulter is given an offset distance from the nominal WFIRST orbit. Target star systems and look vectors are generated using Exoplanet Open-Source Imaging Simulator (EXOSIMS); a boundary value problem is then solved between successive targets. Given a list of possible targets, the minimum time and minimum Δv transfers are computed. These methods are used to estimate the number of possible observations that could be performed with the expected available fuel mass limit imposed by the likely occulter launch vehicle.

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238.16 – Science Advancements for Black Hole Binaries from Observations with NICER

The Neutron Star Interior Composiiton Explorer (NICER; 2017 launch) will advance investigations of black-hole physical properties and accretion physics in strong gravity, which are research themes that flourished during the RXTE era (1996-2012). One of the primary differences between NICER/XTI and RXTE/PCA Instruments is the energy response (0.2-12 keV vs 3-45 keV), with NICER affording a much more direct view of the inner accretion disk, where the maximum temperatures vary in the range 0.2-2 keV. In addition, NICER provides superior spectral resolution (140 eV at Fe K-alpha), superior time resolution (100 ns accuracy), lower background (by factor of 100), and full flexibility for data analyses (with complete information for each photon event). Finally the count rate from NICER's 56 cameras usually exceeds the count rates from RXTE (3 PCUs), except for sources obscured by very high levels of ISM column density (log Nh > 22).

Simulations are shown to support the following expectations for advancement: (1) comprehensive measures of the effective radius and temperature of the inner disk during black hole hard states and transitions; (2) visibility of the disk spectrum to constrain (as seed photons) Comptonization models to infer the properties of the corona;
(3) derivation of black hole spin via simultaneous use of the disk continuum and Fe line profile; (4) investigations of both high- and low-freqency QPOs in an energy range that samples both disk and corona; (5) partnerships with NuSTAR and ASTROSAT to use reflection spectra/timing to study the disk/corona geometry and interplay in different X-ray states.

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Contributing team(s): Nicer Science Team

238.17 – eLISA Telescope In-Field Pointing and Scattered Light Study

The orbital motion of the three spacecraft that make up the eLISA observatory constellation causes long-arm line of sight variations of approximately +/- one degree over the course of a year. The baseline solution is to package the telescope, the optical bench, and the gravitational reference sensor (GRS) into an optical assembly at each end of the measurement arm, and then to articulate the assembly. An optical phase reference is exchanged between the moving optical benches with a single mode optical fiber ("backlink" fiber). An alternative solution, referred to as in-field pointing, embeds a steering mirror into the optical design, fixing the optical benches and eliminating the backlink fiber, but requiring the additional complication of a two-stage optical design for the telescope. We compare the scattered light performance of a realistic in-field pointing design with a baseline telescope design.

This work was funded in part by NASA SAT grant 14-SAT14-0014.

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238.18 – Origins Space Telescope: Study Plan

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its spectrographs will enable 3D surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu. This presentation will provide a summary of the OST STDT, the OST Study Team based at NASA Goddard Space Flight Center, study partners, and the advisory panel to the study. This presentation will also summarize recent activities, including the process used to reach a decision on the mission architecture, the identification of key science drivers, and the key study milestones between 2017 and 2020.

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Contributing team(s): Origins Space Telescope Study Team

238.19 – Origins Space Telescope: Community Participation

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. This poster will outline the ways in which the astronomical community can participate in the STDT activities and a summary of tools that are currently available or are planned for the community during the study. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu.

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Contributing team(s): Origins Space Telescope Study Team

238.20 – Origins Space Telescope: Telescope Design and Instrument Specifications

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, one of the four science and technology definition studies of NASA Headquarters for the 2020 Astronomy and Astrophysics Decadal survey. The renaming of the mission reflects Origins science goals that will discover and characterize the most distant galaxies, nearby galaxies and the Milky Way, exoplanets, and the outer reaches of our Solar system. This poster will show the preliminary telescope design that will be a large aperture (>8 m in diameter), cryogenically cooled telescope. We will also present the specifications for the spectrographs and imagers over a potential wavelength range of ~10 microns to 1 millimeter. We look forward to community input into this mission definition over the coming year as we work on the concept design for the mission. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. We welcome you to contact the Science and Technology Definition Team (STDT) with your science needs and ideas by emailing us at firsurveyor_info@lists.ipac.caltech.edu.

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Contributing team(s): Origins Space Telescope Study Team

238.21 – Origins Space Telescope: Planet-forming disks and exoplanets

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu. This presentation will provide a summary of the science case related to planet formation and exoplanets. Leveraging orders of magnitude of improvements in sensitivity, the Origins Telescope will reveal the path of water from the interstellar medium to the inner regions of planet-forming disks, and determine the total masses of disks around stars across the stellar mass range out to distances of 500 pc. It will measure the temperatures and search for basic chemical ingredients for life on rocky planets. Beyond this, the Origins Telescope will open a vast discovery space in the general areas of star formation, protoplanetary and debris disks, and cool exoplanets in habitable zones.

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Contributing team(s): Origins Space Telescope Study Team

238.22 – Origins Space Telescope: Galaxy and Black Hole Evolution over Cosmic Time

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu. This presentation will provide a summary of the science case related to galaxy formation and evolution. Origins will investigate the connection between black hole growth and star formation, understand the role of feedback from supernovae and active galactic nuclei, probe the multiphase interstellar medium, and chart the rise of metals over cosmic time.

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238.23 – Origins Space Telescope: Solar System Science

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu.

In the Solar System, OST will provide km/sec resolution on lines from planet, moons and comets. OST will measure molecular abundances and isotope ratios in planets and comets. OST will be able to do continuum surveys for faint moving sources such as Kuiper Belt Objects, enabling a census of smaller objects in the Kuiper Belt. If the putative Planet IX is massive enough to be self-luminous, then OST will be able to detect it out to thousands of AU from the Sun.

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238.24 – Origins Space Telescope: Interstellar Medium, Milky Way, and Nearby Galaxies

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu.

This presentation will provide a summary of the science case related to the Interstellar Medium (ISM), the Milky Way, and Nearby Galaxies. Origins will enable a comprehensive view of magnetic fields, turbulence, and the multi-phase ISM; connecting physics at all scales, from galaxies to protostellar cores. With unprecedented sensitivity, Origins will measure and characterize the mechanisms of feedback from star formation and Active Galactic Nuclei (AGN) over cosmic time and trace the trail of water from interstellar clouds, to protoplanetary disks, to Earth itself in order to understand the abundance and availability of water for habitable planets.

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238.25 – The Space Infrared Telescope for Cosmology and Astrophysics and Pending US Contribution

SPICA is a cryogenic space-borne observatory designed for optimal sensitivity in the mid-infrared through submillimeter range: 17-250 microns. The mission is an ESA / JAXA collaboration, now under review in the ESA Cosmic Visions M5 opportunity, which has final approval in 2019, and launch in the late 2020 decade. SPICA will feature a 2.5-meter telescope cooled to below 8K, this offers the potential for 100-1000-fold advances in sensitivity beyond that obtained with Herschel and SOFIA in the far-IR. With a line sensitivity of ~5x10^-20 W/m^2 (1 h, 5 sigma), SPICA will be a complement to JWST and ALMA for deep spectroscopic observations.

Integrated over cosmic history, star formation has occurred predominantly in dust-obscured regions which are inaccessible in the rest-frame UV and optical. Both the luminosity history and the detailed physics that govern it can only be directly measured in the mid-IR-submillimeter. Similarly, forming stars and planetary systems cool primarily through the far-IR. By taking advantage of the low-background platform, the SPICA instruments are designed for these investigations. The SPICA mid-IR instrument (SMI) will provide R~50 imaging spectroscopy and R~1,000 full-band slit-fed spectroscopy from 17 to 36 microns, with a high-resolution (R=25,000) capability from 12-18 microns. The SPICA far-IR instrument (SAFARI) will cover 34 to at least 250 microns with multiple R~300 wide-band grating spectrometer modules coupling to high-sensitivity far-IR detectors. A R~3,000 scanned-etalon module will also be available for Galactic targets with bright continua and/or dense line spectra.

In the current SPICA division of responsibilities, ESA will take the lead role, provide the telescope, the fine-attitude sensor, and the spacecraft bus. JAXA will provide the cryogenic system, the SMI instrument, integrate the telescope and instruments, and provide the launch vehicle. The SAFARI instrument will be provided by a consortium funded by the European national agencies led by SRON. We highlight in this poster the far-IR detector and spectrometer contributions to SAFARI envisioned by our US team; this package is under review at NASA as a Mission of Opportunity.

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Contributing team(s): SPICA Consortium, SAFARI Consortium

238.26 – Depicting the MeV realm with the Compton Pair-Production Telescope (ComPair)

The energy band from a few hundred keV to a few hundred MeV offers a unique window for studying both thermal and the non-thermal astrophysical processes. Important science can be gleaned from investigations of emission mechanisms and environments of the most extreme objects that populate this mostly unexplored energy range.
The Compton-Pair Telescope (ComPair) is a next-generation mission concept building on the pioneering observations by COMPTEL, on the Compton Gamma-Ray Observatory, and the heritage of recent successful missions, such as Fermi-LAT, AGILE, AMS and PAMELA. With its capability of detecting both Compton-scattering events at lower energy and pair-production events at higher energy, ComPair can explore the energy regime from 0.2 keV to > 500 MeV with unprecedented sensitivity. We describe the concept of this wide-aperture instrument and discuss its power to address fundamental questions from a broad variety of astrophysical topics.

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Contributing team(s): ComPair Mission Team

238.27 – Cosmic Evolution Through UV Spectroscopy (CETUS): A NASA Probe-Class Mission Concept

CETUS is a probe-class mission concept proposed for study to NASA in November 2016. Its overarching objective is to provide access to the ultraviolet (~100-400 nm) after Hubble has died. CETUS will be a major player in the emerging global network of powerful, new telescopes such as E-ROSITA, DESI, Subaru/PFS, GMT, LSST, WFIRST, JWST, and SKA. The CETUS mission concept provisionally features a 1.5-m telescope with a suite of instruments including a near-UV multi-object spectrograph (200-400 nm) complementing Subaru/PFS observations, wide-field far-UV and near-UV cameras, and far-UV and near-UV spectrographs that can be operated in either high-resolution or low-resolution mode. We have derived the scope and specific science requirements for CETUS for understanding the evolutionary history of galaxies, stars, and dust, but other applications are possible.

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238.28 – Instrumental and Calibration Advancements for the Dark Ages Radio Explorer (DARE)

The Dark Ages Radio Explorer (DARE) is a space mission concept proposed to NASA to measure with high precision the monopole component of the redshifted 21-cm signal from neutral hydrogen originated during cosmic dawn at redshifts 35 > z > 11. For the 21-cm line, these high redshifts correspond to the frequency range 40-120 MHz. Through its spectral features, this signal will provide a wealth of information about the large-scale physics of the first stars, galaxies and black holes. The signal is expected to have an absolute amplitude below 200 mK, which is five orders of magnitude smaller than the diffuse foregrounds dominated by Galactic synchrotron radiation. In order to avoid the impact of the Earth's ionosphere, which corrupts low-frequency radio waves through refraction, absorption, and emission, this measurement is conducted from orbit above the far side of the Moon. This location is ideal because it enables the Moon to shield the spacecraft from

Solar radiation and terrestrial radio-frequency interference. The DARE instrument is designed around a dual-polarization, widefield, wideband, biconical antenna, which provides full-Stokes capabilities in order to measure and remove the low-level polarized component of the foregrounds. The spacecraft is rotated about its boresight axis at 1 RPM to modulate the foregrounds and separate them from the spatially uniform cosmological signal. The instrument requires exquisite calibration to reach a sensitivity of a few mK in the presence of strong foregrounds. For this purpose, the frequency-dependent antenna beam is characterized to 20 ppm. This is accomplished through a combination of electromagnetic simulations, anechoic chamber measurements, and on-orbit mapping using a calibrated high-power ground-based source. The DARE front-end receiver is characterized on the ground in terms of its input impedance, gain, noise properties, and stability. Its performance is verified when operating on-orbit at a fixed temperature, through bidirectional injection of pilot frequency tones that also allow to verify the stability of the antenna. All these instrumental and calibration advancements allow to precisely measure and characterize a wide range cosmological models.

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238.29 – A Modular Orbital Demonstration of an Evolvable Space Telescope (MODEST)

The “Search for Life” (direct imaging of earth-like planets) will require extremely stable telescopes with apertures in the 10 m to 20 m range. Such apertures are larger than what can be delivered to space using current or planned future launch vehicles. Building and assembling large telescopes in space is therefore likely to require not only multiple launches but importantly assembly in spce. As a result, space-based telescopes with large apertures will require major changes to our conventional telescope design and architecture.

Here we report on the concept for the Modular Orbital Demonstration of an Evolvable Space Telescope (MODEST) to demonstrates the on-orbit robotic and/or astronaut assembly of an optical telescope in space. MODEST is a proposed International Space Station (ISS demonstration that will make use of the standard Express Logistics Carriers (ELCs) and can mounted to one of a variety of ISS pallets.

MODEST will provides significant risk reduction for the next generation of space observatories, and demonstrates the technology needed to assemble a six-mirror phased telescope. Key modest features include the use of an active primary optical surface with wavefront feedback control to allow on-orbit optimization, and the precise surface control to meet optical system wavefront and stability requirements.

MODEST will also be used to evaluate advances in lightweight mirror and metering structure materials such as SiC or Carbon Fiber Reinforced Polymer (CFRP) that have excellent mechanical and thermal properties, e.g. high stiffness, high modulus, high thermal conductivity, and low thermal expansion. Mirrors built from these materials can be rapidly replicated in a highly cost effective manner, making them an excellent candidate for a low cost, high performance Optical Telescope Assembly paving the way for enabling affordable solutions for the next generation of large aperture space-based telescope.

MODEST post-assembly value includes space, ground, and environmental studies, a testbed for new instruments, and a tool for student’s exploration of space.

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238.30 – TeraHertz Space Telescope (TST)

The Terahertz Space Telescope (TST) utilizes breakthrough inflatable technology to create a ~25 m far-infrared observing system at a fraction of the cost of previous space telescopes. As a follow-on to *JWST* and *Herschel,* TST will probe the FIR/THz regime with unprecedented sensitivity and angular resolution, answering fundamental questions concerning the origin and destiny of the cosmos. Prior and planned space telescopes have barely scratched the surface of what can be learned in this wavelength region. TST will pick up where *JWST* and *Herschel* leave off. At ~30μm TST will have ~10x the sensitivity and ~3x the angular resolution of *JWST*. At longer wavelengths it will have ~1000x the sensitivity of *Herschel* and ~7 times the angular resolution. TST can achieve this at low cost through the innovative use of inflatable technology. A recently-completed NIAC Phase II study (Large Balloon Reflector) validated, both analytically and experimentally, the concept of a large inflatable spherical reflector and demonstrated critical telescope functions. In our poster we will introduce the TST concept and compare its performance to past, present, and proposed far-infrared observatories.

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238.31 – Linear-constraint wavefront control for exoplanet coronagraphic imaging systems

A coronagraph is a leading technology for achieving high-contrast imaging of exoplanets in a space telescope. It uses a system of several masks to modify the diffraction and achieve extremely high contrast in the image plane around target stars. However, coronagraphic imaging systems are very sensitive to optical aberrations, so wavefront correction using deformable mirrors (DMs) is necessary to avoid contrast degradation in the image plane. Electric field conjugation (EFC) and Stroke minimization (SM) are two primary high-contrast wavefront controllers explored in the past decade. EFC minimizes the average contrast in the search areas while regularizing the strength of the control inputs. Stroke minimization calculates the minimum DM commands under the constraint that a target average contrast is achieved. Recently in the High Contrast Imaging Lab at Princeton University (HCIL), a new linear-constraint wavefront controller based on stroke minimization was developed and demonstrated using numerical simulation. Instead of only constraining the average contrast over the entire search area, the new controller constrains the electric field of each single pixel using linear programming, which could led to significant increases in speed of the wavefront correction and also create more uniform dark holes. As a follow-up of this work, another linear-constraint controller modified from EFC is demonstrated theoretically and numerically and the lab verification of the linear-constraint controllers is reported. Based on the simulation and lab results, the pros and cons of linear-constraint controllers are carefully compared with EFC and stroke minimization.

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238.32 – Soft x-ray transmission grating spectrometer for X-ray Surveyor and smaller missions with high resolving power

A number of high priority subjects in astrophysics are addressed by a state-of-the-art soft x-ray grating spectrometer, e.g. the role of Active Galactic Nuclei in galaxy and star formation, characterization of the WHIM and the “missing baryon” problem, characterization of halos around the Milky Way and nearby galaxies, and stellar coronae and surrounding winds and disks. An Explorer-scale, large-area (A > 1,000 cm2), high resolving power (R > 3,000) soft x-ray grating spectrometer is highly feasible based on Critical-Angle Transmission (CAT) grating technology, even for telescopes with angular resolution of 5-10 arcsec. Significantly higher performance could be provided by a CAT grating spectrometer on an X-ray-Surveyor-type mission (A > 4,000 cm2, R > 5,000). CAT gratings combine advantages of blazed reflection gratings (high efficiency, use of higher orders) with those of transmission gratings (low mass, relaxed alignment tolerances and temperature requirements, transparent at higher energies) with minimal mission resource requirements. Blazing is achieved through grazing-incidence reflection off the smooth silicon grating bar sidewalls. Silicon is well matched to the soft x-ray band, and 30% absolute diffraction efficiency has been acheived with clear paths for further improvement. CAT gratings with sidewalls made of high-Z elements allow extension of blazing to higher energies and larger dispersion angles, enabling higher resolving power at shorter wavelengths. X-ray data from CAT gratings coated with a thin layer of platinum using atomic layer deposition demonstrate efficient blazing to higher energies and much larger blaze angles than possible with silicon alone. Measurements of the resolving power of a breadboard CAT grating spectrometer consisting of a Wolter-I slumped-glass focusing optic from GSFC and CAT gratings, taken at the MSFC Stray Light Facility, have demonstrated resolving power > 10,000. Thus currently fabricated CAT gratings are compatible with the most advanced grating spectrometer instrument designs for future soft x-ray spectroscopy missions. We will review the most recent CAT grating fabrication and x-ray test results.

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238.33 – Lightweight ZERODUR®: Validation of mirror performance and mirror modeling predictions

Upcoming spaceborne missions, both moderate and large in scale, require extreme dimensional stability while relying both upon established lightweight mirror materials, and also upon accurate modeling methods to predict performance under varying boundary conditions. We describe tests, recently performed at NASA's XRCF chambers and laboratories in Huntsville Alabama, during which a 1.2m diameter, f/1.29 88% lightweighted SCHOTT lightweighted ZERODUR® mirror was tested for thermal stability under static loads in steps down to 230K. Test results are compared to model predictions, based upon recently published data on ZERODUR®. In addition to monitoring the mirror surface for thermal perturbations in XRCF Thermal Vacuum tests, static load gravity deformations have been measured and compared to model predictions. Also the Modal Response (dynamic disturbance) was measured and compared to model. We will discuss the fabrication approach and optomechanical design of the ZERODUR® mirror substrate by SCHOTT, its optical preparation for test by Arizona Optical Systems (AOS), and summarize the outcome of NASA's XRCF tests and model validations.

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238.34 – Use of Plasma Enhanced ALD to Construct Efficient Interference Filters for Astronomy in the FUV - Year 2 Update

Over the past few years the advent of atomic layer deposition (ALD) technology has opened new capabilities to the field of coatings deposition for use in optical elements. At the same time, there have been major advances in both optical designs and detector technologies that can provide orders of magnitude improvement in throughput in the far ultraviolet (FUV) and near ultraviolet (NUV) passbands. Recent review work has shown that a veritable revolution is about to happen in astronomical diagnostic work for targets ranging from protostellar and protoplanetary systems, to the intergalactic medium that feeds gas supplies for galactic star formation, and supernovae and hot gas from star forming regions that determine galaxy formation feedback. These diagnostics are rooted in access to a forest of emission and absorption lines in the ultraviolet (UV), and all that prevents this advance is the lack of throughput in such systems, even in space-based conditions. We are pursuing an approach to use a range of materials to implement stable optical layers suitable for protective overcoats with high UV reflectivity and unprecedented uniformity, and to use that capability to leverage innovative ultraviolet/optical filter construction to enable astronomical science. These materials will be deposited in a multilayer format over a metal base to produce a stable construct. Specifically, we are employing PEALD (plasma-enhanced atomic layer deposition) methods for the deposition and construction of reflective layers that can be used to construct unprecedented filter designs for use in the ultraviolet. Our paper reports on our work as we enter year 2 of our 3-year program.

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238.35 – An Exploration of Software-Based GNSS Signal Processing at Multiple Frequencies

The Global Navigation Satellite System (GNSS; i.e., GPS, GLONASS, Galileo, and other constellations) has recently grown into numerous areas that go far beyond the traditional scope in navigation. In the geosciences, for example, high-precision GPS has become a powerful tool for a myriad of geophysical applications such as in geodynamics, seismology, paleoclimate, cryosphere, and remote sensing of the atmosphere. Positioning with millimeter-level accuracy can be achieved through carrier-phase-based, multi-frequency signal processing, which mitigates various biases and error sources such as those arising from ionospheric effects. Today, however, most receivers with multi-frequency capabilities are highly specialized hardware receiving systems with proprietary and closed designs, limited interfaces, and significant acquisition costs. This work explores alternatives that are entirely software-based, using Software-Defined Radio (SDR) receivers as a way to digitize the entire spectrum of interest. It presents an overview of existing open-source frameworks and outlines the next steps towards converting GPS software receivers from single-frequency to dual-frequency, geodetic-quality systems. In the future, this development will lead to a more flexible multi-constellation GNSS processing architecture that can be easily reused in different contexts, as well as to further miniaturization of receivers.

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238.36 – Origins Space Telescope: Cosmology and Reionization

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu.

A core science goal of the OST mission is to study the the cosmological history of star, galaxy, and structure formation into the epoch of reionization (EoR). OST will probe the birth of galaxies through warm molecular hydrogen emission during the cosmic dark ages. Utilizing the unique power of the infrared fine-structure emission lines, OST will trace the rise of metals from the first galaxies until today. It will quantify the dust enrichment history of the Universe, uncover its composition and physical conditions, reveal the first cosmic sources of dust, and probe the properties of the earliest star formation. OST will provide a detailed astrophysical probe into the condition of the intergalactic medium at z > 6 and the galaxies which dominate the epoch of reionization.

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239 – Making Great Observatories Even Better: Hubble's Hand in Studying the Multi-Wavelength Universe Poster Session

239.01 – A Multiwavelength Study of Three Hybrid Blazars

Hybrid active galactic nuclei (AGN) are rare objects that show jet morphology like that of low-power, Fanaroff-Riley Type I (FR-I) AGN on one side of the central black hole and that of high-power, FR-II AGN on the other. As such, they offer an excellent opportunity to study the physical causes of differences between FR-I and FR-II AGN, but so far very few have been well studied. We obtained new Hubble Space Telescope and Chandra X-ray Observatory observations plus archival Very Long Baseline Array (VLBA) and Very Large Array observations of three hybrid AGN to study their spectral energy distributions and model the emission mechanisms of their jets, knots, and hotspots. Based on our parsec-scale VLBA radio observations, these sources have jets that are highly aligned with the line of sight, and the FR-I morphology jet is pointing toward the observer for two of the sources, and the FR-II jet is for the third. Regardless of these alignment differences, all three yielded only optical upper limits on their jet emission, which definitively rules out a single synchrotron emission mechanism for radio through X-ray energies and implies that their emission mechanisms are more similar to FR-II AGN. Additionally, all three sources show high total radio power typical of FR-II AGN. When these 3 AGN are considered alongside the 10 previously well-studied hybrid AGN, a trend emerges that the majority have approaching FR-I morphology jets with FR-II emission mechanisms. In all 13 cases, the X-ray emission is found in the approaching jet. This raises unresolved questions regarding these sources, highlighting the need for additional multifrequency observations of hybrid AGN.

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239.02 – A Multi-Observatory View of the Alpha Persei Coronal Conundrum

A *ROSAT* pointed survey of the Alpha Per open cluster in the 1990's detected its brightest star, mid-F supergiant α Persei, with an X-ray luminosity and spectral hardness similar to coronally active late-type dwarf members. Later, in 2010, a *Hubble* Cosmic Origins Spectrograph SNAPshot observation of α Per found far-ultraviolet (FUV) coronal-proxy emissions (specifically Si IV 1393 Å) unexpectedly weak. Together with a slight, but suspicious, offset of the *ROSAT* source, these anomalies raised the possibility that an unrecognized late-type companion might be responsible for the coronal X-rays. Recently, a multi-observatory program was carried out to test that premise; on the one hand to directly detect the putative companion, but on the other to better characterize the FUV spectrum of α Per in case it also was captured in X-rays. Initially, ground-based optical coronography from the Apache Point 3.5m, and later near-UV imaging with *HST* Wide Field Camera 3, searched for any close-in faint objects that plausibly could be significant X-ray emitters, but without success. Then, a *Chandra* pointing showed that the X-ray source is single and coincident with the bright star. In tandem, *HST* COS collected a much deeper FUV spectrum of α Per than the earlier brief SNAP. In hindsight, F supergiant Canopus (α Car: F0 Ib) also has a high X-ray luminosity and the same type of low Si IV/X-ray index as α Per. Significantly, the FUV Si IV emissions of both α Per and Canopus align well with the chromospheric atomic oxygen emissions (which must be intrinsic to the luminous stars), within the context of cooler late-F and early-G supergiants, including Cepheid variables. This pointed to the X-rays as the fundamental anomaly. Ironically, the over-luminous X-rays still support the case for a hyperactive dwarf secondary, albeit now spatially unresolved. However, an equally viable alternative is that both F supergiants are members of a novel class of X-ray emitters. Resolving the first possibility now has become more difficult, because the easy solution -- a well separated hyperactive companion -- has been eliminated; while testing the second will require a broader high-energy census of the early-F supergiant class.

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239.03 – The era of *synoptic galactic archeology*: using HST and Chandra observations to constrain the evolution of elliptical galaxies through the spatial distribution of globular clusters and X-ray binaries.

Most of the stellar mass observed today in early-type galaxies is thought to be due to merging and accretion of smaller companions, but the details of these processes are still poorly constrained. Globular clusters, visible from the center to the halo of galaxies, reflect the evolution of their host galaxy in their kinematic, photometric and spatial distributions. By characterizing the spatial distribution of the population of globular clusters extracted from archival HST data of some of the most massive elliptical galaxies in the local Universe with a novel statistical approach, we recently discovered that two-dimensional spatial structures at small radii are common (D'Abrusco et al. 2014a; 2014b; 2015). Such structures, not detectable from ground-based data, can be linked to events in the evolution of the host galaxy. Moreover, we devised an interpretative framework that, based on the form, area and number of globular clusters of such structures, infers the frequency of major mergers and the mass spectrum of the accreted companions.

For some of the galaxies investigated, X-ray data from Chandra joint observing programs were also available. Our method, applied to the distribution of X-ray binaries, has revealed, at least in the case of two galaxies (D'Abrusco et al. 2014a; D'Abrusco et al.23014c) the existence of overdensities that are not associated to globular cluster structures. These findings provide complementary hints about the evolution of the stellar component of these galaxies that can be used to further refine the sequence of events that determined their growth.

In this contribution, we will summarize our main results and highlight the novelty of our approach. Furthermore, we will advocate the fundamental importance of joint observations of galaxies by HST and Chandra as a way to provide unique, complementary views of such systems and unlock the mysteries of their evolution.

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239.04 – An Ultraviolet Counterpart to the Fast X-ray Outflow in the Quasar PG1211+143

We observed the quasar PG1211+143 using the Cosmic Origins Spectrograph on the Hubble Space Telescope in April 2015. Our ultraviolet spectra cover the wavelength range 912--2100 A. We find a broad absorption feature (FWHM~1100 km/s) at an observed wavelength of 1240 A. In the rest frame of PG1211+143 (z=0.081), this corresponds to an outflowing velocity of 0.05807+-0.0003 c, similar to the moderate ionization X-ray absorption system at v~0.066+-0.003 c seen by Pounds et al. (2016) in a 2014 XMM-Newton observation. This feature is weak or absent in archival ultraviolet spectra of PG1211+143, strongly suggesting that this absorption is transient, and intrinsic to PG1211+143.

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239.05 – The Survey of HI in Extremely Low-mass Dwarfs: A Multi-Wavelength Perspective on Low-Mass Galaxy Evolution

The "Survey of HI in Extremely Low-mass Dwarfs" (SHIELD) is a multiwavelength study of local volume low-mass galaxies drawn from the *Arecibo Legacy Fast ALFA* (ALFALFA) catalog. HST/Spitzer joint program GO-12658 revealed the stellar populations of the first 12 SHIELD galaxies (Cannon et al. 2011), allowing accurate distance measurements (McQuinn et al. 2014) and detailed studies of the patterns of recent star formation in each galaxy (McQuinn et al. 2015). These HST and Spitzer images are a critical interpretive benchmark for ground-based optical imaging and spectroscopy (Haurberg et al. 2015), as well as for sensitive VLA HI spectral line imaging of the SHIELD galaxies (McNichols et al. 2016; Teich et al. 2016). These results have furthered our understanding of the evolution of galaxies in a mass regime that was previously only sparsely populated. With the low-redshift ALFALFA catalog now complete, the scope of the SHIELD program has been expanded to include all 82 galaxies that meet distance, line width, and HI flux criteria for being gas-rich, low-mass galaxies. In HST program 13750, images of 18 more SHIELD galaxies have again set the physical scales for supporting HI spectral line imaging with both the VLA and the WSRT (Gordon et al. 2016). Taken as a whole, the ongoing SHIELD program is one of the most comprehensive multiwavelength studies of the physical properties of low-mass galaxies outside of the Local Group.

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240 – Cool Stars & Others: Surveys, Spectra, Rotation, Fundamentals Poster Session

240.01 – Photometry and Kinematics of Ultracool Dwarfs in the Pan-STARRS 3pi Survey

The Pan-STARRS 1 3π Survey (PS1) has observed the entire sky north of −30° in five optical bands (*grizy*) over an average of 12 epochs spanning four years, generating an exceptional new resource for discovering and characterizing ultracool dwarfs. We present our analysis of the PS1 photometry and proper motions of over 2,000 M, L, and T dwarfs, building a comprehensive picture of the local ultracool population. We highlight ultracool binaries, subdwarfs, and young objects in our analysis, identifying features that distinguish them from the field population.

Author(s): William M. J. Best1, Eugene A. Magnier1, Michael C. Liu1, Kimberly Mei Aller1, Zhoujian Zhang1
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240.02 – A Pan-STARRS1 Proper-Motion Survey for Young Brown Dwarfs in the Taurus and the Upper Scorpius Star-Forming Regions

Young brown dwarfs are of prime importance to investigate the universality of the initial mass function (IMF) and to understand the physical connections between substellar and planetary-mass objects. Pan-STARRS1 (PS1) 3π survey (δ ≥ -30°) is finished and has obtained stacked images reaching down to the planetary regime (≤ 13 M_{Jup}) in nearby star-forming regions, thus providing an innovative tool to search for brown dwarfs. Using photometry and astrometry from PS1, WISE, 2MASS and UKIDSS, we are performing the widest and deepest brown dwarf survey in Taurus (≈370 deg^2, ~1 Myr) and Upper Scorpius (USco, ≈450 deg^2, ~10 Myr), which are among the closest star-forming regions. Our work is the first to measure proper motions, a robust proxy of membership, for Taurus and USco brown dwarf candidates over such large area and long time baseline (~13 yr by combining PS1 and 2MASS). Our spectroscopic follow-up has found the lowest-mass objects in both regions (Taurus: ≈ 6 M_{Jup}; USco: ≈ 14 M_{Jup}), and has yielded a success rates of ≈ 80% and ≈ 90% in Taurus and USco, respectively, far better than any previous searches (≤ 50%). Our newly confirmed members have already added ≈ 60% more brown dwarfs in USco and more than doubled the number of L-type members (≤ 20 M_{Jup}) in both regions. Upon completion, our discoveries will be a significant addition to the substellar regimes of the Taurus and the USco IMF and will provide more benchmarks to investigate the compositions of substellar and planetary atmospheres.

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240.03 – DECam Survey for Substellar and Low-mass Stellar Members of Sco-Cen

We present the results of a DECam imaging survey for low-mass stellar and substellar objects in the nearby Sco-Cen OB association. The DECam survey was taken in izY bands in 2013 and 2015 and covered $\sim$87 deg^2 in the two nearest and oldest subgroups, Upper Cen-Lup ($\sim$142 pc) and Lower Cen-Cru ($\sim$118 pc; both with mean ages $\sim$16 Myr). Using color-magnitude and proper motion selection, we identify 391 candidate Sco-Cen members with masses ranging from near the D-burning limit of $\sim$13 M$_{Jup}$, through the H-burning limit, up to $\sim$0.4 M$_\odot$. Our initial spectroscopic follow-up with the ARCoIRIS and COSMOS spectrographs for 19 objects have yielded young M dwarfs showing signatures of low surface-gravity. Our survey yields the first constraints on the substellar and low-mass initial mass function and disk fraction in the two oldest Sco-Cen subgroups, and will yield a large sample of young, low-surface gravity M and L-type objects of constrained age, distance, and chemical composition. We acknowledge support from NSF award AST-1313029 and the REU Site in Physics and Astrophysics at the University of Rochester supported by NSF award PHY-1156339.

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240.04 – Your Age is Showing: Understanding the Spectral Features of Young Brown Dwarfs

Brown dwarfs are substellar objects that continuously cool, shrink, and fade over billions of years. These physical changes lead us to expect that young objects will have spectral indicators of low gravity. We selected 11 brown dwarfs ranging in spectral type from M7-L7 whose optical and/or low resolution NIR spectroscopy suggest that they are low gravity, hence young, objects. Using high-resolution (R~20,000) near-infrared data from the NIRSPEC instrument at the Keck II telescope in Hawaii, we analyzed J-band (1.1-1.4 μm) spectra of these targets. We calculated their radial velocities and combined those values with previously calculated parallax distances and proper motions to determine their likelihood of membership in nearby young moving groups, successfully placing three of them. We also compared our high-resolution spectra to observations of confirmed young (<500 Myr old) and field age (1-5 Gyr old) brown dwarfs. We examined differences in the gravity-sensitive potassium (K I) lines at 1.175 μm and 1.25 μm both qualitatively and quantitatively. By analyzing the high resolution spectroscopy of these candidate young brown dwarfs we can evaluate the consistency of spectral indicators of youth across spectral type, age, resolution, and wavelength regime.

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240.05 – Principal Component Analysis of Brown Dwarfs

Principal component analysis is a technique for reducing variables and emphasizing patterns in a data set. In this study, the data set consisted of the attributes of 174 brown dwarfs. The PCA was performed on several photometric measurements in near-infrared wavelengths and colors in order to determine if these variables showed a correlation with the physical parameters. This research resulted in two separate models that predict luminosity and temperature. The application of principal component analysis on the near-infrared photometric measurements and colors of brown dwarfs, along with models, provides alternate methods for predicting the luminosity and temperature of brown dwarfs using only photometric measurements.

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240.06 – Comparison of BT Settl Model Spectra in NIR to Brown Dwarfs and Massive Exoplanets

Brown dwarfs and giant exoplanets are difficult to observe, which hampers our understanding of their properties. Model spectra, such as the BT Settl model grid, can provide an opportunity to augment and validate our understanding of these faint objects by serving to contrast and complement our analysis of their observed spectra. We present work from an upcoming paper that leverages this opportunity. The near infrared (NIR) wavelength region is favorable for analysis of low mass brown dwarfs and high mass gaseous companions, in particular the *K* band (1.97 - 2.40 μm) due to its relatively high resolution and high signal-to-noise ratio wavelength range for spectra of planetary companions. We present a method to analyze two regions of the *K* band spectral structure (2.03 - 2.10 μm and 2.215 - 2.290 μm), and apply it to a sample of objects with field gravity, low gravity, and planetary mass as well as the BT Settl model grid for a similar range of effective temperatures and surface gravities. A correlation between spectral structure and effective temperature is found for the shorter wavelength region and there is evidence of gravity dependence for the longer wavelength range. This work suggests that the *K* band has the potential to be an indicator for brown dwarf and exoplanet surface gravity and effective temperature. We also present preliminary analysis from another upcoming paper. We examine equivalent widths of K I absorption lines at 1.1693 μm, 1.1773 μm, 1.2436 μm and 1.2525 μm in a selection of L dwarfs to explore their physical properties by comparing them to equivalent measurements in the BT Settl model grid.

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240.07 – Spectral Variability at the L/T Transition and Beyond

We present HST/WFC3 spectral time series (1-1.7 microns) of 3 variable brown dwarfs. The targets consist of 2 L/T transition brown dwarfs whose large photometric variability is thought to arise due to patchy cloud coverage, and one unusually blue mid-L dwarf that displays lower levels of variability. The observations add significantly to the number of L/T transition objects that have been monitored with WFC3, and allow us to test whether emerging trends (e.g. muted variability in the water absorption band) are shared by all L/T transition objects, indicative of common cloud structures and number of surface components. Furthermore, the spectral response of the blue L-dwarf is compared to those of the L/T transition brown dwarfs in order to investigate whether similar cloud structures are responsible for its variability and unusual colors. Our results suggest that spectral variability of L/T transition dwarfs is not uniform within this population, and that a wider range of heterogeneous cloud structures are required to explained the strong variations observed at these spectral types.

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240.08 – Too Cool for Stellar Rules: A Bayesian Exploration of Trends in Ultracool Magnetism

Ultracool dwarfs, the lowest mass red dwarfs and brown dwarfs (spectral types M7–Y9), are fully convective objects with electrically neutral atmospheres due to their extremely cool temperatures (500–3000 K). Radio observations of ultracool dwarfs indicate the presence of magnetic field strengths on the order of ~kG, however the dynamo driving these fields is not fully understood. To better understand ultracool dwarf magnetic behavior, we analyze photometric radio detections of 196 dwarfs (spectral types M7–T8), observed in the 4.5–8.5 GHz range on the Karl G. Jansky Very Large Array (VLA) and the Australia Telescope Compact Array (ATCA). The measurements in our sample are mostly upper limits, along with a small percentage of confirmed detections. The detections have both large uncertainties and high intrinsic scatter. Using Bayesian analysis to fully take advantage of the information available in these inherently uncertain measurements, we search for trends in radio luminosity as a function of several fundamental parameters: spectral type, effective temperature, and rotation rate. In this poster, we present the preliminary results of our efforts to investigate the possibility of subpopulations with different magnetic characteristics using Gaussian mixture models.

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Contributing team(s): BDNYC

240.09 – The Search for Signatures Of Transient Mass Loss in Active Stars

In order to understand habitability of exoplanets, we must understand their environments and how their host star shapes them. Stellar eruptive events are an important factor when considering habitability. The lack of experimental evidence necessitates the heavy reliance on solar scaling relationships when determining the impact of stellar eruptive events. Typically, stellar eruptive events cannot be observed in the same manner as solar events. The research we are conducting is proposing a new method for detecting Coronal Mass Ejections (CMEs), which are a type of stellar eruptive event. As CMEs travel through the stellar atmosphere, they are able to produce a Type II radio burst. Observation of Type II radio burst is the best method to identify and categorize CMEs. The LOw Frequency ARray (LOFAR) provides a means for detecting this event. Fifteen hours of observation on YZ Canis Minoris (YZ CMi), a nearby M dwarf flare star, was used to test this method. Ongoing research about jointly observed flares and CMEs is discussed to further expand the methodology. We explore using solar multi-wavelength observations to provide greater constraints on CMEs and further test the applicability of solar scaling relationships. We determine how well the velocity, mass, and CME kinetic energy can be constrained using the types of datasets available to stellar astronomers when compared to direct corona graphic solar observations.

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240.10 – H_2 Fluorescence in M dwarf Systems: A Stellar Origin

Observations of Lyα-driven H_2 fluorescence can be a useful tool for measuring the abundance of H_2 in exoplanet atmospheres. This emission has been previously observed in M dwarfs with planetary systems but at too low of a signal to determine its origin. It may have been originating in the atmospheres of planets, but conditions within these systems also mean that the H_2 could be residing on the stellar surface or in a circumstellar disk. We use observations from the ``Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanet Host Stars" (MUSCLES) *Hubble Space Telescope* (*HST*) Treasury Survey to study H_2 fluorescence in M dwarfs with and without confirmed planets to determine the origin of the emission. The results are further supported by the direct imaging of a candidate M dwarf system using the *HST*-Advanced Camera for Surveys/Solar Blind Channel. We constrain the location of the fluorescing H_2 through analysis of the line profiles and determine that the emission is originating on the star. We verify that this interpretation is consistent with 1D radiative transfer models that are optimized using the spectra of the MUSCLES stars and find that the H_2 likely resides in starspots or a cool region of the lower chromosphere.

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240.11 – Modeling molecular hydrogen emission in M dwarf exoplanetary systems

Exoplanets orbiting low-mass stars are prime candidates for atmospheric characterization due to their astronomical abundance and short orbital periods. These planets orbit stars that are often more active than main sequence solar-type stars. They are exposed to differing levels of ultraviolet radiation which can cause traditional “biosignature” gases to be generated abiotically, potentially causing false-positive identifications of life. We modeled the recently discovered molecular hydrogen emission in the ultraviolet spectra (1350 – 1650 Å) as arising from the stellar surface, excited by radiation generated in the upper chromosphere. The model was compared with observed hydrogen emission from the “Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanet host Stars” (MUSCLES) survey by conducting a grid search and implementing a chi-squared minimization routine. We considered only progressions from the [1, 4] and [1, 7] first excited electronic levels. Our modeling procedure varied the atomic hydrogen column density (in the chromosphere) as well as the photospheric molecular hydrogen column density and temperature. The model required as an input a reconstructed intrinsic Lyman α profile which served as the pumping radiation for the molecular hydrogen. We found that an atomic hydrogen column density of $\log_{10}N(\mathrm{H\ I}) = 14.13 \pm 0.16\ \mathrm{cm}^{-2}$ represents a breaking point above which there is not enough Lyman α flux available to excite a significant molecular hydrogen population into the [1, 7] state. We also present H_2 temperatures which may suggest that star spots on low mass stars persist longer, and encompass more area than star spots on solar-type stars.

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Contributing team(s): Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanet host Stars (MUSCLES)

240.12 – Tuning Into Brown Dwarfs: Long-Term Radio Monitoring of Two Very Low Mass Dwarfs

The very lowest-mass (VLM) stars and brown dwarfs, with effective temperatures T < 3000 K, exhibit mixed magnetic activity trends, with H-alpha and X-ray emission that declines rapidly beyond type M7/M8, but persistent radio emission in roughly 10-20% of sources. The dozen or so VLM radio emitters known show a broad range of emission characteristics and time-dependent behavior, including steady persistent emission, periodic oscillations, periodic polarized bursts, and aperiodic flares. Understanding the evolution of these variability patterns, and in particular whether they undergo solar-like cycles, requires long-term monitoring. We report the results of a long-term JVLA monitoring program of two magnetically-active VLM dwarf binaries, the young M7 2MASS 1314+1320AB and older L5 2MASS 1315-2649AB. On the bi-weekly cadence, 2MASS 1314 continues to show variability by revealing regular flaring while 2MASS 1315 continues to be a quiescent emitter. On the daily time scale, both sources show a mean flux density that can vary significantly just over a few days. These results suggest long-term radio behavior in radio-emitting VLM dwarfs is just as diverse and complex as short-term behavior.

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240.13 – Knowing Our Neighbors: Four New Nearby High Proper Motion Systems

Obtaining a well-understood, volume-limited (and ultimately volume-complete) sample of stellar systems within 25 pc is essential for determining the stellar luminosity function, the mass-luminosity relationship, the stellar velocity distribution, and the stellar multiplicity fraction. Such a sample also provides insight into the local star formation history. Towards that end, the Research Consortium On Nearby Stars (RECONS) team measures trigonometric parallaxes to establish which systems truly lie within the 25-pc radius of the Solar Neighborhood. Recent astrometric measurements with the CTIO/SMARTS 0.9-m telescope establish three high proper motion systems as members (2MASS J02511490-0352459, 2MASS J15345704-1418486, and 2MASS J09211410-2104446) and confirm a fourth (2MASS J23062928-0502285).

All four proper motions exceed 0.9”/yr. 2MA0251 travels 2.1497±0.0009”/yr in 149.20±0.05° at a distance of 11.0±0.4 pc. 2M2306 moves 1.0344±0.0007”/yr in 118.50±0.08° at a distance of 12.7±0.2 pc. 2MA1534 goes 0.9726±0.0004”/yr in 251.50 ±0.05° at a distance of 10.93±0.10 pc. 2MA0921 shifts 0.9489±0.0003”/yr in 164.70±0.04° at a distance of 12.3±0.2 pc. The corresponding tangential velocities are 112.4, 62.4, 50.4, and 55.5 km/s whereas the median for parallaxes previously published by RECONS is 53 km/s. With radial velocities in the literature of -75.5 to 80.53 km/s, none of these is a candidate member of any young moving groups.
To characterize these late M–early L systems more fully, RECONS obtained *VRI* photometry; their *I* -band magnitudes range from 14.10 to 16.55. Over their astrometric baselines of 7.75 to 8.99 years, these demonstrated long-term *I*-band variability of 0.0135 mag. or less, indicating they may be older systems.
With each new confirmation, we come closer to completing the census of the Solar Neighborhood.
NSF grants AST 05-07711 and AST 09-08402, NASA-SIM, Georgia State University, the University of Virginia, Hampden-Sydney College, and the Levinson Fund of the Peninsula Community Foundation supported this research. CTIOPI was an NOAO Survey Program and continues as part of the SMARTS Consortium. We

thank the SMARTS Consortium and the CTIO staff, who enable the small telescope operations at CTIO.

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240.14 – Characterization of Low-mass K2 planet hosts using Near-Infrared Spectroscopy

The raw number of discovered exoplanets now exceeds several thousand, but we must understand the stars if we aim to understand their planets in detail. Of particular interest are M dwarf stars, which are often favored for exoplanet study because (1) they host small planets in greatest abundance, (2) they make up about 70% of stars in our galaxy, and (3) the planets that orbit them that are comparatively easier to find and study than planets around larger stars. Our work aims to characterize the infrared spectra of 50 M dwarfs with new and unstudied transiting planets discovered by NASA's K2 Mission. We employ empirical relations from the literature with magnesium, aluminum and sodium absorption lines in H and K band to determine the temperatures, radii and luminosities. In addition, we measure the deformation of the spectra in K band by water (another empirical metric for M dwarfs) which, in tandem with absorption features, is linked to [Fe/H] metallicity. We have found from a preliminary sample of 36 stars, that the temperatures range from 2,900 to 4,100 K, with radii between 0.2 $R_\odot$ to 0.6$R_\odot$ and log($L/L_\odot$) values from -3.4 to -0.5. The determination of all these properties improves our understanding of the planet's properties, such as its size, mass, and surface temperature, and provides clues about the formation of the star and its planets.

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240.15 – A Nearby Survey of M-Dwarfs

We present the results of a survey of 913 M-dwarf stars from the Lepine and Shara Proper Motion(LSPM) catalog within 25 parsecs of the Sun. Data for these targets was collected with the Robo-AO camera on the Palomar 60-in telescope. Separation and position angles were measured and compared for two epochs of the images, separated by two years, containing multiple stars to look for changes. We analyzed these positional data, combined with available 2MASS photometric data, to try to determine which stars are in gravitationally bound systems. This research was conducted measure the statistics of multiple M-dwarf systems within 25pc. Identifying and confirming higher ordered systems at both wide and small separations will help improve understanding of M-dwarf formation by comparing these results to star formation models.

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240.16 – Investigating the Spectroscopic Variability and Magnetic Activity of Photometrically Variable M Dwarfs in SDSS

Magnetic activity, a wide range of observable phenomena produced in the outer atmospheres of stars, is currently not well understood for M dwarfs. In higher mass stars, magnetic activity is powered by a dynamo process involving the differential rotation of a star's inner regions. This process generates a magnetic field, heats up regions in the atmosphere, and produces emission line radiation (H-alpha) from collisional excitation. Using the Sloan Digital Sky Survey's (SDSS) Time Domain Spectroscopic Survey (TDSS), we will compare the H-alpha emission line strengths for a sample of 12,000 known photometrically variable M dwarfs observed in the PAN-STARRS1 survey with those of a known non-variable sample. This will be done in order to test whether photometric variability of the sample correlate with chromospheric H-alpha emission features and if not, explore the alternate reasons for that photometric variability, like binarity.

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240.17 – Toward a Comprehensive Sample of VLM Chemical Abundances with APOGEE

Understanding the formation and evolution of very low-mass (VLM, M < 0.1 Msun) stars and brown dwarfs requires detailed information about their physical properties and chemical compositions, which in turn necessitates high-resolution spectroscopy. The Apache Point Observatory Galactic Evolution Experiment (APOGEE) is a R~ 22,500 spectrograph mounted on the 2.5 m SDSS telescope that has provided near-infrared (H-band, 1.5-1.7 micron) spectra of more than 150,000 stars down to a magnitude of H=12.2. The reduction pipeline produces precise, model-dependent determinations for temperature, surface gravity, metallicity and individual abundances for the majority of these targets. However, below Teff ≈ 3000 K, this pipeline does not produce reliable parameters. We have identified a sample of 46 M3-L5 dwarfs observed by this survey at distances of 5-30 pc by cross-matching the APOGEE catalog to catalogs of known late-M, L, T dwarfs. We characterize this sample using existing photometry and spectroscopy from other surveys, and examine the properties of their APOGEE spectra, including correlating atomic equivalent width measurements to parameters inferred from model fits of broad-band, low-resolution data and defining empirical trends . We discuss a potential sample for further APOGEE measurements that would diversify these trends and allow the use of APOGEE data to examine kinematics, rotation and multiplicity across the hydrogen-burning mass limit.
This work is supported the SDSS Faculty and Student (FAST) initiative.

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240.18 – Modeling Stellar Parameters for High Resolution Late-M and Early-L Dwarf SDSS/APOGEE Spectra

The Apache Point Observatory Galactic Evolution Experiment (APOGEE) of the Sloan Digital Sky Survey IV has measured high resolution (R~22,500), near-infrared (1.51-1.70 μm) spectra for nearly 100,000 stars within the Milky Way Galaxy. While the APOGEE experiment was designed to research Galactic structure by targeting bright stellar populations in the disk, we have focused attention on the lesser-studied subset of faint and low-temperature late-M and early-L dwarfs, with the objective of characterizing their chemical abundances. Using spectral synthesis routines from the Starfish package, we report preliminary determinations of Teff, logg, and [Fe/H] for a small sample of spectra using PHOENIX models ranging in the 2,300 to 3,000K temperature grids.

This work is supported by the SDSS Faculty and Student (FAST) initiative, funded by the Alfred P. Sloan Foundation.

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Contributing team(s): UCSD FAST Team

240.19 – Characterizing the Resolved M6 Dwarf Twin LP 318-218AB

The lowest-mass stars and brown dwarfs are among the most common objects in the Milky Way Galaxy, but theories of their formation and evolution remain poorly constrained. Binary systems are important for understanding the formation of these objects and for making direct orbit and mass measurements to validate evolutionary theories. We report the discovery of LP 318-218, a high proper motion late M dwarf, as a near equal-brightness binary system with a separation of 0.72 arcseconds. Resolved near-infrared spectroscopy confirms the components as nearly identical M6 twins. We using our resolved photometry and spectroscopy to estimate the distance, projected separation and tangential velocity of the system, and confirm common proper motion. We also perform atmosphere model fits to the resolved spectra to assess their physical properties. We place LP 318-218 in context with other widely-separated late M dwarf binaries.

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Institution(s): *1. University of California, San Diego, 2. University of Guanajuato*

240.20 – Does the Eclipsing Binary KIC 10935310 Contain a Massively Inflated M Dwarf?

Stellar evolution models are known to under-predict the radii of low-mass stars by between 5% and 10%, and there are a number of theoretical explanations for this discrepancy including metallicity and age variations, and magnetic suppression of convection. An eclipsing binary system in the Kepler field has been reported to have stars with masses of 0.68 and 0.34 solar and radii of 0.61 and 0.90 solar, respectively. We investigate this system with a new code under development that uses a Gaussian process technique to account for the out of eclipse light variations. We combine new NIR light curve data with the Kepler data and literature RVs to assess the feasibility that this system contains a hugely inflated M dwarf, or if another explanation of the data is preferred.

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240.21 – M Dwarf Mysteries

During RECONS' 17-year (so far) astrometry/photometry program at the CTIO/SMARTS 0.9m, we have observed thousands of the ubiquitous red dwarfs in the solar neighborhood. During this reconnaissance, a few mysterious characters have emerged ...

The Case of the Mercurial Stars: One M dwarf has been fading steadily for more than a decade, at last measure 6% fainter than when it was first observed. Another has grown brighter by 7% over 15 years. Are these brightness changes part of extremely long stellar cycles, or something else entirely?

The Case of Identical Stellar Twins that Aren't: Two M dwarfs seem at first to be identical siblings traveling together through the Galaxy. They have virtually identical spectra at optical wavelengths and identical colors throughout the VRIJHK bands. Long-term astrometry indicates that they are, indeed, at the same distance via parallax measurements, and their proper motions match precisely. Yet, one of the twins is FOUR times brighter than the other. Followup work has revealed that the brighter component is a very close spectroscopic double, but no other stars are seen. So, the mystery may be half solved, but why do the close stars remain twice as bright as their widely-separated twin?

The Case of the Great Kaboom!: After more than 1000 nights of observing on the reliable 0.9m telescope, with generally routine frames reading out upon the screen, one stellar system comprised of five red dwarfs flared in stunning fashion. Of the two distinct sources, the fainter one (an unresolved double) surpassed the brightness of the brighter one (an unresolved triple), increasing by more than three full magnitudes in the V filter. Which component actually flared? Is this magnificent outburst an unusual event, or in fact typical for this system and other M dwarfs?

At the AAS meeting, we hope to probe the cognoscenti who study the Sun's smaller cousins to solve these intriguing M Dwarf Mysteries.

This effort has been supported by the NSF through grants AST-0908402, AST-1109445, and AST-1412026, and via observations made possible by the SMARTS Consortium.

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Contributing team(s): RECONS Team

240.22 – The Rotational Properties of M Dwarfs

We seek to understand how low-mass stars spin down over time. The primary mechanism by which isolated stars dissipate angular momentum is through the interaction between their magnetic fields and stellar winds. As fully convective stars, the late M dwarfs are expected to shed angular momentum less efficiently than hotter, more massive stars. We investigate the relationship between stellar rotation, age, and effective temperature using data from several sources, including the Apache Point Observatory Galactic Evolution Experiment (APOGEE) M Dwarf Survey.

Author(s): Steven Gilhool[1], Cullen Blake[1]
Institution(s): *1. University of Pennsylvania*

240.23 – Differential rotation as a model for starspots in magnetically active stars

The Kepler mission has provided an opportunity to significantly expand our understanding of starspots. We have implemented a MCMC method to determine spot parameters of input light curves using a differential rotation spot model. We generated model light curves and explored parameter space in order to test the reliability of our method in retrieving input parameters and to investigate what constraints on spot parameters can be determined from photometric data. We also applied our method to light curves of magnetically active Kepler stars, using only a few spots. One interesting initial conclusion is that it is often possible to replicate complicated light curves over many rotation periods without the need for any spot evolution on stars with rotation periods less than 20 days. We have also begun investigating to what extent spot evolution is preferred as the alternative model for stellar variability. Of course, it is very likely that real stars exhibit both phenomena.

Author(s): Christopher James Agostino[1], Gibor S. Basri[1]
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240.24 – Identification of Misclassified Rotational Variables in the ASAS Catalog

Rotating variables are a subset of extrinsic variable stars in which variations in the apparent brightness of a star are tied to its rotation. Among these are BY Draconis stars, K or M dwarfs that feature transient spots. The light curves of these stars have similarities to those of pulsating variables, leading to misclassification by automated programs. Likewise, the transient and unpredictable nature of the spots can lead automated programs to miss the period of the star's rotation and lead to both misclassification of these stars as "miscellaneous" as well as erroneous period determinations. A survey by P. Wils of a random sample of stars classified as either Cepheids or Beta Cepheid pulsating variables in the ASAS (All Sky Automated Survey) catalog demonstrated that BY Draconis stars were an important polluter of this data set. Work by J. Johnson and K. Larsen on this data set analyzed light curves using the AAVSO's VStar program as well as used proper motion and color indices to find additional BY Draconis stars that had been classified as either Cepheids or Beta Cepheids, as well as a number of Ellipsoidal variables. These are non-eclipsing binaries in which the shape of each star is distorted by their mutual gravitational pull. As the stars orbit each other, the elongated stars rotate, yielding two maximum and two minimum magnitudes per cycle with a period equal to the orbital period. Thus these stars can be misclassified as "miscellaneous" type and with periods that are only half of the true period. C. Hoover and K. Larsen investigated stars from the ASAS catalogue with periods up to 15 days that were included in the Variable Star Index (VSX) under the classification "miscellaneous." Light curve analysis using VStar, as well as color indices and other physical properties, were used to identify both Ellipsoidal variables and spotted stars of the RS Canum Venaticorum type (binary systems that include a spotted star) in this data set. Taken together, both studies confirm that there are numerous rotational variables still left to be correctly identified within the ASAS data set, and demonstrate the limitations of automated classification systems to properly identify such stars.

Author(s): Kristine Larsen[1], Jessica M. Johnson[2], Corwin Hoover[1]
Institution(s): *1. Central Connecticut State University, 2. Earth & Planetary Sciences Department, University of New Mexico*

240.26 – Gyrochronology of Stars in Wide Binaries in the Kepler K2 Cycle 5 Field

We are determining rotation periods for an ensemble of over 100 wide non-interacting binary stars in the K2 Cycle 5 field that contain two main sequence dwarfs, as well as a smaller sample containing at least one white dwarf component. Observations of such coeval pairs provide the basis for our new investigation of rotation-based age determinations. Such "*gyrochronology*" ages can achieve a precision that exceeds most other current methods of stellar age determination. A status report on our analysis of the light curves extracted from the K2 Cycle 5 field will be presented.

Author(s): Terry D. Oswalt[1], Derek L. Buzasi[2], Tomomi Otani[1]
Institution(s): *1. Embry-Riddle Aeronautical University, 2. Florida Gulf Coast University*

240.27 – M Dwarfs in the Solar Neighborhood: Analysis of 16,000 SUPERBLINK-K2 Light Curves

The Kepler 2 mission is targeting large numbers of relativity nearby (d < 100pc) G, K, & M dwarfs selected from the SUPERBLINK survey of stars with proper motions >40mas/yr. Kepler 2 campaigns 0 through 5 monitored a total of 16,097 of these cool main-sequence stars. We used the autocorrelation function to search for fast rotators by identifying short-period photometric modulation in their light curves due to star spots. We identify 209 candidate fast rotators with rotation less than 4 days that show light curve modulation we believe to be due to star spots. The majority of these fast rotators are likely to be young stars, as evidenced by their kinematics. However, our search also uncovers a number of fast rotators that have kinematics consistent with older ages, including two stars that appear to be associated with the Galactic halo. These two stars show clear light curve modulation indicative of stellar rotation. We suggest these stars may be tidally locked, close binary systems.

Author(s): Dicy Ann E. Saylor[1], Sebastien Lepine[1], Erik Petigura[3], Ian Crossfield[2]
Institution(s): *1. Georgia State University, 2. UA/LPL, 3. University of California*

240.28 – The PTI Giant Star Angular Size Survey: Effective Temperatures & Linear Radii

We report new interferometric angular diameter observations of over 200 giant stars observed with the Palomar Testbed Interferometer (PTI). These angular diameters are combined with bolometric fluxes derived from detailed spectral energy distribution (SED) fits, to produce robust estimates of effective temperature (T_EFF). These SED fits include reddening estimates and are based upon fits of empirical spectral templates to literature photometry, and narrow-band photometry obtained at the Lowell 31" telescope. The 58 nights of 31" observing have produced over 45,000 new photometric data points on these stars, allowing for flux and reddening determination with unprecident precision. Over the range from G5III to M8III, T_EFF estimates are precise to 50K per spectral type. For the 87 objects in Gaia DR1, radius estimates are improved over the Hipparcos estimates (van Leeuwen 2007) but only by a factor of 1.7 reduction in error, and are typically ~6% per star.

Author(s): Gerard van Belle3, Kaspar von Braun3, David R. Ciardi[2], Genady Pilyavsky[1]
Institution(s): *1. Arizona State University, 2. Caltech, 3. Lowell Observatory*

240.29 – The Fundamental Stellar Parameters of FGK Stars in the SEEDS Survey

Large exoplanet surveys have successfully detected thousands of exoplanets to-date. Utilizing these detections and non-detections to constrain our understanding of the formation and evolution of planetary systems also requires a detailed understanding of the basic properties of their host stars. We have determined the basic stellar properties of F, K, and G stars in the Strategic Exploration of Exoplanets and Disks with Subaru (SEEDS) survey from echelle spectra taken at the Apache Point Observatory's 3.5m telescope. Using ROBOSPECT to extract line fluxes and TGVIT to calculate the fundamental parameters, we have computed Teff, log(g), vt, [Fe/H], chromospheric activity, lithium abundance, and the age for our sample. Our methodology was calibrated against previously published results for a portion of our sample. The future meta-analysis of the results of the SEEDS survey will utilize our results to constrain the occurrence of detected co-moving companions with the properties of their host stars.

Author(s): Evan Rich[1], John P. Wisniewski[1]
Institution(s): *1. University of Oklahoma*
Contributing team(s): the SEEDS team

240.30 – Fundamental Stellar Parameters with HST/FGS Dynamical Masses and HST/STIS Spectroscopy of M Dwarf Binaries

Mass is the most fundamental stellar parameter, and yet model independent dynamical masses can only be obtained for a small subset of closely separated binaries. The high angular resolution needed to characterize individual components of those systems means that little is known about the details of their atmospheric properties. We discuss the results of HST/STIS observations yielding spatially resolved optical spectra for six closely separated M dwarf systems, all of which have HST/FGS precision dynamical masses for the individual components ranging from 0.4 to 0.076 M_{Sol}. We assume coevality and equal metallicity for the components of each system and use those constraints to perform stringent tests of the leading atmospheric and evolutionary model families throughout the M dwarf mass range. We find the latest models to be in good agreement with observations. We discuss specific spectral diagnostic features such as the well-known gravity sensitive Na and K lines and address ways to break the temperature-metallicity-gravity degeneracy that often hinders the interpretation of these features. We single out a comparison between the systems GJ 469 AB and G 250-29 AB, which have nearly identical mass configurations but different metallicities, thus causing marked differences in atmospheric properties and overall luminosities.

This work is funded by NASA grant HST-GO-12938. and By the NSF Astronomy and Astrophysics Postdoctoral Fellowship program through NSF grant AST-1400680.

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Contributing team(s): RECONS

240.31 – Spectrophotometry of Twenty of the Brightest Stars in the Southern Sky

We have obtained spectra of 20 bright southern stars (including

Sirius, Canopus, Betelgeuse, Rigel, and Procyon) using the CTIO 1.5-m telescope and its grating spectrograph RCSPEC. The brightness of the targets required the use of a 7.5 magnitude neutral density filter. Given a Kurucz model spectrum of Sirius (t = 9850 K, log g = 4.30, [Fe/H] = +0.4) with an appropriate spectral resolution, we can place the spectrophotometry on the system of Sirius, which is much less problematic than basing the ultimate calibration on Vega. The resulting *B*- and *V*-band synthetic photometry compares well with that of Cousins, with minimal color terms. Our synthetic *R*- and *I*-band photometry indicates non-zero offsets and color-terms with respect to Cousins' data.

Author(s): Kevin Krisciunas[1], Nicholas B. Suntzeff[1], Bethany Kelarek[1], Kyle Bonar[1], Joshua Stenzel[1]
Institution(s): *1. Texas AandM University*

240.32 – Harvard Observing Project monitoring of Boyajian's Star (KIC 8462852)

Between 2009 and 2013, the *Kepler* spacecraft observed ~200,000 stars, repeatedly measuring their brightness to look for regular dimmings that could indicate the presence of a transiting planet (Borucki et al. 2010). This endeavor led to the discovery of thousands of planets. However, the data pertaining to one star, KIC 8462852, nicknamed "Tabby's Star" or "Boyajian's Star" indicated sporadic dimmings thought to be resulting from massive, evolving, and erratic shapes passing in front of the star (Boyajian et al. 2016, Wright and Sigurdsson 2016). Additional observations have indicated that KIC 8462852 has faded by approximately 20% over the past century (Wright and Sigurdsson 2016). *Kepler* is now observing other areas of space, and consequently, ground-based efforts have emerged in order to continue tracking the brightness of KIC 8462852. The Harvard Observing Project (HOP) is an observational astronomy initiative that engages undergraduate students and provides graduate students with the opportunity to lead sessions of data collection. During the fall 2016 semester, HOP will be observing KIC 8462852 in BVRI filters using Harvard's 16-inch DFM Clay telescope. We will present a light curve of the star spanning the course of three months.

Author(s): Clea F Schumer[1], Andrew Vanderburg[1], Allyson Bieryla[1], Theron Carmichael[1], Lehman H Garrison[1], Jane Huang[1], John Lewis[1], Andrew Mayo[1], Munazza Alam[1], Sebastian Gomez[1], Harshil Kamdar[1], Sihan Yuan[1], Rodrigo Cordova[1]
Institution(s): *1. Harvard University*

240.33 – Analytic, piecewise solution to the Lane-Emden equation for stars with complex density profiles

The polytropic models of stars are used for a variety of applications in computational astrophysics. These are typically obtained by numerically solving the Lane-Emden equation for a star in hydrostatic equilibrium under assumption that the pressure and density within the star obey the polytropic equation of state. We present an efficient analytic, piecewise differentiable solution to the Lane-Emden equation which allows "stitching" of different polytropes to represent complex pressure and density profiles. This approach can be used to model stars with distinct properties in their cores and envelopes, such as the evolved red giant and horizontal branch stars.

Author(s): Jeff Miller[1], Tamara Bogdanovic[1]
Institution(s): *1. Georgia Institute of Technology*

240.34 – The Evolution of Starspots on LO Pegasi

LO Pegasi is an ultrarotator (P = 10.1538 hr) and young solar analog that exibits large starspots on its surface. Starspots are regions of strong magnetic field analogous to sunspots that inhibit convective transport of energy from deeper layers, causing the spots to be cooler and thus darker than the surrounding photosphere. The star's brightness varies as the spots are carried into and out of view of Earth by the star's rotation, so that photometry can provide insight into their characteristics. The amount of rotational modulation depends on the sizes, shapes, and locations of the spots, along with the inclination of the rotation axis to the line of sight, the brightness contrast between the spots and the rest of the surface, and the amount of limb darkening. The brightness contrast and limb darkening differ amond different photometric filter passbands, such that multi-filter observations provide additional information about spot latitudes compared to single-filter observations. We present surface images of LO Pegasi based on an indirect light-curve inversion algorithm applied to BVRI photometry obtained at Perkins Observatory in Delaware, OH from 2006-2016, which include variations in the size of a polar spot deduced from year-to-year variations in the star's average brightness.

Author(s): Robert O. Harmon3, Mallory Cochran3, Derek Shank3, Nicholas Sweeney[2], Oana Vesa[1]
Institution(s): *1. Albion College, 2. Haverford College, 3. Ohio Wesleyan Univ.*

240.35 – PyHammer: An Automatic and Visual Suite for Spectral Typing Stars

We present a computing product (dubbed "PyHammer"), which can automatically assign estimates of spectral type, metallicity and radial velocity, and/or be used to visually classify stellar spectra. PyHammer uses empirical templates with known spectral types and metallicities as comparisons to automatically determine the spectral type and an estimate of the metallicity of a star by measuring prominent line indices and performing a weighted least squares minimization. The PyHammer GUI allows the user to visually compare their spectra to the templates and determine the spectral type and metallicity. We have created the templates used by PyHammer by co-adding individual spectra from the Sloan Digital Sky Survey's Baryon Oscillation Spectroscopic Survey (BOSS). The templates cover spectral types O5 through L3, are binned by metallicity from -2.0 dex through +1.0 dex, and are separated into main sequence (dwarf) stars and giant stars. This code is based on the "Hammer" spectral typing facility (Covey et al. 2007) and has been updated to include metallicity information, radial velocity calculations, improved automatic estimates, and now is in python (instead of IDL). PyHammer is publicly available to the community on GitHub (github.com/BU-hammerTeam /PyHammer).

Author(s): Aurora Kesseli[1], Andrew A West[1], Brandon Harrison[1], Mark Veyette[1], Daniel Feldman[1]
Institution(s): *1. Boston University*

240.36 – FTS Spectra from the Mayall 4-m Telescope, 1975-1995

The complete archive of spectra obtained with the Fourier Transform Spectrometers in use at the Mayall 4m telescope at the Kitt Peak National Observatory from 1975 through 1995 is now available to the community. The archive is hosted at Indiana University Bloomington, and includes nearly 10,000 individual spectra of more than 800 different astronomical sources. The FTS produced spectra in the wavelength regime from roughly 0.9 to 5 microns (11,000 to 2000 cm^{-1}), mostly at relatively high spectral resolution. The archive can be searched to identify specific spectra of interest, and the spectra can be viewed online and downloaded in FITS format for analysis. Once a spectrum of interest has been identified, all spectra taken on the same date are provided to allow users to identify appropriate hot star spectra for telluric line division.

The archive can be accessed on the web at https://sparc.sca.iu.edu.

Author(s): Catherine A. Pilachowski[1], Kenneth H. Hinkle[2], Michael Young[1], Harold Dennis[1], Arvind Gopu[1], Robert Henschel[1], Soichi Hayashi[1]
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241 – Young Stellar Objects, Very Young

Stars, T-Tauri Stars, H-H Objects Poster Session

241.01 – Constraining the orbits of young binary systems with ALMA

Measuring the orbits of young binary systems can provide the stars' individual stellar masses as well as insight into the dynamical effects they should have on each others' protoplanetary disks. As a byproduct of our ALMA observations of disks in young binary systems, we are able to measure precise relative separations of binaries with separations of 0.22--0.35 arcsec (~ 30--50 AU at the distance of the Taurus star-forming region). Most of these systems were first resolved in the early 1990s, so our epoch 2015 observations add an additional point in the orbit that is 20--25 years after the discovery epoch. While this coverage does not yet yield a definitive orbit, the extended coverage allows improved constraints on the binary orbital parameters. We present updated orbital constraints on a number of young binary systems, including XZ Tau, GH Tau, GN Tau, IS Tau, V955 Tau, and JH 112.

This work makes use of the following ALMA data: ADS/JAO.ALMA#2011.0.00150.S. and ADS/JAO.ALMA#2013.1.00105.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada) and NSC and ASIAA (Taiwan), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Author(s): Natasha Nogueira[2], Eric L. N. Jensen[2], Rachel L. Akeson[1]
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241.02 – The Young Visual Binary Database

We have obtained adaptive optics imaging and high-resolution H-band and in some cases K-band spectra of each component in close to 100 young multiple systems in the nearby star forming regions of Taurus, Ophiuchus, TW Hya, and Orion. The binary separations for the pairs in our sample range from 30 mas to 3 arcseconds. The imaging and most of our spectra were obtained with instruments behind adaptive optics systems in order to resolve even the closest companions. We are in the process of determining fundamental stellar and circumstellar properties, such as effective temperature, Vsin(i), veiling, and radial velocity, for each component in the entire sample. The beta version of our database includes systems in the Taurus region and provides plots, downloadable ascii spectra, and values of the stellar and circumstellar properties for both stars in each system. This resource is openly available to the community at http://jumar.lowell.edu/BinaryStars/. In this poster we describe initial results from our analysis of the survey data. Support for this research was provided in part by NSF award AST-1313399 and by NASA Keck KPDA funding.

Author(s): Lisa A. Prato[2], Ian Avilez[2], Thomas Allen[2], Saeid Zoonematkermani[2], Lauren Biddle[2], Ryan Muzzio[2], Matthew Wittal[2], Gail Schaefer[1], Michal Simon3
Institution(s): *1. Georgia State University , 2. Lowell Observatory, 3. SUNY Stony Brook*

241.03 – Effective Temperatures for Young Stars in Binaries

We have observed about 100 multi-star systems, within the star forming regions Taurus and Ophiuchus, to investigate the individual stellar and circumstellar properties of both components in young T Tauri binaries. Near-infrared spectra were collected using the Keck II telescope’s NIRSPEC spectrograph and imaging data were taken with Keck II’s NIRC2 camera, both behind adaptive optics. Some properties are straightforward to measure; however, determining effective temperature is challenging as the standard method of estimating spectral type and relating spectral type to effective temperature can be subjective and unreliable. We explicitly looked for a relationship between effective temperatures empirically determined in Mann et al. (2015) and equivalent width ratios of H-band Fe and OH lines for main sequence spectral type templates common to both our infrared observations and to the sample of Mann et al. We find a fit for a wide range of temperatures and are currently testing the validity of using this method as a way to determine effective temperature robustly. Support for this research was provided by an REU supplement to NSF award AST-1313399.

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241.04 – Variable Stellar and Circumstellar Properties of the Young Binary VV CrA

VV CrA is a 2 arcsecond young binary system in the Corona Australis star forming region. The NE component, fainter in the near-infrared and invisible at optical wavelengths, dominates in the thermal infrared. The system has drawn attention because of its high degree of variability, significant cicrumstellar emission, and the mysterious nature of the infrared companion. Using high-resolution H- and K-band spectroscopy taken with the NIRSPEC spectrometer at the 10 m Keck II telescope, we have for the first time determined the spectral types of both components: the optically dominant primary is an M0 and the infrared compaion is an earlier K7 type star. Both components show significant and variable levels of H-band veiling, observed over 4 to 5 epochs during a period of 4 years; at times the veiling almost completely obscures the photospheric absorption lines. Hydrogen emission lines are observed at both H (Brackett 16) and K (Brackett gamma), consistent with the high rates of mass accretion described in previous studies. We determine values of Vsin(i), effective temperature, veiling, and radial velocity for both components and describe these results in the context of models of the nature and orientation of the system proposed by Smith et al. (2009) and Scicluna et al. (2016). The geometry of the VV CrA system may present a unique opportunity to study not only young star evolution in the binary environment but also to explore cirumstellar disk structure in high detail.
Support for this research was provided by an REU supplement to NSF award AST-1313399.

Author(s): Ian Avilez[1], Lisa A. Prato[1], Thomas Allen[1], Nuria Meilani Laure Wright-Garba[1], Lauren Biddle[1], Ryan Muzzio[1]
Institution(s): *1. Lowell Observatory*

241.05 – Orbiting Clouds of Material at or near the Keplerian Co-Rotation Radius in Late M Dwarfs WTTs of Upper Sco

Light curves for more than 1000 low mass members of the Upper Sco star forming region were obtained by K2 in Fall 2014. From the subset without obvious IR excesses, we have identifed ~25 stars (all WTTs) as having periodic photometric variability that is not easily explained by well-established physical mechanisms such as star spots, eclipsing binaries, or pulsation. All of these unusual stars are mid-to-late M dwarfs with photometric periods generally less than 1.5 day. For some stars, the light curve is a superposition of a normal star-spot induced (sinusoidal) pattern and one of the unusual variability patterns we have identified. For this set of stars, the two periods agree to within our uncertainties, suggesting that the material responsible for the unusual variability is either on the surface of the star or is orbiting the star at the Keplerian co-rotation radius. Our data strongly favor the latter geometry. In this poster, we present typical light curves for these young, fully-convective stars and discuss possible physical mechanisms to explain their unusual light curves.

Author(s): John R. Stauffer[1], Trevor J. David[1], Lynne Hillenbrand[1], Luisa M. Rebull[1], Ann Marie Cody[2]
Institution(s): *1. Caltech, 2. NASA/Ames Research Center*
Contributing team(s): K2Clusters

241.06 – Is the Young UY Auriga System a Triple?

In an effort to understand the nature of the young binary, UY Aur, we examined the variable behavior of the entire, unresolved 0.9 arcsecond system, as well as the behavior of the angularly resolved, individual A and B components. UY Aur is an approximately 2 Myr old, classical T Tauri in the Taurus-Auriga star forming region and is one of a handful of young systems to host a primordial circumbinary disk, as well as individual circumstellar disks. Using the the facility infrared, high-resolution NIRSPEC spectrograph behind the adaptive optics system at the 10-meter Keck II telescope, we observed a dramatic change in the spectra of UY Aur B between 2003 and 2010. We also identified flux variability in the individual components of 1—2 magnitudes, particularly in the secondary star, on the basis of historical photometry. Thermal dust and line emission observed with millimeter interferometry indicates complex dynamical behavior of the circumbinary and circumstellar dust and led Tang et al. (2014) to speculate that UY Aur B may itself be a binary. Our adaptive optics imaging with the Keck II telescope showed no evidence for a close companion to the B component, although the marked change in our spectra of this star suggest that it could be a spectroscopic binary. We are currently limited by the paucity of angularly resolved observations, both photometric and spectroscopic, hampering the interpretation of the data. High-cadence, angularly resolved spectroscopy and photometry will be required to confirm the potential higher-order multiplicity of this system. This research was supported in part by NSF grants AST-1461200 and AST-1313399.

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241.07 – Interpreting Infant Stars: SOFIA Imaging of Protostars in L1630 and NGC 2264

Infrared imaging studies of deeply embedded young stellar objects (YSOs) provide unique insight into the initial phases of star formation. We have used the FORCAST camera aboard SOFIA to image mid-infrared emission from YSOs within the L1630 and NGC 2264 star forming regions. We detect fifteen YSOs in NGC 2264 and five YSOs in L1630, some of which are resolved in the mid-infrared for the first time. These SOFIA data, combined with previous WISE and Spitzer Space Telescope infrared observations, allow us to classify each SOFIA-detected YSO. Blackbody fits to the spectral energy distributions in the 10-40 micron region allow us to constrain the YSO evolutionary states and disk and envelope temperatures for each source. One source in the L1630 region and two sources in the NGC 2264 region are potential examples of highly unusual candidate Class 0 or Class 0/I YSOs with X-ray counterparts. These sources will help us further our understanding of accretion and magnetic processes during the earliest stages of star formation.

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Institution(s): *1. Dudley Observatory, 2. Rensselaer Polytechnic Institute, 3. Rochester Institute of Technology, 4. Space Science Institute*

241.08 – A search for the lasts gasps of disk accretion in Orion T Tauri stars

Using the echelle mode of the Michigan/Magellan Fiber System (M2FS) on the Magellan/Clay telescope at Las Campanas Observatory, we obtained high resolution spectra (R~35000) of a sample of ~4 - 10 Myr old T Tauri stars distributed in ten 0.5 deg diameter fields in the Orion OB1 association.
We present here a search for accretion signatures among a sample of weak-line T Tauri stars (WTTS). These are young stars that on the basis of their classification in low-resolution spectra, are assumed to lack a primordial disk and therefore should not be actively accreting. We look for signatures of disk accretion at modest or low levels by measuring the width at 10% height of the H-alpha profile, and looking for a redshifted absorption feature. In parallel, we determine which WTTS among the M2FS sample have infrared excesses indicating a circumstellar disk, to see which disk-bearing WTTS also show indications of accretion. We propose that such WTTS accreting at low levels are T Tauri stars at or nearing the end of their accretion phase. Our goal is to build a large sample of these objects so that we can place statistical contraints on how long the accretion phase lasts in solar-like and low-mass stars.

Author(s): Catherine Clark3, Cesar Briceno[2], Nuria Calvet3, Jesus Hernandez[1]
Institution(s): *1. Centro de Investigaciones de Venezuela, 2. Cerro Tololo Inter-American Observatory, 3. University of Michigan*

241.09 – X-ray Observations of LkCa 15: A T Tauri Star Hosting a Protoplanetary System

A suspected protoplanet in the dust-depleted inner disk gap of the T Tauri star LkCa 15 was reported by Kraus & Ireland (2012). More recent ground-based images strikingly confirm their result and provide tantalizing evidence that as many as three protoplanets may be orbiting within 20 AU of the star. LkCa 15 is quite young (age 1-4 Myr) and the protoplanets may still be accreting. We present results of X-ray observations of LkCa 15 obtained with XMM-Newton. These observations confirm that LkCa 15 is a bright X-ray source, as inferred from an earlier 2009 Chandra observation. We will discuss the X-ray spectral and timing properties of LkCa 15 and implications of its bright X-ray emission for physical conditions in the inner disk where the protoplanets are forming.

Author(s): Steve L. Skinner[1], Manuel Guedel[2]
Institution(s): *1. Univ. Of Colorado, 2. Univ. of Vienna*

241.10 – Finding High Quality Young Star Candidates in Ceph C using X-ray, Optical, and IR data

We looked for new candidate young stars within the star forming region of Ceph OB3, more specifically in a region of this molecular cloud called Ceph C. While this region lies in the galactic plane and is included in several large surveys, Ceph C has not been well studied in the past and few young stellar objects (YSOs) have been identified there. The YSOVAR team (Rebull et al. 2014) has time-series monitoring data of this region, and in order to understand the diversity of the light curves, it is crucial to understand which objects in the field of view are likely YSOs, and which are foreground/background objects. The goal of our study is to identify candidate YSO sources as well as support the greater understanding of the variety, evolution, and variability of young stars.
Our search for young stars includes data in X-ray, optical, and IR. Data points used are from Chandra, SDSS, IPHAS, 2MASS, Spitzer IRAC and MIPS, and WISE, giving us data over many orders of magnitude, 0.001 to 25 microns (0.36 to 25 microns without the X-rays). The catalogs were merged across all available wavelengths. Each source was inspected in all available images to insure good matches and quality of data across wavelengths and to eliminate poor candidates, those with contamination or confusion, and non-YSO objects. Spectral energy distributions (SEDs) for each candidate YSO were constructed and compared to images for greater assessment and reliable YSO identification. Color-color and color-magnitude diagrams have been created for the sources in this region and are used in conjunction with images, SEDs, X-ray, IR excess, and variability properties to identify candidate YSOs.
Support provided for this work by the NASA/IPAC Teacher Archive Research Program (NITARP), which receives funding from the NASA ADP program.

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Institution(s): *1. Bioscience High School, 2. Caltech, 3. McCall-Donnelly High School, 4. Milken Community Schools, 5. Pilot Rock High School, 6. Ukiah High School*

241.11 – An Infrared Search for Young Stellar Objects in IC 1396

About 700 parsecs away from Earth, IC1396 lies along the galactic plane, in the direction of the constellation Cepheus, and includes many dark nebulae, including the Elephant's Trunk Nebula. IC 1396A has been examined with a variety of telescopes, including Spitzer, 2MASS, IPHAS, Chandra, and WISE. The YSOVAR project (Rebull et al. 2014) also has Spitzer monitoring data in this region at 3.6 and 4.5 microns. Our team has merged these catalogs and identified candidate YSOs using IR color selection, X-ray detection, and variability metrics. In order to interpret the YSOVAR light curves, it is critical to understand which of the 700+ YSO candidates in this region are likely YSOs, and which are foreground/background stars or are extragalactic objects. As a first attempt to confirm these candidate YSOs, we have created spectral energy distributions (SEDs) for wavelengths from IPHAS r band to 24 microns, which we use, coupled with image inspection, to confirm (or refute) YSO candidates from this list of identified YSO candidates. We will then compare our vetted list of YSO candidates to the lists of YSO candidates already identified in the literature in this region. The goal of this study is to identify candidate YSO sources, as well as support the greater understanding of the variety, evolution and variability of young stars. This project is a collaborative effort of high school students from three states. They analyzed data individually and later collaborated online to compare results. This project is the result of many years of work with the NASA/IPAC Teacher Archive Research Program (NITARP).

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Institution(s): *1. Breck School, 2. Caltech, 3. Carmel Catholic High School, 4. Glencoe High School*

241.12 – A full 1---40 micron spectral energy distribution for the Becklin-Neugebauer object: Placing constraints on disk size for a runaway massive young stellar object

The Becklin-Neugebauer (BN) Object—one of the brightest infrared obejcts in the sky—is a highly luminous young stellar object (YSO) deeply embedded in Orion Molecular Cloud 1 (OMC-1), which sits behind the Orion Nebula (M42). The BN object is likely a 8—15 $M_\odot$ star and has no obvious optical counterpart due to high visual extinction on the line of sight. Furthermore, recent radio studies show that BN is moving towards the northwest at approximately 26 km/s with respect to the Orion Nebula Cluster (ONC), which may indicate that BN was dynamically ejected from either the Trapezium or from within OMC-1 itself. Near-IR polarimetry suggests that BN is surrounded by a large (R=800 AU) disk, which is surprising since a close encounter leading to an ejection would likely disrupt and/or truncate a disk of this size. In this poster presentation, we present new SOFIA-FORCAST grism spectroscopy of BN from 10—40 µm. In conjunction with previous SOFIA-FORCAST photometry and data form the literature, we present the full 1—40 µm SED of BN which we compare to theoretical models using the HOCHUNK-3D radiative equilibrium code. We report constraints on disk parameters and discuss implications for dynamical ejection scenarios.

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241.13 – Probing the Evolution of Massive Young Stellar Objects using Weak Class II 6.7GHz Methanol Maser Emission

We present results from an investigation of class II 6.7GHz methanol masers towards four Massive Young Stellar Objects (MYSOs). The sources, selected from the Red MSX Source (RMS) Survey (Lumsden et al. 2013), were previously understood to be non-detections for class II methanol maser emission in the methanol multi-beam (MMB) Survey (Caswell et al. 2010.) Class II methanol masers are a well-known sign post of massive star forming regions and may be utilized to probe their relatively poorly understood formation. It is possible that these non-detections are simply weak masers that are potentially associated with a younger evolutionary phase of MYSOs as hypothesized by Olmi et al. (2014). The sources were chosen to sample various stages of evolution, having similar 21 to 8 micron flux ratios and bolometric luminosities as other MYSOs with previous class II methanol maser detections. We observed all 4 MYSOs with ATCA (~2" resolution) at 10 times deeper sensitivity than previously obtained with the MMB survey and have a spectral resolution of 0.087kms^-1 . The raw data is reduced using the program Miriad (Sault, R. J., et al., 1995) and deconvolutioned using the program CASA (McMullin, J. P., et al. 2007.) We determine one of the four observed MYSOs is harboring a weak class II methanol maser. We discuss the possibility of sensitivity limitations on the remaining sources as well as environmental and evolutionary differences between the sources.

Author(s): Bethany Ann Ludwig[2], Nichol Cunningham[1]
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241.14 – Massive Star Formation in the Cygnus-X DR15 Complex

To unravel the mysteries of massive star formation it is necessary to observe Young Stellar Objects (YSOs) in a variety of environments and evolutionary stages. The Cygnus-X region, at a distance of 1.4kpc, is one of the closest massive star-forming complexes and so offers an excellent view of the earliest stages of massive stars and clusters. A key area in this complex is DR15, a cluster population with many intriguing objects including a molecular pillar and InfraRed Dark Cloud (IRDC) that is likely to host newly forming massive stars. Previous infrared studies incorporating data from Spitzer and Herschel have built catalogs of YSOs in the DR15 region, revealing its abundance of massive star formation. To improve on these catalogs and to probe the earliest stages of star formation, we have observed the region at high spatial resolution using the Submillimeter Array (SMA). The SMA data are more sensitive to objects in earlier evolutionary phases and provide additional constraints when modeling the Spectral Energy Distribution (SED) of each star, resulting in more accurate values for each star's mass and accretion rate. The SMA data allow us to trace the particular YSOs that are actively accreting and drive molecular outflows, which influence the ISM and chemical trends across the region. DR15 offers an exciting chance to expand our understanding of the processes behind massive star formation.

Author(s): Anna Laws[1], Joseph L. Hora[1], Qizhou Zhang[1]
Institution(s): *1. Harvard-Smithsonian CfA*

241.15 – Bipolar Outflows Properties from Class 0/I protostars in Perseus

The Mass Assembly of Stellar Systems and their Evolution with the SMA (MASSES) program is a key project by the Submillimeter

Array (SMA) telescope that is observing the 70 youngest protostars in the Perseus molecular cloud. From SMA CO(2-1) and continuum observations, we investigate correlations among the YSOs properties, including outflow opening angles, ages, luminosities, envelope masses, and temperatures. No discernable pattern between measured angle versus bolometric temperature was found, independent of the mass or luminosity. These results indicate that the evolutionary sequence is more chaotic than originally predicted in Arce & Sargent (2006).

Author(s): Oscar A. De La Rosa[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*
Contributing team(s): Mass Assembly of Stellar Systems and their Evolution with the SMA (MASSES) Program

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242 – Neutron Stars (Pulsars, Magnetars, Pulsar Wind Nebulae) Poster Session

242.01 – Time Evolution of Pulsar Magnetosphere: An Implicit Approach

In this project we attempt to understand the structure of pulsar magnetosphere, its dynamics and evolution. This is done by developing a computationally intense *implicit finite difference* (FD) approach, under the approximation of *force-free electrodynamics*. Recent studies have suggested an important role of current sheets (CS) in pulsar spin down mechanisms. However, its contribution to high energy emissions, flux outflow, acceleration sites and mechanisms are not completely understood. A better resolution of CS will play a significant role in our understanding of local and global structure of the magnetosphere, which is the main objective of this work. In this first of a series of studies, we demonstrate and verify the existence of CS thereby supporting the Contopoulos et al. (CKF, 1999) type magnetosphere. This is important as CKF type magnetosphere is the new benchmark in pulsar modelling. The implementation of resistivity approach and its superiority over the traditional *explicit* approach will be addressed. The implicit formulation in the high conductivity limit will improve our understanding of the magnetosphere where copious amount of plasma is generated. Once a consistent global structure of the magnetosphere is addressed we will identify the local models and sites to understand the acceleration mechanisms responsible for high energy emission which dominates pulsar emission.

Author(s): Sushilkumar Sreekumar[1], Eric M. Schlegel[1]
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242.02 – Timing will Tell: Constraining Pulsar Timing Errors in the Search for Gravitational Waves

Millisecond pulsars produce extremely precise, clock-like electromagnetic radiation pulses. Theoretically, noise in the arrival times (TOAs) of these individual pulses could be used to measure nanohertz-frequency gravitational waves. However, variability in the individual pulse shapes and TOAs due to intrinsic effects of the pulsar, known as pulsar jitter, can mask the noise caused by gravitational waves. We examine the effects of both brightness and time resolution on jitter in a sample of 10 millisecond pulsars observed by the NANOGrav collaboration regularly over an 11-year observation span. We find that several pulsars show quantifiable jitter on their brightest days while others do not, and that jitter grows more pronounced both in pulsars with a high signal-to-noise ratio and as the observer approaches the time resolution of a single millisecond pulse. We provide two methods of quantifying jitter to allow for comparison, both between observations of different pulsars and between observations of the same pulsar on different days.

Author(s): Ellianna Schwab[1], Scott M. Ransom[2]
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Contributing team(s): NANOGrav

242.03 – Long-Term Timing of Globular Cluster Pulsars

Pulsar timing is a powerful astrophysical tool that allows us to study both pulsars and their environment. Timing models provide information about the pulsar itself, including mass, position, and orbital parameters for pulsars in binary systems. Timing models also provide information about the pulsar's neighborhood and about the interstellar medium (ISM) between the pulsar and the Earth. We present the results of timing two millisecond globular cluster pulsars over five years, as well as steps involved in preparing the data for use in the timing model. Data was obtained using the Robert C. Byrd Green Bank Telescope (GBT) observing at 1.5 GHz between 2011 and 2015. Here, a description of the data processing procedure is given, and timing results including dispersion measure and higher order rotational period derivatives are discussed.

Author(s): Sergio Roi Smith[2], Ryan S Lynch[1]
Institution(s): *1. Green Bank Observatory, 2. Howard University*

242.04 – A Multi-Frequency Study of Nearby MSP J1400-1431

Millisecond pulsar (MSP) J1400-1431 was discovered by Pulsar Search Collaboratory (PSC) students in 2012 and a preliminary timing solution was published a year later by Rosen et al. (2013). Using a new localization method and additional measured pulse times of arrival, we find that the initial published position was incorrect. With the improved position, we have obtained a phase-connected timing solution spanning 4.5 years, also measuring proper motion, spin period, period derivative, dispersion measure, and five Keplerian binary parameters to high precision. PSR J1400-1431 is in a nearly circular, 9.5 day orbit around a white dwarf (Mwd > 0.26 Msun) companion. Using the Southern Astrophysical Research (SOAR) and Keck Low-Resolution Imaging Spectrometer (LRIS) optical telescopes, we observe J1400-1431's white dwarf companion in R, I, and V bands to measure absolute magnitudes, color and temperature; this provides valuable information about the white dwarf companion's composition and therefore, clues about the binary system's evolutionary history. We also report faint detections of MSP J1400-1431 in gamma rays (Fermi) and X-rays (XMM).

Author(s): Joe K Swiggum[2], David L.A. Kaplan[2], Maura McLaughlin[3], Duncan Lorimer[3], Brad Barlow[1]
Institution(s): *1. High Point University, 2. University of Wisconsin - Milwaukee, 3. West Virginia University*

242.05 – Steep Spectrum Pulsar Candidates Near Sgr A*

There is a large excess of gamma ray emission that has been detected by the Fermi Space Telescope towards the galactic center. The leading hypothesis is that this emission originates from a population of pulsars at the galactic center. However, the pulsars cannot be easily detected in radio wavelengths due to the large angular scattering that smears the pulsed emission at the galactic center. Instead of looking for radio pulsations, we search for radio sources within a 2.5 degree radius of the galactic center to identify sources whose power-law spectra is characteristic of pulsars i.e. $S=\lambda^{-\alpha}$, $\alpha \leq -1.5$. We will present how we acquired our candidates, and the follow up observations with the VLA to show our results and conclusions.

Author(s): Deven Bhakta[2], Dale A. Frail[1]
Institution(s): *1. NRAO, 2. Texas Tech University*

242.06 – Black Widow Pulsar radiation hydrodynamics simulation using Castro: Methodology

A black widow pulsar (BWP) is a millisecond pulsar in a tight binary system with a low mass star. The fast rotating pulsar emits intense radiation, which injects energy and ablates the companion star. Observation of the ablation is seen as pulsar eclipses caused by a larger object than the companion star Roche lobe. This phenomenon is attributed to a cloud surrounding the evaporating star. We will present the methodology for modeling the interaction between the radiation coming from the pulsar and the companion star using the radiation hydrodynamics code Castro. Castro is an

adaptive mesh refinement (AMR) code that solves the compressible hydrodynamic equations for astrophysical flows with simultaneous refinement in space and time. The code also includes self-gravity, nuclear reactions and radiation. We are employing the gray-radiation solver, which uses a mixed-frame formulation of radiation hydrodynamics under the flux-limited diffusion approximation. In our setup, we are modeling the companion star with the radiation field as a boundary condition, coming from one side of the domain. In addition to a model setup in 2-d axisymmetry, we also have a 3-d setup, which is more physical given the nature of the system considering the companion is facing the pulsar on one side. We discuss the progress of our calculations, first results, and future work.
The work at Stony Brook was supported by DOE/Office of Nuclear Physics grant DE-FG02-87ER40317

Author(s): Maria Barrios Sazo[2], Michael Zingale[2], Weiqun Zhang[1]
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242.07 – A New, Low Braking Index For the LMC Pulsar B0540-69

We report the results of a 16 month monitoring campaign using the *Swift* satellite of PSR B0540-69, a young pulsar in the Large Magellanic Cloud. Phase connection was maintained throughout the campaign so that a reliable ephemeris could be determined, and the length of the campaign is adequate to accurately determine the spin frequency and its first and second derivatives. The braking index n is 0.031 ± 0.013 (90% confidence), a value much lower than previously reported for B0540-69 and almost all other young pulsars. The monitoring campaign is continuing, and the pulsar remains in its high spin-down state. We use data from the extensive monitoring campaign with RXTE to show that timing noise is unlikely to significantly affect the measurement. This is the first measurement of the braking index in the pulsar's recently discovered high spin-down state. We discuss possible mechanisms for producing the low braking index.

Author(s): Francis E. Marshall4, Lucas Guillemot[1], Alice Kust Harding4, Pierrick Martin3, David A Smith[2]
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242.08 – Post-outburst radio monitoring of the high magnetic field pulsar PSR J1119-6127

We have carried out radio monitoring observations of PSR J11119-6127 following its recent X-ray outburst in July 2016. While initial observations failed to detect the presence of pulsed emission, subsequent observations two weeks later show bright detections of the pulsar at S-band and a significant detection at X-band as the S-band pulse profile returns to a single-peaked shape. From these measurements, we were able to estimate a spectral index over a relatively wide range of radio wavelengths. We also detected an unusual multiple- peaked radio profile and single pulse events. Further observations show an evolving pulse profile that is quite unique among known radio pulsars. PSR J1119-6127 is clearly a transition object, i.e. a high-magnetic field neutron star that is normally a rotation- powered pulsar in radio and X-rays, but also shows transient magnetar-like behavior, i.e. behavior unlikely to be powered solely by rotation, but also by release of stored magnetic energy. We will discuss recent results and implications for understanding the emission behavior of high magnetic field pulsars.
This research was performed at the Jet Propulsion Laboratory, California Institute of Technology, under the Research and Technology
Development Program, under a contract with the National Aeronautics and
Space Administration.

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242.09 – FRB 121102: Searching for a Host

The origin of the highly-dispersed millisecond-duration pulses known as fast radio bursts (FRBs) is currently unknown. The large dispersion measures suggest extragalactic (possibly cosmological) distances, but exotic Galactic models can not yet be ruled out. To better understand the source of FRBs, we must localize a burst sufficiently to identify a host or counterpart at other wavelengths. As the only FRB currently known to show repeated bursts, FRB 121102 offers the best opportunity for an accurate position measurement. Using deep VLA observations at 3 GHz taken in the B and C arrays, we studied the radio sources detected in the FRB 121102 field. We also conducted a detailed multi-wavelength investigation of the field using observations at optical (Gemini), UV (Swift UVOT), and x-ray (Swift and Chandra), as well as using archival catalogs of infrared (ALLWISE, GLIMPSE) and H-alpha (IPHAS) sources. By cross-matching catalogs at different wavelengths, we are able to classify many sources as stars, galaxies, or AGN. From the deep multi-epoch multi-configuration VLA 3 GHz data, we identify over 200 new radio sources and assess their variability on timescales of days to months. We present a catalog of sources that will be useful for identifying a counterpart to FRB 121102.

Author(s): Matthew W. Abruzzo5, Robert Wharton3, Shami Chatterjee3, James M. Cordes3, Cees Bassa[2], Geoffrey C. Bower[1], Sarah Burke-Spolaor[10], Bryan J. Butler[10], Demorest Paul[10], Jason Hessels[2], Victoria M. Kaspi7, Casey J. Law[11], Maura McLaughlin[12], Scott M. Ransom9, Paul Scholz4, Andrew Seymour[8], Laura Spitler[6], Shriharsh P. Tendulkar7
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242.10 – Seeking Fast Radio Burst Origins Using the Very Large Array

Fast radio bursts (FRBs) are transient pulses of radio emission lasting on the order of milliseconds. There have been ~25 FRB sources discovered to date with pulse widths ranging from 1 to 15 ms, and flux densities typically ranging from 0.3 to 2.0 Jy (Petroff et al. 2016). These FRBs have dispersion measures (DMs) on the order of hundreds of pc/cc, well in excess of the expected Galactic contribution. This has lead many to believe that FRBs are extragalactic in origin, with leading progenitor theories suggesting some connection to neutron star related events. However, plausible origin theories remain numerous (Popov & Pshirkov 2016). Thus, localization will be a critical contribution to our understanding of FRBs. Spatial identification of a progenitor would not only help us whittle down origin theories but also allow us to utilize FRBs as invaluable cosmological probes of the intergalactic medium. All reported FRBs to date have been discovered with single dish telescopes that have insufficient resolution for confident localization. In contrast, the Very Large Array (VLA) has the capability to detect and localize FRBs to arcsecond precision. Project realfast takes advantage of this unique localization capability to conduct FRB searches at the VLA in quasi-real-time. We present recent realfast data, including the development of FRB visualization using interferometric imaging, and a discussion of thermal noise candidates and common types of radio frequency interference detected by realfast software. We also present the results of the FRB candidate search for the most recent 150 hour VLA observing campaign. This campaign focused on observations of nearby galaxies with high star-formation rates, and we are thus able to perform a sharp test on any correlation between FRB rates and star-forming galaxies, as might be expected if FRBs originate from neutron stars in nearby galaxies. This analysis allows us to put a lower limit on the characteristic distance to FRBs.

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Institution(s): *1. National Radio Astronomy Observatory, 2. University of Virginia*
Contributing team(s): Realfast

242.11 – Quasi-Periodicities in the Anomalous Emission Events in Pulsars B1859+07 and B0919+06

A quasi-periodicity has been identified in the strange emission shifts in pulsar B1859+07 and possibly B0919+06. These events, first investigated by Rankin, Rodriguez & Wright in 2006, originally appeared disordered or random, but further mapping as well as Fourier analysis has revealed that they occur on a fairly regular basis of approximately 150 rotation periods in B1859+07 and perhaps some 700 in B0919+06. The events-which we now refer to as "swooshes"-are not the result of any known type of mode-changing, but rather we find that they are a uniquely different effect, produced by some mechanism other than any known pulse-modulation phenomenon. Given that we have yet to find another explanation for the swooshes, we have appealed to a last resort for periodicities in astrophysics: orbital dynamics in a binary system. Such putative "companions" would then have semi-major axes comparable to the light cylinder radius for both pulsars. However, in order to resist tidal disruption their densities must be at least some 10^5 grams/cm^3-therefore white-dwarf cores or something even denser might be indicated.

Author(s): Haley Wahl[1], Joanna M. Rankin[1]
Institution(s): *1. University of Vermont*

242.12 – Follow-up Observations of the Magnetar PSR J1745-2900 and Sgr A*

We have recently presented radio continuum light curves of the magnetar PSR J1745-2900, located ~3 arcseconds from Sgr A*, obtained with multi-epoch VLA observations between 2012 and 2014. During this period, a powerful X-ray outburst from PSR J1745-2900 occurred, followed by enhanced radio emission detected approximately ten months later. We have continued monitoring the flux of the magnetar using the VLA in its B configuration, at K (21.2 GHz), Ka (32 GHz) and Q (41 GHz) bands. The motivation for these observations was to determine whether its flux density is still fluctutaing. We present the results of four epochs' observations between 2 June 2016 and 15 August 2016, which include light curves of both the magnetar and Sgr A*. In addition, we present light curves of Sgr A* based on past observations taken in recent years to measure flux variability on a longer time scale.

Author(s): Rebecca Rimai Diesing[2], Farhad Yusef-Zadeh[2], Lorant Sjouwerman[1], Doug Roberts[2]
Institution(s): *1. National Radio Astronomy Observatory, 2. Northwestern University*

242.13 – Nuclear pasta in protoneutron stars: simulations of neutrino emission from nucelar de-excitation

Nuclear pasta is an exotic phase of matter with densities near $\rho \approx \rho_0 = 10^{14}$ g cm^{-3} that consists of complex structures with geometries resembling spaghetti, lasagna, gnocchi, and other types of pasta. It is predicted to appear in the inner crust of neutron stars, protoneutron stars, and the collapsing cores of massive stars. It is hypothesized that nuclear pasta has a significant effect on transport and neutrino scattering properties of neutron and protoneutron stars. If this is true, then it is possible to find observational signatures of nuclear pasta. We present a calculation of neutrino emmissivity of pasta phases due to de-excitation of neutrons. We discuss observational implications on the neutrino signal of protoneutron stars.

Author(s): Matthew Charles Witt[1], William Newton[1]
Institution(s): *1. Texas A&M University, Commerce*

242.14 – High Time Resolution Studies with the GBT

The detection of neutron stars 49 years ago has created many new and independent branches of research. In 1967, fast rotating neutron stars, or pulsars, became the first objects of this kind to be discovered at radio wavelengths -- more than 30 years after their theoretical prediction.
In spite of numerous studies throughout the years, the mechanism of the observed radio emission of pulsars is still not understood. Recent technological developments allow observations of pulsars with time resolutions extending into the nanoseconds range, providing a unique insight into the momentary state of a pulsar. Radio giant pulses are known to occur non-periodically in certain phase ranges, exhibit much higher peak flux densities than regular pulses, and to have pulse widths ranging from the micro- to nanoseconds. Their characteristics make them suitable for high time resolution studies. We present the first high time resolution observations of the original millisecond pulsar PSR B1937+21 carried out with the Robert C. Byrd Green Bank Radio Telescope.

Author(s): Natalia Lewandowska[1], Ryan S Lynch[1]
Institution(s): *1. Green Bank Observatory*

242.16 – The Arecibo Remote Command Center Network

The Arecibo Remote Command Center (ARCC) network is an education, research, and training program for undergraduates, graduate students, and postdocs spanning multiple institutions. ARCC members use the Arecibo 305-m radio telescope to remotely conduct pulsar survey and timing observations, and they search the data collected to find new radio pulsars using a custom pulsar candidate viewer. Timing data are used in the ongoing NANOGrav search for gravitational waves using pulsar timing arrays. The ARCC program also serves as an effective introduction for students to radio pulsar research. Currently ARCC has seven institutional members and dozens of participants. Our poster provides some general background about the ARCC program at Franklin and Marshall College and serves as a catalyst for in-person conversations and discussions about ARCC, including the benefits of joining the ARCC network and some specifics on how to join.

Author(s): Fronefield Crawford[1], Fredrick Jenet[7], Brian Christy[4], Timothy Dolch[2], Alma Guerreo-Miller[7], Volker Quetschke[7], Xavier Siemens[8], Tristan L. Smith[5], Kevin Stovall[6], Leslie Wade[3], Madeline Wade[3]
Institution(s): *1. Franklin and Marshall College, 2. Hillsdale College, 3. Kenyon College, 4. Notre Dame of Maryland University, 5. Swarthmore College, 6. University of New Mexico, 7. University of Texas Rio Grande Valley, 8. University of Wisconsin - Milwaukee*

242.17 – Searches for Optical Counterparts to Fermi Unassociated Sources with the Intermediate Palomar Transient Factory

The Intermediate Palomar Transient Factory (iPTF) has accumulated an extensive optical variability dataset across the Northern Sky, including at low Galactic latitudes ($|b| < 20$ degrees). We are using this dataset to search for optical counterparts to unassociated Fermi gamma-ray sources, particular the companions of eclipsing binary millisecond pulsars. So-called redback binary millisecond pulsars are a key evolutionary stage in the recycling process that spins up millisecond pulsars. The Roche-distorted and irradiated pulsar companion produces a periodic signature at the orbital period that may be readily identified with iPTF. We report on the progress of this search and present interesting candidates found.

Author(s): Eric Christopher Bellm[1], Thomas A Prince[1], David L.A. Kaplan[2], Thomas Kupfer[1], Megan E. DeCesar[2], Russ Laher[1], Frank J. Masci[1], David L. Shupe[1]
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Contributing team(s): Intermediate Palomar Transient Factory Collaboration

242.18 – Upper Limits On High-Frequency Single-Source Gravitational Waves

In the coming years, pulsar timing arrays (PTAs) are poised to detect gravitational waves (GWs) from supermassive black hole binary systems. In addition to measuring the GW stochastic background, PTAs can also detect single-source GWs. By analyzing data taken over many years, PTAs are typically sensitive to nanohertz-frequency GW sources. However, the microhertz to millihertz GW frequency regime is outside the typical range of PTA sensitivity, and is relatively unexplored. Through analysis of multiple-hour long observations of particular pulsars routinely measured by the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), we searched for continuous wave (CW) sources at GW frequencies in the microhertz to millihertz regime. Using such single-pulsar measurements taken by the NRAO Green Bank Telescope, we applied CW detection algorithms to the datasets. While no CW sources were detected within the data, new upper limits on the strains of single-source GWs were found in the GW frequency range of 10 microhertz to 1 millihertz. By repeatedly simulating sources with known strains, we determined the minimum strains required for CW detection, and showed that these minimum strains place upper limits on the strengths of potential sources. Due to the positions of the pulsars analyzed, we also placed stronger directional limits on CW sources in the high GW frequency regime.

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242.19 – The CHIME Fast Radio Burst Project

Fast Radio Bursts are a recently discovered phenomenon consisting of short (few ms) bursts of radio waves that have dispersion measures that strongly suggest an extragalactic and possibly cosmological, but yet
unknown, origin. The Canadian Hydrogen Intensity Mapping Experiment was designed to study Baryon Acoustic Oscillations through mapping of redshifted hydrogen, in order to constrain the nature of Dark Energy. CHIME, currently under construction in Penticton, BC in Canada, consists of 4 cylindrical paraboloid reflectors having total collecting area 80 m x 100 m, and will be sensitive in the 400-800 MHz band. With 2048 independent feeds hung along the cylinder axes, CHIME is a transit telescope with no moving parts, but is sensitive to the full ~200 sq. degrees overhead in 1024 formed beams, thanks to the largest correlator ever built. Given CHIME's enormous sensitivity, bandwidth and unprecedented field of view for the radio regime, CHIME will be a superb instrument for studying Fast Radio Bursts, with expected detected event rates of several to several dozen per day, hence promising major progress on the origin and nature of FRBs.

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Contributing team(s): CHIME/FRB Collaboration

243 – Cataclysmic Variables, Novae, & Symbiotic Stars Poster Session

243.01 – Realistic MHD Modelling of Cataclysmic Variable Spin-Down

The orbital evolution of cataclysmic variables with periods above the "period gap" (>3 hrs) is governed by angular momentum loss via the magnetized wind of the unevolved secondary star. The usual prescription to study such systems takes into account only the magnetic field of the secondary and assumes its field is dipolar. It has been shown that introduction of the white dwarf and its magnetic field can significantly impact the wind's structure, leading to a change in angular momentum loss rate and evolutionary timescale by an order of magnitude. Furthermore, the complexity of the magnetic field can drastically alter stellar spin-down rates. We explore the effects of orbital separation and magnetic field configuration on mass and angular momentum loss rates through 3-D magnetohydrodynamic simulations. We present the results of a study of cataclysmic variable orbital evolution including these new ingredients.

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243.02 – Cataclysmic Variables discovered in the ChaMPlane Survey

We present the Cataclysmic Variables discovered in the Chandra Multi-wavelength Plane Survey (ChaMPlane). ChaMPlane is designed to survey the point X-ray sources discovered by the Chandra X-ray Observatory in the galactic plane in order to constrain the X-ray binary population in the Galaxy. The survey includes the data from the Chandra achieve, as well as the optical and infrared images and spectroscopes. CV candidates are first identified from the Chandra and optical imaging in the deep V, I, R, H-alpha bands. Then optical spectroscopic follow-ups are conducted to confirm their status. CVs are identified by their hydrogen Balmer and helium emission lines, often broadened and double peaked due to the accretion disk rotation around the primary. We present the spectra of 25 CVs obtained from the Magellan, CTIO-4m and WIYN telescopes.

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243.03 – The Kepler2 70-day Observation of the Eclipsing Cataclysmic AC Cnc

We describe our analysis of the *Kepler*2 data on the eclipsing novalike cataclysmic variable AC Cnc. Our requested observations were obtained using the 1-minute cadence instrument mode. AC Cnc has an 8-hour orbital period; the *Kepler*2 observations span ~70 days, yielding ~200 eclipses and ~109,000 observations. The observations are very `clean' with essentially no contamination by nearby objects and essentially no drift of AC Cnc over the observation span. We detect the primary and secondary eclipses as well as a continuous evolution of the brightness from a minimum to a maximum and back. We also detect two `stunted' outbursts with an amplitude typical of Z~Cam stars rather than CV stunted outbursts.

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243.05 – Detecting Nova Shells around known Cataclysmic Variable systems

Nova shells are hydrogen-rich nebulae around Cataclysmic Variables that are created when a Nova outburst takes place. Learning more about Nova shells can help us get a better understanding of the long-term evolution of white dwarfs in active Cataclysmic Variables. In this project, we present the search for Nova shells around 1700 Cataclysmic Variables, using Hα images from the Palomar Transient Factory (PTF) survey. The PTF Hα survey started in 2009 using the 48" Oschin telescope at Palomar Observatory and is the first of its type covering the whole northern hemisphere while reaching 18 mags in 60 seconds of exposure. We concentrated our search on the IAU catalogue of Historical Novae, as well as on the SDSS and the Ritter-Kolb catalogue of Cataclysmic Variables. We numerically analyzed radial profiles centered on the target sources to search for excess emission potentially associated with the shells. Out of 1700 Cataclysmic Variables present in these catalogues, we detected 25 Nova shells, out of which 20 are not observed before.

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243.06 – The Fall and Rise of FO Aquarii - King of the

Intermediate Polars
In May of 2016, the intermediate polar FO Aqr was detected in a low state for the first time in its observational history. We present time-resolved photometry of the system during its recovery from this faint state. Strong periodicities at 22.5 min and 11.26 min, matching the spin-orbit beat frequency and twice its value, dominate the power spectra. A pulse at the spin frequency is also present but at a much lower amplitude than is normally observed in the bright state. By comparing our power spectra with theoretical models, we infer that a substantial amount of accretion was stream-fed during our observations, in contrast to the disk-fed accretion that dominates the bright state. In addition, we find that FO Aqr's rate of recovery has been unusually slow in comparison to rates of recovery seen in other magnetic cataclysmic variables, with an e-folding time of 115+/-7 days. The recovery also shows irregular variations in the median brightness of as much as 0.2 mag over a 10-day span. We further find that the arrival times of the spin pulses are dependent upon the system's overall brightness.

Swift and Chandra X-ray observations show that the hard X-ray flux faded during the low-state while the flux of soft X-ray has increased. The decreased mass accretion rate is likely the cause of the lower hard X-ray flux. In contrast, the accretion disk column density is likely lower in the faint state allowing more soft X-rays to escape the system.

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243.07 – Recent Observations of AG Pegasi's Latest Outburst Phase by Harvard Observing Project
AG Pegasi (AG Peg) is a symbiotic binary star composed of a red supergiant and a white dwarf. Between 1860 and 1870, AG Peg brightened from magnitude 9 to 6, before gradually dimming. In 2015, the star began another brightening phase. The outbursts are thought to be caused by accretion of material onto the white dwarf. Once there is enough hydrogen accreted, hydrogen shell-burning starts leading to the the star's evolution into a A-supergiant with a high mass-loss rate (Kenyon et al. 1993). The Harvard Observing Project (HOP) collected photometric data in BVRI filters using Harvard's 16-inch Clay Telescope in the Fall term of 2015 and again in the Fall term of 2016. HOP is designed to get undergraduate students interested in astronomy and observing, and to allow graduate students opportunities to interact with undergraduates and get more observing/teaching experience. This study monitors the luminosity of AG Peg to constrain the amplitude and duration of the latest outburst.

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243.08 – Long-term Accretion Variations of the Magnetic Cataclysmic Variable Star QQ Vulpecula

Magnetic cataclysmic variable stars have brightness variations that repeat with each revolution of the two stars about the center of mass of the system. However, in the case of QQ Vulpecula (QQ Vul), this brightness variation pattern changes in the long term. This study makes use of two decades worth of data from the Roboscope Telescope as well as data from the American Association of Variable Star Observers (AAVSO) database to examine the long-term evolution of QQ Vul's phase curves. Nightly observations using the Maria Mitchell Association's Vestal and Loines Observatories supplemented this analysis by clarifying short-term brightness variation. The long-term data was divided into four commonly observed behavioral types ranging from a double peaked curve of ~15.5 magnitude to a ~15.0 magnitude curve that had a primary minimum and a slow, linear rise in brightness in place of the secondary minimum. The nightly data kept within the confines of these categories, though the secondary minimum in the nightly data never vanished. No periodicity was found in the long-term variations. The model often invoked to explain the double peaked curve consists of single pole accretion in which a partial self-eclipse causes the secondary minimum and cyclotron beaming causes the primary minimum. However, the long-term variation may indicate a changing accretion rate, which may manifest itself in changes to the shape, size, or location of the accretion spot on the white dwarf such that it lessens or removes the secondary minimum. This project was supported by the NSF REU grant AST-1358980, the Massachusetts Space Grant, and the Nantucket Maria Mitchell Association.

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244 – White Dwarfs Poster Session

244.01 – Orbital Stability of the Hierarchical Triple System HIP 3678
HIP 3678 is a hierarchical triple system located in the center of planetary nebula (PN) NGC 246. The central star of the PN is a 0.84 M_sun PG 1159 star with a near-equal-mass K-dwarf companion and a recently discovered 0.1 M_sun tertiary companion at a projected separation of 500 AU. Using the highly-accurate, non-symplectic IAS15 integrator in REBOUND, we investigate the long-term stability of the system for scenarios consistent with current observational constraints on the orbital parameters.

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244.02 – Searching For Infrared Excesses Around White Dwarf Stars
Many WDs have been found to be "polluted," meaning they contain heavier elements in their atmospheres. Either an active process that counters gravitational settling is taking place, or an external mechanism is the cause. One proposed external mechanism for atmospheric pollution of WDs is the disintegration and accretion of rocky bodies, which would result in a circumstellar (CS) disk. As CS disks are heated, they emit excess infrared (IR) emission. WDs with IR excesses indicative of a CS disk are known as dusty WDs. Statistical studies are still needed to determine how numerous dusty, polluted WDs are, along with trends and correlations regarding rate of planetary accretion, the lifetimes of CS disks, and the structure and evolution of CS disks. These findings will allow for a better understanding of the fates of planets along with potential habitability of surviving planets.

In this work, we are trying to confirm IR excesses around a sample of 69 WD stars selected as part of the WISE InfraRed Excesses around Degenerates (WIRED) Survey (Debes et al. 2011). We have archival data from WISE, Spitzer, 2MASS, DENIS, and SDSS. The targets were initially selected from the Sloan Digital Sky Survey (SDSS), and identified as containing IR excesses based on WISE data. We also have data from the Four Star Infrared Camera array, which is part of Carnegie Institution's Magellan 6.5 meter Baade Telescope located at Las Campanas Observatory in Chile. These Four Star data are much higher spatial resolution than the WISE data that were used to determine if each WD has an IR excess. There are often not many bands delineating the IR excess portion of the SED; therefore, we are using the Four Star data to check if there is another source in the WISE beam affecting the IR excess.

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244.03 – Transit probabilities for debris around white dwarfs

The discovery of WD 1145+017 (Vanderburg et al. 2015), a metal-polluted white dwarf with an infrared-excess and transits confirmed the long held theory that at least some metal-polluted white dwarfs are actively accreting material from crushed up planetesimals. A statistical understanding of WD 1145-like systems would inform us on the various pathways for metal-pollution and the end states of planetary systems around medium- to high-mass stars. However, we only have one example and there are presently no published studies of transit detection/discovery probabilities for white dwarfs within this interesting regime. We present a preliminary look at the transit probabilities for metal-polluted white dwarfs and their projected space density in the Solar Neighborhood, which will inform future searches for analogs to WD 1145+017.

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244.04 – White Dwarf Pollution by Disk Accretion of Tidally Disrupted Rocky Bodies

Approximately 30% of cool white dwarfs (WDs) show heavy elements which should otherwise sediment out of their atmospheres (Koester et al. 2014; Zuckerman et al. 2010). The prevailing model for the pollution of white dwarf photospheres invokes the formation of a solid disk upon a rocky body falling within the WD Roche radius, which is then transported inward by Poynting-Robertson drag (e.g., Metzger et al. 2012, Rafikov 2011). At high temperatures close to the WD, solid particles sublimate to gas that accretes onto the WD and viscously spreads outward. This concept is supported by observations of Ca II emission from WD disks (e.g., Manser et al. 2016). The model by Metzger et al. (2012) successfully explains the range in inferred mass accretion rates (10^10 g/s, Farihi et al. 2010), provided the gaseous disks viscously spread at rates consistent with a partially suppressed magnetorotational instability (MRI). However, Metzger et al. (2012) do not consider disk chemistry or dust-to-gas mixing in their model, and do not calculate the degree of ionization to explore the extent of MRI in WD disks.

We present a 1-D model of a gaseous WD disk accretion, to assess the extent of the magnetorotational instability in WD disks. The disk composition is considered with changes in sublimation rate by pressure. The degree of ionization is determined by considering UV, X-ray, and high-temperature ionization. We calculate the rate of viscous spreading and accretion rates of metals onto WDs.

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244.05 – Three-Dimensional Simulations of the Convective Urca Process in Pre-Supernova White Dwarfs

A significant source of uncertainty in modeling the progenitor systems of Type Ia supernovae is the dynamics of the convective Urca process in which beta decay and electron capture reactions remove energy from and decrease the buoyancy of carbon-fueled convection in the progenitor white dwarf. The details of the Urca process during this simmering phase have long remained computationally intractable in three-dimensional simulations because of the very low convective velocities and the associated timestep constraints of compressible hydrodynamics methods. We report on recent work simulating the A=23 (Ne/Na) Urca process in convecting white dwarfs in three dimensions using the low-Mach hydrodynamics code MAESTRO. We simulate white dwarf models inspired by one-dimensional stellar evolution calculations at the stage when the outer edge of the convection zone driven by core carbon burning reaches the A=23 Urca shell. We compare our methods and results to those of previous work in one and two dimensions, discussing the implications of three dimensional turbulence. We also comment on the prospect of our results informing one-dimensional stellar evolution calculations and the Type Ia supernovae progenitor problem.

This work was supported in part by the Department of Energy under grant DE-FG02-87ER40317.

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244.06 – Spectroscopic Reductions of White Dwarf Stars to Support Dark Energy Survey Calibrations

The Dark Energy Survey is an imaging survey that covers 5000 square degrees in the Southern hemisphere to map galaxies and gather information on dark energy. Science requirements for the survey require a 0.5% uncertainty in color, driven by supernova science. The Dark Energy Survey relies a calibration technique that uses white dwarf stars to set zero points. These white dwarf spectra are fit to models which are used to generate synthetic photometry. These values are compared to the measured values from the survey to verify that the zero points are correct. We present results to date of the spectroscopic reductions of these white dwarf stars in support of the calibrations for the Dark Energy Survey.

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245 – Extrasolar Planets: Characterization & Theory Poster Session

245.01 – Characterizing Extrasolar Planets from Transit Light Curves obtained at the Universidad de Monterrey Observatory – Part 2

At the Universidad de Monterrey Observatory (MPC 720) we have maintained a program for observing extrasolar planet transit light curves with telescopes of modest size and standard photometric filters since 2005. In our archives we have over 325 transits of over 70 known systems. Our goal is to combine individual transit light curves of the same system to increase the S/N of the data. We then analyze it together with the radial velocity information from the literature in order to confirm, improve or revise the main parameters that characterize the transiting system. It is important to continue observing these systems not only to improve and refine our understanding of them, but also to record any possible transient phenomenon and monitor for possible period changes, as reflected in the mid-transit times, due to the gravitational influence of additional planets in the system.
In this second presentation we report our observations of 42 individual exoplanet transit light curves and the results from successfully combining six light curves for HAT-P-3 (Ic), twenty-one for TrES-3 (6 in V, 5 in Rc, 6 in Ic and 4 in z'), seven for XO-2 (Ic), four for XO-3 (Ic), and four for XO-4 (Ic). From these we then derive planet sizes (R_p/R_*), orbital distances (a/R_*) and orbital inclinations (*i*) for these systems. In most cases we confirm the parameters reported in the literature with similar uncertainties, validating our methodology. From our mid-transit times and those of the literature we do not find any statistically significant deviations from a fixed orbital period for these systems.

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245.02 – Simulated JWST/NIRISS Spectroscopy of Anticipated TESS Planets and Selected Super-Earths Discovered from K2 and Ground-Based Surveys

The 2018 launch of James Webb Space Telescope (JWST), coupled with the 2017 launch of the Transiting Exoplanet Survey Satellite (TESS), heralds a new era in Exoplanet Science, with TESS projected to detect over one thousand transiting sub-Neptune-sized planets (Ricker et al, 2014), and JWST offering unprecedented spectroscopic capabilities. Sullivan et al (2015) used Monte Carlo simulations to predict the properties of the planets that TESS is likely to detect, and published a catalog of 962 simulated TESS planets. Prior to TESS launch, the re-scoped Kepler K2 mission and ground-based surveys such as MEarth continue to seek nearby Earth-like exoplanets orbiting M-dwarf host stars. The exoplanet community will undoubtedly employ JWST for atmospheric characterization follow-up studies of promising exoplanets, but the targeted planets for these studies must be chosen wisely to maximize JWST science return. The goal of this project is to estimate the capabilities of JWST's Near InfraRed Imager and Slitless Spectrograph (NIRISS)—operating with the GR700XD grism in Single Object Slitless Spectrography (SOSS) mode—during observations of exoplanets transiting their host stars. We compare results obtained for the simulated TESS planets, confirmed K2-discovered super-Earths, and exoplanets discovered using ground-based surveys. By determining the target planet characteristics that result in the most favorable JWST observing conditions, we can optimize the choice of target planets in future JWST follow-on atmospheric characterization studies.

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245.03 – Exploring *JWST*'s Capability to Constrain Habitability on Simulated Terrestrial *TESS* Planets

In the following, we have worked to develop a flexible "observability" scale of biologically relevant molecules in the atmospheres of newly discovered exoplanets for the instruments aboard NASA's next flagship mission, the James Webb Space Telescope (*JWST*). We sought to create such a scale in order to provide the community with a tool with which to optimize target selection for *JWST* observations based on detections of the upcoming Transiting Exoplanet Satellite Survey (*TESS*). Current literature has laid the groundwork for defining both biologically relevant molecules as well as what characteristics would make a new world "habitable", but it has so far lacked a cohesive analysis of *JWST*'s capabilities to observe these molecules in exoplanet atmospheres and thereby constrain habitability. In developing our Observability Scale, we utilized a range of hypothetical planets (over planetary radii and stellar insolation) and generated three self-consistent atmospheric models (of dierent molecular compositions) for each of our simulated planets. With these planets and their corresponding atmospheres, we utilized the most accurate *JWST* instrument simulator, created specically to process transiting exoplanet spectra. Through careful analysis of these simulated outputs, we were able to determine the relevant parameters that effected *JWST*'s ability to constrain each individual molecular bands with statistical accuracy and therefore generate a scale based on those key parameters. As a preliminary test of our Observability Scale, we have also applied it to the list of *TESS* candidate stars in order to determine *JWST*'s observational capabilities for any soon-to-be-detected planet in those solar systems.

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Contributing team(s): Planetary Systems Laboratory, Virtual Planetary Laboratory

245.04 – Reaching the Diffraction Limit: High-Resolution Imaging for Exoplanet and Stellar Studies

Speckle imaging allows telescopes to achieve diffraction limited imaging performance by effectively `freezing out' atmospheric seeing. The resulting speckles are correlated and combined in Fourier space to produce reconstructed images with resolutions at the diffraction limit of the telescope. Two new speckle instruments are being built for the 8-m Gemini and 3.5-m WIYN telescopes and will be made available to the community in 2017. We envision their primary use to be validation and characterization of exoplanet targets from the NASA K2 and TESS missions as well as RV or other discovered exoplanets but the features of these new high-speed imaging instruments offer much more utility to the community. Our speckle interferometry instruments provide the highest resolution astronomical imaging available on any single telescope.

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245.05 – WIRC-POL: A near-IR spectro-polarimetric imager at Palomar Observatory

The 200-inch Hale Telescope at Palomar Observatory is the largest equatorial-mounted telescope in the world. Combining a large aperture, extremely stable tracking, and no differential motion of optics, it introduces low and stable instrument polarization, making it uniquely suited for time-resolved polarimetry. Its prime focus currently hosts the Wide-field InfraRed Camera (WIRC), which is being refurbished with a new H2 detector, 32 channel readout electronics, grism, focal-plane mask and polarization grating. This will transform it into WIRC-POL — a machine for high-precision photometry, and slitless low-resolution (R~150) spectroscopy and spectro-polarimetry. Two key science programs are starting in 2017: (1) a large spectro-polarimetric survey of approximately 1000 LTY field brown dwarfs, probing atmospheric composition, physical properties, and cloud dynamics at the L-T transition, and (2) a survey of transiting exoplanets, using the high photometric stability and slitless spectroscopy mode to characterize exoplanet atmospheres from spectra obtained in transit and secondary eclipse, and search for transit-timing variations in multiple planet systems. Here we present an overview of the instrument upgrades and the exciting scientific questions we aim to address.

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Contributing team(s): WIRC-POL team

245.06 – Hobby-Eberly Telescope Optical Transmission Spectroscopy of the Hot Jupiter WASP-12b

Transmission spectroscopy of exoplanetary atmospheres is an extremely useful tool that can be used for understanding exoplanetary composition as well as potentially revealing star-planet interactions from radiation, magnetic fields, and more. The hot Jupiter planet WASP-12b is interesting in that it is very close to its star (0.02 AU), has a large calculated scale height, has had water and metals detected in its atmosphere, and has had varying observational and theoretical constraints placed on its C/O ratio. Here we present a preliminary analysis of the optical transmission spectrum of WASP-12b taken with the Hobby-Eberly Telescope (HET). Our data covers the optical wavelength range from approximately 4800 to 6850 Angstroms. Most notably this includes two Balmer lines of hydrogen (H-alpha at 6563 Angstroms and H-beta at 4861 Angstroms) and the sodium D doublet (at 5890 and 5896 Angstroms). Due to the relative faintness of the system's central star and different instrumental settings, the analysis involves several challenges that are not present in previous transmission spectroscopy observations with the HET.

This work is supported by NASA Exoplanet Research Program grant 14-XRP14_2-0090 to the University of Nebraska-Kearney. The Hobby-Eberly Telescope is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford

University, Ludwig-Maximilians-Universitat Munchen, and Georg-August-Universitat Gottingen and is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly.

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245.07 – Using Transmission Spectroscopy to Determine the Rotation Rate of HD 189733b

It is essential to determine atmospheric dynamics of exoplanets in order to gain a complete understanding of their characteristics, such as their chemical composition, radiative transfer processes, and, eventually, their habitability. One of the main observables used to study an exoplanet atmosphere is its transmission spectrum, the shape and intensity of which are inherently entwined with atmospheric and planetary dynamics. We are particularly interested in how the transmission spectrum can be used to determine the rotation rate of hot Jupiters (closely-orbiting, Jupiter-sized exoplanets, which are expected to be tidally locked) by fitting high resolution observed spectra to models. These high-resolution spectra (R ~ 105) detect atmospheric and planetary motions on order of kilometers per second, and we have developed a model that generates transmission spectra of a similar resolution. We begin with a 3D General Circulation Model that (for a given rotation rate) self-consistently models atmospheric and planetary motion by solving a combination of meteorology and radiative transfer equations. The result is a three-dimensional map of the temperature, pressure, and wind speed at several thousand points within our three-dimensional model atmosphere. The atmospheric output is then interpreted by our transmission spectrum code to calculate the widths, Doppler shifts, and intensities of the spectral lines for given chemical concentrations. By accurately modeling the high resolution spectra using twelve different rotation rates, under two different chemical composition regimes, and fitting them to the observed spectra, we can more tightly constrain the rotation rate of our planet of interest, HD 189733b. In a previous study, its rotation rate was determined within a confidence interval of 1.5σ, and we aim to improve upon this measurement by comparing this more accurate model to higher resolution observations.

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245.08 – Determining Vsin(i) of Young Planet-hosting Stars

Constraining the spin-orbit alignment of close-in planets in young systems can provide insight on their migratory history. We can combine Vsin(i) with measurements of the stellar rotation period and radius to determine the star's orbital inclination, which we can compare to that of the planet as determined from the transit. Vsin(i) is determined from the rotational broadening on the star's spectral lines, so it is ideal to work with young, fast-rotating stars where broadening is more easily measured. We measure Vsin(i) of seven planet-hosting stars within the Praesepe star cluster by using high-resolution spectra from the Immersion Grating INfrared Spectrometer (IGRINS) in the K and H band filters. We develop a program to fit the model onto each order of the spectra using a set of optimized parameters which takes into account complicating factors such as instrumental broadening, stellar motion, and atmospheric turbulence. For our final result, we find that all planet hosts are spin-orbit aligned within measurement errors.

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245.09 – A search for inversion layers in hot Jupiters with high-resolution spectroscopy

At present, the existence of thermal inversion layers in hot Jupiter atmospheres is uncertain due to conflicting results on their detection. However, understanding the thermal structure of exoplanet atmospheres is crucial to measuring their chemical compositions because the two quantities are highly interdependent. Here, we present high-resolution infrared spectroscopy of a hot Jupiter taken at 3.5 μm with CRIRES (R~100,000) on the Very Large Telescope. We directly detect the spectrum of the planet by tracing the radial-velocity shift of water features in its atmosphere during approximately one tenth of its orbit. We removed telluric contamination effects and the lines of the host star from our observed combined light spectra using singular value decomposition, then cross-correlated these processed spectra with a grid of high spectral resolution molecular templates containing features from water, methane, and carbon dioxide. The templates included atmospheric profiles with and without thermal inversion i.e. emission and absorption lines, respectively. We find evidence of water emission features in the planet's dayside spectrum at a signal-to-noise of 4.7, indicative of a thermal inversion in the planet's atmosphere within the pressures ranges probed by our observations. The direct detection of emission lines at high spectral resolution in the planet spectrum make it one of the most unambiguous detections of a thermal inversion layer in an exoplanet atmosphere to date. However, we are carrying out further data analysis to ensure the robustness of the signal. Future observations of other molecules that could cause inversion layers, e.g. titanium oxide, would provide strong additional evidence of the inversion and help further our understanding of the behavior of highly irradiated giant planet atmospheres.

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245.10 – Regular satellite formation and evolution in a dead zone

The dead zone in a circumplanetary disk is a non-turbulent region at the disk midplane that is an ideal location for regular satellite formation. The lower viscosity in the dead zone allows small objects to accrete and grow. We model the evolution of a circumplanetary disk with a dead zone for a range of disk and dead zone parameters. We investigate how these affect the formation and subsequent evolution of regular satellites that form in the disk.

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245.11 – Quantifying the Effects of Temperature on Rocky Planets

Rocky planets can be very diverse in structure and composition compared to the Earth. Their temperature profiles could also differ greatly from Earth's depending on their mass and distance from their host stars. Interior structure models of rocky exoplanets have not yet studied the full range of possible temperature profiles. We develop a simulation, PyPlanet, for a rocky planet with an arbitrary number of layers and equations of state. We apply this model to explore many possible temperature profiles and quantify the thermal effects on the mass-radius relations of rocky planets.This detailed modeling will be crucial for making robust inferences about rocky planet structure and composition from transit and radial velocity observations.

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245.13 – Transit Timing Variation analysis with Kepler light curves of KOI 227 and Kepler 93b

By searching for transit signals in approximately 150,000 stars, NASA's Kepler Space telescope found thousands of exoplanets over its primary mission from 2009 to 2013 (Tenenbaum et al. 2014, ApJS, 211, 6). Yet, a detailed follow-up examination of Kepler light curves may contribute more evidence on system dynamics and planetary atmospheres of these objects. Kepler's continuous observing of these systems over the mission duration produced light curves of sufficient duration to allow for the search for transit timing variations. Transit timing variations over the course of many orbits may indicate a precessing orbit or the existence of a non-transiting third body such as another exoplanet. Flux contributions of the planet just prior to secondary eclipse may provide a measurement of bond albedo from the day-side of the transiting planet. Any asymmetries of the transit shape may indicate thermal asymmetries which can measure upper atmosphere motion of the planet. These two factors can constrain atmospheric models of close orbiting exoplanets. We first establish our procedure with the well-documented TTV system, KOI 227 (Nesvorny et al. 2014, ApJ, 790, 31). Using the test case of KOI 227, we analyze Kepler-93b for TTVs and day-side flux contributions. Kepler-93b is likely a rocky planet with $R = 1.50 \pm 0.03$ Earth Radii and $M = 2.59 \pm 2.0$ Earth Masses (Marcy et al. 2014, ApJS, 210, 20). This research is funded by a NASA EPSCoR grant.

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245.14 – Blue Skies through a Blue Sky: an attempt to detect Rayleigh scattering in an exoplanet atmosphere from a ground-based telescope

When studying planetary atmospheres, scattering signatures, such as Rayleigh scattering, can often be the most easily characterized signal. This is especially true in terrestrial atmospheres, where Rayleigh scattering is the dominant spectral feature in optical wavelengths. These scattering signatures, unlike molecular or atomic line absorption, are broad and continuous, and are char- acterized by a single slope. Rayleigh scattering provides an imporant glimpse into the atmospheric composition of an exoplanet's atmosphere, and a Rayleigh scattering detection on a smaller, ground-based telescope can be a useful method to identify interesting science targets for larger, space-based telescopes.

We will present observations of three exoplanets using the HYDRA multi- object spectrometer on the WIYN telescope at Kitt Peak National Observatory. We obtained two transits each for WASP 12b and GJ 3470b, and one transit for HD 189733b, for a range of wavelengths between 4500 Å and 9201 Å. A successful Rayleigh scattering detection in the atmospheres of these planets using this in- strument would represent a step forward in our current detection capabilities and open up the study of planetary atmospheres to smaller, ground-based telescopes.

Data presented herein were obtained at the WIYN Observatory from telescope time allocated to NN-EXPLORE through the scientific partnership of the National Aeronautics and Space Administration, the National Science Foundation, and the National Optical Astronomy Observatory. This work was supported by a NASA WIYN PI Data Award, administered by the NASA Exoplanet Science Institute.

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245.15 – The HD 202206 Exoplanetary System: Companion Masses and (in)Stability

Correia et al. (2005) first reported a Doppler spectroscopy discovery of the exoplanetary companions to HD 202206, obtaining values M_b sin i=17.4MJup and M_c sin i=2.44MJup. The title of their paper "A pair of planets around HD 202206 or a circumbinary planet?" indicated a need for astrometry capable of measuring inclination. Hence, we included this system in a Hubble Space Telescope Fine Guidance Sensor (FGS) astrometry proposal to measure the architectures of several promising candidate systems, all relatively nearby with companion M sin i values and periods suggesting measurable astrometric amplitudes.

Simultaneous modeling of thirty-one FGS observation sets obtained over three years and the Correia et al. radial velocities yields a parallax and preliminary mass estimates for HD 202206 b and HD 202206 c.

Using either the original Correia et al. (2005) or the Couetdic et al. (2010) M sin i values, HD 202206 fails the stability criteria derived by Petrovich (2015). Thus far our astrometric masses have done nothing to ameliorate that situation. A combination of additional RV measurements and Gaia astrometry should further illuminate our understanding of the dynamics of this interesting system.

References
Correia et al. (2005) A&A, 440, 751
Couetdic et al. (2010) A&A, 519, A10
Petrovich (2015) ApJ, 808, 120

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245.16 – Exoplanet Transit Analysis of KIC 8462852

KIC 8462852 was among the ~100k stars observed by NASA's *Kepler* satellite over its primary mission. Unlike a typical exoplanet harboring star, its light curve exhibits an abnormal shape with multiple unexpectedly large depths. Several explanations for this behavior have been presented, such as circumstellar dust or a family of comets in orbit around the star as being the source of its fluctuations in brightness. We focus on the exoplanet hypothesis and apply the analysis of the transit detection method to KIC 8462852's light curve. From this method we determined radii and semi-major axes of possible exoplanets in the range of 0.7 to 7.21 M_J (Jupiter Masses) and 8.27 to 402.65 AU, respectively. By method of maximum likelihood, we fit probability distribution functions to histograms of observed planet radii and semi-major axes. Using these functions to calculate tail-probabilities for the planet masses and orbital semi-major axes from our transit analysis, we determined that our exoplanets have a probability of being drawn from observed distributions of 2.41×10^{-163} to 7.59×10^{-5} % and therefore verify the improbability of the exoplanet explanation hypothesis.

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245.17 – A Search for Host Stars of Free-Floating Planetary Mass Objects

Over the past decade, the number of free-floating planetary-mass objects (FFPMOs) and imaged planets in widely-bound orbits (from hundreds to thousand of AU) have increased steadily, but the origin of these objects and the relationship between them is unclear. To test if known free-floating objects could actually be distant companions to stars, we searched for wide co-moving companions around a sample of 77 young brown dwarfs and FFPMOs using the PPMXL proper motion catalog. Contamination rates (the probability of field stars co-moving by chance) were then calculated using nearby but unrelated fields, and host star candidates were further vetted using their positions in color magnitude diagrams. Using this method, we recovered all previously known widely-bound host stars within our sample and identified several promising widely separated systems, with separations ranging from 10^4-10^5 AU. Follow up radial velocities are currently being obtained to validate the shared space motion of the most promising candidates; if confirmed, these will be the widest planetary systems known.

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245.18 – Obliquities of Exoplanet Host Stars from Precise Distances and Stellar Angular Diameters

The next generation of exoplanet space photometry missions proposed by both NASA and ESA promise to discover small transiting planets around the nearest and brightest main-sequence stars. The physical and rotational properties of these stars, in conjunction with Gaia-precision distances, can be used to determine the inclination of the stellar rotation axis. Given edge-on orbital paths for transiting planets, stellar inclinations can be interpreted as obliquities projected into the line of sight, which can be used to more clearly reveal the system architectures of small planets and the factors that drive their orbital evolution. To demonstrate the method, we use a sample of simulated target stars for the NASA Transiting Exoplanet Survey Satellite (TESS) mission. Based on predicted characteristics of these stars and likely measurement uncertainties, we show that the expected TESS discoveries will allow us to finely differentiate the true underlying obliquity distribution. Under conservative assumptions in our illustrative example -- in which the true distribution is assumed to contain systems drawn from both well-aligned and isotropic distributions (e.g., due to multiple migration channels) -- the fraction of well-aligned systems can be determined to within 0.15, thus enabling constraints on the evolutionary processes that shape system architectures. Moreover, because of the excellent astrometric precision expected from Gaia, this technique will also be applicable to the large number of planets already discovered by Kepler orbiting much more distant stars.

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245.19 – The Perfect Map

Thermal phase curves and eclipses provide the best constraints on the atmospheric temperature and circulation of short-period planets. The temperature structure of a planet can be expressed as a sum of spherical harmonics. Each spherical harmonic has a corresponding harmonic light curve, which is a function of system geometry (orbital inclination, planet/star radius ratio, and orbital separation). Depending on system geometry, there may be significant degeneracies between harmonic light curves: very different maps may produce similar light curves. Here we use Principal Component Analysis (PCA) to identify and quantify these degeneracies. Starting from a set of harmonic light curves, we use PCA to calculate the set of orthonormal "eigen-light-curves". In addition, PCA determines the importance of every eigen-light-curve, telling us which components provide the most information. From these eigen-curves we can then reconstruct corresponding "eigen-maps". These eigen-light-curves and eigen-maps are the mathematically ideal basis set for inverting phase curve and eclipse data to create maps of a planet's emission. We determine how many eigen-maps can be fit to full-orbit light curves, as a function of photometric precision and system geometry.

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245.20 – How obliquitiy influences the climate of aquaplanets

The obliquity of the rotation axis plays an important role in the climate and the atmospheric circulation of planets. Using a general circulation model of intermediate complexity, Planet Simulator (PlaSim), we modelled aquaplanets at varying obliquities between 0°and 90°. Changing obliquity leads to significant changes in the circulation and surface temperature. For planets with low obliquities, the climate is warm, and the mean surface temperatures remain almost constant throughout the year. For high obliquities, the mean global temperatures drop below freezing, and the planets experience strong seasons with large regions covered in ice at times throughout the year. These two regimes are the result of changes in the Hadley cells. These findings provide insight into our own planet's climate as well as the climates and habitability of exoplanets.

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245.21 – Small Friends of Hot Jupiters

Hot Jupiters are Jupiter-sized gas giant exoplanets that closely orbit their host star in periods of about 10 days or less. Early models hypothesized that these exoplanets formed away from the star, then over time drifted to their characteristically closer locations. However, new theories predict that Hot Jupiters form at their close proximity during the process of core accretion (Batygin et al. 2015). In fact, a super-Earth and a Neptune-sized exoplanet have already been detected in the Hot Jupiter-hosting star WASP-47 (Becker et al. 2015). We will present our analysis of radial velocity time series plots to determine whether low–mass, short–period planets have been previously overlooked in systems of stars which host Hot Jupiters.

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245.22 – The Occurrence Rate of Hot Jupiters

As the first kind of exoplanet to be discovered, hot Jupiters have always been objects of interest. Despite being prevalent in radial velocity and ground-based surveys, they were found to be much rarer based on Kepler observations. These data show a pile-up at radii of 9-22 Rearth and orbital periods of 1-10 days. Computing accurate occurrence rates can lend insight into planet-formation and migration-theories. To get a more accurate look, the idea of reliability was introduced. Each hot Jupiter candidate was assigned a reliability based on its location in the galactic plane and likelihood of being a false positive. Numbers were updated if ground-based follow-up indicated a candidate was indeed a false positive. These reliabilities were introduced into an occurrence rate calculation and yielded about a 12% decrease in occurrence rate for each period bin examined and a 25% decrease across all the bins. To get a better idea of the cause behind the pileup, occurrence rates based on parent stellar metallicity were calculated. As expected from previous work, higher metallicity stars yield higher occurrence rates. Future work includes examining period distributions in both the high metallicity and low metallicity sample for a better understanding and confirmation of the pile-up effect.

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245.23 – Constraining hot Jupiter's atmospheric structure and dynamics through Doppler shifted emission spectra

In recent years, astronomers have begun successfully observing the atmospheres of extrasolar planets using ground-based telescopes equipped with spectrographs capable of observing at high spectral resolution (R~105). Such studies are capable of diagnosing the atmospheric structure, composition, and dynamics (winds and rotation) of both transiting and non-transiting exoplanets. However, few studies have examined how the 3-D atmospheric dynamics could alter the emitted light of hot Jupiters at such high spectral resolution. Here, we present a model to explore such influence on the hot Jupiters' thermal emission spectra. Our aim is to investigate the extent to which the effects of 3-D atmospheric dynamics are imprinted on planet-averaged thermal emission spectra. We couple together a 3-D general circulation model of hot Jupiter atmospheric dynamics (Rauscher

& Menou, 2012) with a radiative transfer solver to predict the planet's disk-integrated emission spectrum as a function of its orbital phase. For the first time, we self-consistently include the effects of the line-of-sight atmospheric motions (resulting from winds and rotation) in the calculation to produce Doppler-shifted spectral line profiles that result from the atmospheric dynamics. We focus our study on three benchmark hot Jupiters, HD 189733b, HD 209458b, and WASP-43b which have been the focus of previous detailed observational studies. We find that the high-resolution Doppler shifted thermal emission spectra can be used to diagnose key properties of the dynamical atmosphere – the planet's longitudinal temperature and wind structure, and its rotation rate.<embed height="0" id="xunlei_com_thunder_helper_plugin_d462f475-c18e-46be-bd10-327458d045bd" type="application/thunder_download_plugin" width="0" />

Author(s): Jisheng Zhang[1], Eliza Kempton[1], Emily Rauscher[2]
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245.24 – Let's Grow Old Together: The Simultaneous Evolution of Planet and Host Star

The low-density sub-Neptune sized planets that Kepler found in abundance are intriguing due to their unexpected survival at close orbital separations (a< 1 AU) and their absence from our Solar System. Several of these planets orbit stars that have evolved off the main sequence, or are nearing the end of their main sequence lifetimes (e.g., Kepler-10, Kepler-11, Kepler-36). Previous simulations of sub-Neptune size planet evolution, however, have neglected the changing stellar irradiance incident on the planet. We adapt MESA (Modules for Experiments in Stellar Astrophysics) to evolve low-mass exoplanets with hydrogen-helium envelopes and model how their radii and mass loss rates change as their host stars evolve off the main sequence. We assess the extent to which implementing changing irradiation improves characterization of the possible current and initial compositions of observed exoplanets.

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245.25 – The effect of stellar radiation on exoplanet atmospheric heating and mass loss

Our project aims to investigate the influence of stellar activity and high-energy radiation on short-period transiting exoplanet atmospheric heating and mass loss. Mass loss in closely orbiting gaseous exoplanets could be significant enough to evaporate a significant portion of the atmosphere over the total system lifetime. A current question of interest is how Neptune-class gas giants might change over time from being exposed to intense X-ray and UV flux radiated from the star. Our research aims to estimate current and total mass loss for four Neptune-class exoplanets that have both measured radii and masses. We use computer software to reduce and analyze Chandra X-ray observations of Neptune-class exoplanets, including HAT-P-11b and archival data of GJ 436b, to calculate the high-energy incident flux for each planet. We then estimate the current-epoch mass-loss rate and construct integrated mass-loss histories. We test whether planets receiving the greatest dose of high-energy radiation also tend to be the lowest mass and the most dense, suggestive of evaporation. These observations provide essential empirical input for understanding and modeling the potential evolutionary transformation of hot gas giants into less massive and more dense remnants.

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245.26 – Atmospheric evaporation in super-Earth exoplanet systems

We investigate the influence of stellar activity on atmospheric heating and evaporation in four super-Earth exoplanets: HD 97658 b, GJ 1214 b, 55 Cnc e, and CoRoT-7 b. We use X-ray observations of the host stars to estimate planetary mass loss. We extracted net count rates from a soft band image, converted it to flux using PIMMS for a standard coronal model, calculated the intrinsic stellar luminosity, and estimated the current-epoch mass-loss rate and the integrated mass lost. Our aim is to determine under what circumstances current super-Earths will have experienced significant mass loss through atmospheric irradiation over the system lifetime. We hypothesize that closely-orbiting exoplanets receiving the greatest amount of high-energy stellar radiation will also tend to be sculpted into lower mass and more dense remnant cores.

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245.27 – Swift X-ray monitoring of M dwarf coronal variability

We present new Swift observations of two M dwarfs with known exoplanets: GJ 15A and GJ 674. GJ 15A b is around 5.3 Earth masses with an 11.4 day orbital period, while GJ 674 is around 11.1 Earth masses with a 4.7 day orbital period. GJ 15A was observed several times in late 2014 and then monitored at approximately weekly intervals for several months in early 2016, for a total exposure of 18 ks. GJ 674 was monitored at approximately weekly intervals for most of 2016, for a total exposure of 40 ks. We provide light curves and hardness ratios for both sources, and also compare to earlier archival X-ray data. Both sources show significant X-ray variability, including between consecutive observations. We quantify the energy distribution for coronal flaring, and compare to optical results for M dwarfs from Kepler. Finally, we discuss the implications of M dwarf coronal activity for exoplanets orbiting within the nominal habitable zone.

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245.28 – Effects of exomoon's magnetic field on generation of radio emissions

In the recent work by Noyola et al. (2014, 2016), a novel technique of detection of exomoons through the radio emissions produced by the magnetic field interactions between exoplanet-exomoon pair is emulated based upon the processes occurring in the Jupiter-Io system. Their calculations have shown that the radio signal from the distant extra-solar planetary systems is detectable by current technology provided that the systems emanating the radio waves are relatively closer, have some form of atmosphere, and have larger exomoons. In this work, we explore the effect of exomoon's magnetic field on the radio emission processes by considering a hypothetical magnetic exomoon and re-calculating the resulting radio flux. Then, a limit to the exomoon's magnetic field is proposed based on the signal amplification versus the dampening effect the magnetic field induces on the secondary conditions such as the containment of ions within the exomoon's magnetic field and the effect of the plasma torus density that co-orbits with the moon. The energy from the exomoon's magnetic field is expected to amplify the radio signal, hence increasing the probability of detection of the first exomoons.

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245.29 – The Influence of Volcanic Aerosols on Planetary Habitability

On rocky planetary bodies such as Proxima Centuri b, the detection of sulphate aerosols may indicate volcanism and tectonic activity;

ingredients hypothesized to be necessary for planetary habitability. However, due to the effect of atmospheric aerosols on a planet's energy balance, coupled with eruption constituent and frequency uncertainties, the potential impact of volcanic activity on planetary habitability remains unresolved. Here, we employ multi-column climate models in conjunction with a parameter space approach to test the effect of volcanic aerosols on planetary climate with various climate sensitivities. Preliminary results indicate that volcanic activity could provide a means of extending the inner edge of the habitable zone (IHZ), depending on eruption constituents and frequency. Previous work using transit spectra simulations have demonstrated the possibility of detecting transient aerosols of volcanic origin. Our work investigates the range of habitability implications detection of such aerosols would imply.

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246 – Large Scale Structure, Cosmic Distance Scale Poster Session

246.01 – A Catalog of Proper Motions to Dynamically Measure the Hubble Expansion and the Evolution of Large-Scale Structure

Objects and structures gravitationally decoupled from the Hubble expansion will appear to shrink in angular size as the universe expands. Observations of extragalactic proper motions can thus directly reveal the cosmic expansion without reliance on canonical cosmological models. Relatively static structures such as galaxies or galaxy clusters will show an apparent fractional angular compression of ~ 15 microarcseconds/yr in the local universe. Pairs of gravitationally bound objects (separations less than ~ 150 Mpc) will also show a deviation from pure cosmic expansion due to the collapse of large-scale structure. We have created a catalog of quasar proper motions to detect and measure these effects through the angular expansion / contraction of quasar pairs rather than with the Doppler method, which relies on cosmological models such as the "distance ladder." With our catalog, we have confirmed that large separation pairs (600 - 10^4 Mpc comoving) show no net convergence or divergence, 0.18 +/- 0.18 microarcseconds/yr, consistent with Hubble expansion and significantly inconsistent with static structures, as expected. For pairs with comoving separations 150 < r < 300 Mpc, we have detected an unexplained expansion that is faster than the Hubble expansion, 9.7 +/- 1.7 microarcseconds/yr. For pairs with separations < 150 Mpc, we expect a pairwise contraction from the collapse of large-scale structure, but lack enough pairs to significantly detect this effect. We measure an insignificant divergence of 6.3 +/- 2.8 microarcseconds/yr. We are currently expanding our proper motion catalog using the VLBA, Gemini and Gaia in order to dynamically detect the evolution of large-scale structure. This will be the largest extragalactic proper motion catalog to date and will include new and updated proper motions with errors < 1 microarcseconds/yr for many well-known quasars. Finally, this project will provide a dynamical means to confirm the isotropy of the universe, to measure the Hubble constant, and to measure or constrain the primordial gravitational wave background.

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246.02 – Using Quasar Pairs to put Constraints on Cosmological Parameters

For the last five billion years the universe has been expanding in size at an increasing rate. With modern technology we are able to observe objects at very high redshift, which were created in the early universe. Being able to analyze and observe these objects allows us to put specific constraints on the universe (age, size, dark matter fraction...etc). Looking at the spectra of highly redshifted objects, such as quasars, we can see a series of absorption lines called the Lyman alpha forest. The angular correlation in the Lyman alpha spectra of quasar pairs allows us to measure the size of the absorbing objects. This works best at very small-scale (below one arcmin). The most recent use of this method consisted of 32 quasar pairs and only two of those had a sky separation below 1 arcmin (Coppolani et al., 2006). The sample size that is used in this work is from the SDSS-III DR12. This catalog has over 1500 quasar pairs below two arcmin separation, giving us much lower error bars, and therefore putting much better constraints on the cosmological parameters that can be inferred from the correlation function.

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246.03 – Detecting the BAO using Discrete Wavelet Packets

We use wavelet packets to investigate the clustering of matter on galactic scales in search of the Baryon Acoustic Oscillations. We do so in two ways. We develop a wavelet packet approach to measure the power spectrum and apply this method to the CMASS galaxy catalogue from the Sloan Digital Sky Survey (SDSS). We compare the resulting power spectrum to published BOSS results by measuring a parameter β that compares our wavelet detected oscillations to the results from the SDSS collaboration. We find that β=1 indicating that our wavelet packet methods are detecting the BAO at a similar level as traditional Fourier techniques. We then use wavelet packets to decompose, denoise, and then reconstruct the galaxy density field. Using this denoised field, we compute the standard two-point correlation function. We are able to successfully detect the BAO at $r \approx 105\ h^{-1}$ Mpc in line with previous SDSS results. We conclude that wavelet packets do reproduce the results of the key clustering statistics computed by other means. The wavelet packets show distinct advantages in suppressing high frequency noise and in keeping information localized.

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246.04 – Does the HI Mass Function Vary with Environment?

Based on analysis of a large dataset from the ALFALFA survey, Jones et al. (2016) recently claimed that the slope of the HI mass function is constant across different galactic environments, defined by their density. They point out that this finding is "perplexing" given that many previous studies have found that the HI mass functions of groups of galaxies have flat slopes, while the general field has a relatively steep slope. I argue that the analysis of Jones et al., and similar analyses in the past, is flawed as they examine the HI mass function of the galaxies found in environments with a given density, summed across the survey, not the HI mass function actually present in the individual structures at that density. If the position of the knee in the HI mass function were to vary between these structures, then the slope of the HI mass function found by summing across all of the structures with a given density would be steeper than the slope actually found in the individual structures. For example, if a survey were to contain three groups of galaxies, all with flat HI mass functions, but with the 'knee', at the mass of the largest galaxy in the group, at 10^8, 10^9 and 10^{10} solar masses, then the summed HI mass function would appear to have a knee at 10^{10} solar masses and a steep slope below this, rather than the flat slope that is actually present in the individual environments. It is not possible, therefore, to say from the analysis of Jones et al. that there is no dependence of the HI mass function on environment. This scenario explains the "seemingly contradictory findings" of Jones et al. and the earlier studies of individual groups as being due to differences in what is being studies, without having to invoke methodological errors in the derivation of the HI mass function. The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation (AST-1100968), and in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association.

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246.05 – Galaxy Interaction in Overdense Environments

Examining protoclusters is an important method for developing our understanding of the formation and evolution of large galaxy clusters found in the local universe. Many of the z≈2-3 protoclusters contain overdensities of dusty star-forming galaxies (DSFG) which have stellar formation rates greater than 100 M_{sun}/year. Due to the short depletion time (≈100Myr) of molecular gas in the DSFGs contained in these protoclusters, the assembly of protoclusters is believed to be a rapid and occasional process. One possible mechanism for this rapid assembly is an enhanced frequency of interaction between galaxies. We analyzed one of these protoclusters at z= 2.1 to determine if the frequency of mergers is affected by the overdense environment. Previous works have shown that galaxies may interact more frequently in overdense environments but do not provide adequate significance to confirm this connection. Using the COSMOS2015 catalog, galaxies in the protocluster are evaluated with the following criteria for merger candidates: existence of neighboring galaxies in a 10-30 kpc radius, agreement of photometric redshift with neighbor(s) within 1σ, and stellar mass ratio calculation for merger candidates in terms of minor mergers (>4:1) and major mergers (1:1 - 4:1). Our analysis confirms that interacting galaxies are found more frequently in overdense environments (δ > 0.5). Based on further analysis using spectroscopic redshifts from the ZFIRE Survey to evaluate the uncertainty present by using the photometric redshifts, we find that σ_Δ/(1+z_s) = 0.05 for the photometric redshifts from z= 1.50 to z= 2.50. In the future it will be helpful to analyze mergers in other stages of interaction to see if the enhanced merger frequency is still evident.

Author(s): Derek Holman[1], Chao-Ling Hung[2]
Institution(s): *1. University of Tennessee at Chattanooga, 2. University of Texas at Austin*

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247 – Black Holes Poster Session

247.01 – Super-resolution Polarimetric Imaging of Black Holes using the Event Horizon Telescope

Black holes are thought to reside in the centers of many galaxies; however, due to their diminutive size, we have yet to directly detect and image a black hole. The Event Horizon Telescope (EHT), a global array for 1.3mm very long baseline interferometry (VLBI), has been designed to observe and image the supermassive black hole in the center of the Milky Way (Sagittarius A*), as well as the one in the center of the nearby giant elliptical galaxy M87. The nominal resolution of the EHT is around 30 µas, comparable to the size of the black hole's event horizon. For this reason, we require super-resolution to accurately reconstruct images in total intensity and linear polarization. High fidelity polarimetric imaging can be used to test general relativity and to characterize the magnetic field structure surrounding black holes, which is important for understanding its role in mediating the innermost accretion and outflow region. We employ new sparse imaging techniques based on compressed sensing for linear polarimetry. Using synthetic data of M87 observations with the EHT, we find that our new techniques improve upon the standard CLEAN by a factor of ten regardless of resolution, as measured by the differences in mean squared error (MSE). We conclude that compressed sensing proves to be an effective method for linear polarimetric imaging.

Author(s): Mollie Pleau[2], Kazunori Akiyama[1], Vincent L. Fish[1]
Institution(s): *1. MIT Haystack Observatory, 2. Smith College*

247.02 – Optical Observations and Modeling of a Possible Black Hole HMXB and Cygnus X-1 Progenitor

HD96670 is a single line spectroscopic binary in the Carina OB2 association. The source shows variable HeII emission in the GOSSS survey of O-star spectra (Sota et al. 2014). We did follow up high resolution spectroscopic observations with the 1.5m SMARTS telescope and CHIRON spectrograph, and improved the mass function of the system to f(m) = 0.1026 M_sun. We also carried out photometric observations with the AAVSO astronet telescope network and the 1.3m SMARTS telescope and determined an orbital period of P = 5.2838 days. This means that for an O8.5V primary, the minimum secondary mass is > 3.4 M_sun, therefore ruling out a white dwarf or neutron star secondary. The most likely companion is either a B star, or a black hole. We also modeled the light curve using the PHOEBE light curve synthesis software in order to constrain the parameters of the system.

Author(s): Sebastian Gomez[1], Jonathan E. Grindlay[1]
Institution(s): *1. Harvard University*

247.03 – Long-term X-ray and Optical Monitoring of RZ2109

We present the results of a long-term monitoring of the X-ray and optical emission from the black hole in the extragalactic globular cluster RZ2109 aimed at determining the origin and nature of this accreting globular cluster black hole. We include analysis of three years of new Chandra X-ray data and Gemini and SOAR optical spectroscopy, along with archival X-ray and optical data. Previous work has shown that RZ2109 hosts a bright (L$_X \simeq 4 \times 10^{39}$ ergs/s) and moderately variable X-ray source, along with strong, broad [OIII] 5007 line emission. We use the extensive new data to quantify the variability in both the X-rays and bright [OIII]5007 emission line, and any potential relationship between these two.

It is possible this should give (L$_{5007} X \times 10^{37}$ ergs/s, with a velocity FWHM of $\simeq X$ km/s).

Author(s): Kristen C Dage[2], Steve E. Zepf[2], Thomas J. Maccarone3, Mark Peacock[2], Arunav Kundu[1]
Institution(s): *1. Eureka Scientific, 2. Michigan State University, 3. Texas Tech University*

247.04 – Longterm Multi-wavelength Monitoring of the Relativistic Tidal Disruption Event Swift J164449.3+573451

We present late-time multi-frequency radio and X-ray observations of the relativistic tidal disruption event Swift J164449.3+573451 (Sw 1644+57) extending through ~2000 days after the initial Swift discovery. We apply relativistic equipartition synchrotron arguments to the radio emission in order to constrain the late-time temporal evolution of the physical parameters of the jet, including the size of the emitting region and the surrounding density profile, as well as the minimum total energy. The equipartition parameters are used to infer the cooling frequency and place constraints on the fraction of energy in the electrons and magnetic field respectively. We find that the system is not in equipartition. Chandra X-ray observations beginning ~1400 days after the initial Swift/BAT trigger are used to determine the source of the late-time X-ray emission, following a rapid decline at 500 days, indicating a transition to a thin disk as the accretion rate falls below the Eddington accretion rate. We explore scenarios in which the X-ray emission does not emerge from the forward shock based on our modeling of the data. These results are combined with earlier data in order to characterize the evolution of the event over a duration of five years following the initial onset of the jet.

Author(s): Tarraneh Eftekhari[1], Edo Berger[1], Ashley Zauderer[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

247.05 – The contribution of SUBARU-HSC faint galaxies to the Spitzer-CIB fluctuations in COSMOS

We investigate the possible contribution of the diffuse background of optical galaxies to the source subtracted cosmic infrared background fluctuations of the COSMOS field. Using data from the COSMOS catalogue and from HSC observations, we artificially created optical galaxies images of the COSMOS. The power spectrum at four different AB magnitude intervals, [mlim, mlim-2, mlim-4, mlim-6], and four redshift intervals, [0-1, 1-2, 2-3, 3-4], for these images were then calculated and compared to the power spectrum of an infrared image of the same field. We found that the coherence of these two images was close to zero and determined that the optical galaxies must only contribute a negligible contribution to the infrared background in the COSMOS field.

Author(s): Joyce Guo[1], Nico Cappelluti[1], Yanxia Li[1], Rachel Ann Cooper[1]
Institution(s): *1. Yale University*

247.06 – Exploring Sources of Gravitational Waves From Star Cluster Dynamics

The recent detection of ripples in space-time by the Laser Interferometer Gravitational-wave Observatory (LIGO) has ushered in the age of gravitational wave astronomy. Binary black hole systems formed in the center of modest star clusters offer a possible gravitational wave source detectable by the LIGO or Laser Interferometer Space Antennae (LISA) collaborations. We simulate clusters containing 1-40K objects using direct integration from a customized version of NBODY6++GPU. We identify Binary Black Hole (BBH) objects of interest by an inspiral time sufficiently less than the age of the universe such that their coalescence might be detectable. Such objects are tracked through time within our N-body simulations to characterize the role of dynamics in the evolution of the BBH system using member exchanges and large orbital eccentricity changes as indicators of dynamic's influence. We produce 41 BBH system candidates for detection by LIGO, all of which are dynamically formed. We observe several trends in the production of these potential BBH LIGO sources: a low-N cutoff in initial cluster size between 1-5K objects, high eccentricity oscillations, and the frequent formation of stable triple systems with the BBH as the inner binary.

Author(s): Joshua Fuhrman[1], Aaron M. Geller[2], Carl L. Rodriguez[2], Frederic A. Rasio[2]
Institution(s): *1. Carnegie Mellon University, 2. Northwestern University*

247.07 – Distinguishing Between Formation Channels for Binary Black Holes with LISA

The recent detections of GW150914 and GW151226 imply an abundance of stellar-mass binary-black-hole mergers in the local universe. While ground-based gravitational-wave detectors are limited to observing the final moments before a binary merges, space-based detectors, such as the Laser Interferometer Space Antenna (LISA), can observe binaries at lower orbital frequencies where such systems may still encode information about their formation histories. In particular, the orbital eccentricity and mass of binary black holes in the LISA frequency band can be used together to discriminate between binaries formed in isolation in galactic fields and those formed in dense stellar environments such as globular clusters. In this letter, we explore the orbital eccentricity and mass of binary-black-hole populations as they evolve through the LISA frequency band. Overall we find that there are two distinct populations discernible by LISA. We show that up to ~90% of binaries formed either dynamically or in isolation have eccentricities measurable by LISA. Finally, we note how measured eccentricities of low-mass binary black holes evolved in isolation could provide detailed constraints on the physics of black-hole natal kicks and common-envelope evolution.

Author(s): Katelyn Breivik[2], Carl L. Rodriguez3, Shane L. Larson[1], Vassiliki Kalogera[2], Frederic A. Rasio[2]
Institution(s): *1. Adler Planetarium, 2. Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) and Dept. of Physics and Astronomy, Northwestern University, 3. MIT-Kavli Institute for Astrophysics and Space Research*

247.08 – Chandra HETGS and VLBI Observations of SS 433

In a previous Chandra High Energy Transmission Grating Spectrometer (HETGS) observations of SS 433, we found a large Doppler shift change on a time scale of 20 ks, a time much shorter than the known dynamical times. The rapid change could be related to the formation and ejection of a jet knot, as observed in VLBI observations, perhaps as a leptonic jet impinges on a disk wind and shock heats it. New data were obtained to test this model in a long continuous HETGS observation. The VLBA and Chandra HETGS data were obtained but while no radio ejections were observed during the Chandra observation, there were interesting aspects to the observations. First, although the jet emission lines were expected to vary with the usual precession period (162 days) or with the period of the nodding motion (6.6 days), we did not detect the expected Doppler shifts in over 120 ks of exposure. Furthermore, there is new evidence for jet curvature that has not been previously reported.

Support for this work was provided in part by the National Aeronautics and Space Administration (NASA) through the Smithsonian Astrophysical Observatory (SAO) contract SV3-73016 to MIT for support of the Chandra X-Ray Center (CXC), which is operated by SAO for and on behalf of NASA under contract NAS8-03060. Support was also provided by NASA under grant GO4-15040A to MIT.

Author(s): Herman L. Marshall[2], David H. Roberts[1], Norbert S. Schulz[2]
Institution(s): *1. Brandeis University, 2. MIT*

247.09 – Measuring X-ray Binary Accretion State Distributions in Extragalactic Environments using XMM-Newton

X-ray binary systems (XRBs) in the MW can exist in several different accretion states, and many have been found to vary along specific tracks on intensity-color diagrams. Observationally measuring the distributions of these accretion states in a variety of environments can aid in population synthesis modeling and ultimately help us understand the formation and evolution of XRBs and their compact object components (i.e., black holes and neutron stars). Recent innovative studies with *NuSTAR* have demonstrated the utility of color-color and intensity-color diagrams in differentiating between XRB accretion states in extragalactic environments (NGC 253, M83, and M31). The key to *NuSTAR's* success is its sensitivity above »10keV, where spectral differences between accretion states are most pronounced. However, due to the relatively low spatial resolution and large background of *NuSTAR*, the constraints from these diagrams is limited to only bright sources in nearby galaxies. In this poster, we present evidence that *XMM-Newton* observations of M83 in the 4.0-12.0 keV range can be used to create similar color-intensity and color-color diagrams and therefore differentiate between these accretion states. We will further discuss plans to leverage *XMM-Newton's* vast archive and 17-year baseline to dramatically expand studies of accretion state distributions and state transitions for XRB populations in extragalactic environments.

Author(s): Lacey West4, Bret Lehmer4, Mihoko Yukita[2], Ann E. Hornschemeier3, Andrew Ptak3, Daniel R. Wik3, Andreas Zezas[1]
Institution(s): *1. Crete, 2. Johns Hopkins University, 3. NASA GSFC, 4. University of Arkansas*

247.10 – Active Galactic Nuclei from He II: a more complete census of AGN in SDSS galaxies yields a new population of low-luminosity AGN in highly star-forming galaxies

In order to perform a more complete census of active galactic nuclei (AGN) in the local Universe, we investigate the use of the He II emission line diagnostic diagram by Shirazi & Brinchmann (2012) in addition to the standard methods based on other optical emission lines. The He II based diagnostics is more sensitive to AGN ionization in the presence of strong star formation than conventional line diagnostics. We survey a magnitude-limited sample of 81,192 galaxies from the Sloan Digital Sky Survey Data Release 7 at $0.02 < z < 0.05$ and apply both the conventional BPT emission line diagnostic diagrams, as well as the He II diagram to identify AGN. In this sample, 1,075 galaxies are selected as AGN using the BPT diagram, while an additional 234 galaxies are identified as AGN using the He II diagnostic, representing a 22% increase of AGN in the parent galaxy sample. We use archival

Chandra observations to confirm the AGN nature of candidates selected through He II based diagnostic. Finally, we explore the host galaxy properties of these new He II selected AGN candidates and find that they are most common in star-forming galaxies on the blue cloud and on the main sequence where ionization from star-formation is most likely to mask AGN emission in the BPT lines. We note in particular a high He II AGN fraction in galaxies above the high-mass end of the main sequence where quenching is expected to occur. We discuss how this technique can help inform galaxy/black hole co-evolution scenarios.

Author(s): Rudolf E Baer[1], Anna Weigel[1], Lia F. Sartori[1], Kyuseok Oh[1], Michael Koss[1], Kevin Schawinski[1]
Institution(s): *1. ETH Zurich*

247.11 – You're Cut Off: HD and MHD Simulations of Truncated Accretion Disks

Truncated accretion disks are commonly invoked to explain the spectro-temporal variability from accreting black holes in both small systems, i.e. state transitions in galactic black hole binaries (GBHBs), and large systems, i.e. low-luminosity active galactic nuclei (LLAGNs). In the canonical truncated disk model of moderately low accretion rate systems, gas in the inner region of the accretion disk occupies a hot, radiatively inefficient phase, which leads to a geometrically thick disk, while the gas in the outer region occupies a cooler, radiatively efficient phase that resides in the standard geometrically thin disk. Observationally, there is strong empirical evidence to support this phenomenological model, but a detailed understanding of the disk behavior is lacking. We present well-resolved hydrodynamic (HD) and magnetohydrodynamic (MHD) numerical models that use a toy cooling prescription to produce the first sustained truncated accretion disks. Using these simulations, we study the dynamics, angular momentum transport, and energetics of a truncated disk in the two different regimes. We compare the behaviors of the HD and MHD disks and emphasize the need to incorporate a full MHD treatment in any discussion of truncated accretion disk evolution.

Author(s): J. Drew Hogg[1], Christopher S. Reynolds[1]
Institution(s): *1. The University of Maryland*

247.12 – On the Supermassive Black Hole-Galaxy Coevolution

In recent years, a major focus of astronomy has been the study of the effects of supermassive black holes (SMBH) on their host galaxies. Recent results have found strong correlations between SMBH mass and host galaxy properties, most notably in the bulge velocity dispersion and galaxy stellar mass. We utilize these relations along with a novel convolution method to construct number density models of different galaxy properties. Using these models, we compare two fundamental methods for constructing a black hole mass function (BHMF) with the $M_\bullet$-σ and $M_\bullet$-M_* relations. With these methods, we estimate the redshift evolution of the BHMF and, based on that, compare mass growth histories of central black holes and their host galaxies. Additionally, we utilize a data compilation of over 500 galaxies with individual measurements of galaxy properties (BH mass, stellar velocity dispersion, stellar mass, etc.) and classify galaxies by their morphologies in order to shed light on the controversial Shankar et al. (2016) argument that observations are biased in favor of massive SMBHs. We find that such a bias has little impact on the SMBH-galaxy relations.We conclude that the galaxy sample is a fair representation of the local universe and argue that our BH number density and scaling relations can be employed in the future to constrain relevant mechanisms for galaxy formation. We *emphasize* that this is the most comprehensive and accurate study of SMBH-galaxy coevolution as of now. Most of this work was carried out by high school students working under the auspices of the Science Internship Program at UC Santa Cruz.

Author(s): Sahil Hegde[2], Shawn Zhang[1], Aldo Rodriguez3, Joel R. Primack3
Institution(s): *1. Amador Valley High School, 2. Prospect High School, 3. University of California, Santa Cruz*

247.13 – Measuring the Stellar Kinematics of the S0 Galaxy NGC 4203

Black holes lie at the centers of every large galaxy, and their masses can be measured in two ways, by modeling the motions of stars or gas. Both methods suffer from different systematic effects, therefore comparisons between the two are important for assessing the consistency of the methods and the effects on the black hole - host galaxy relations. However, there are only a few cases in which a galaxy's black hole mass has been determined using both stellar and gas-dynamical methods. The nearby, S0 galaxy NGC 4203 provides the opportunity to conduct this necessary cross-check. Here we present near infrared adaptive optics observations of NGC 4203 taken with the integral field spectrograph OSIRIS on the Keck II telescope. We measure the velocity, velocity dispersion, and higher-order velocity moments, h_3 and h_4, within ~100 pc of the galaxy's center. We find that the galaxy is rotating, and that there is a drop in velocity dispersion at the nucleus. The stellar kinematics on these small spatial scales are essential for a robust determination of the NGC 4203 black hole mass, which can then be compared to a gas-dynamical determination from existing Hubble Space Telescope observations.

Author(s): Zuzana Isabelle Calbo[1], Jonelle Walsh4, Aaron J. Barth5, Remco van den Bosch[2], Joseph C. Shields3, Marc Sarzi[6]
Institution(s): *1. Hofstra University, 2. Max Planck Institute for Astronomy, 3. Ohio University, 4. Texas A&M University, 5. University of California, Irvine, 6. University of Hertfordshire*

247.14 – Efficiency of Dynamical Friction in Presence of Black Hole Radiative Feedback

Dynamical friction is a physical mechanism thought to be responsible for pairing of supermassive black holes (SMBHs) in the aftermath of galactic mergers. It arises when a massive perturber traveling through a background medium creates in it a density wake. The wake, which trails the perturber on its trajectory, causes it to slow down by gravitational interaction. In the case of gas rich galactic mergers, dynamical friction allows the SMBHs immersed in gas to shed orbital energy and angular momentum and to sink to the center of the newly formed galaxy where they can form gravitationally bound pairs. The SMBHs which are subject to gaseous dynamical friction inevitably accrete some of the surrounding gas, giving rise to the emission of ionizing radiation that emerges from the innermost parts of their accretion flows. This radiation can dramatically modify the thermodynamic properties of the surrounding gas including the density wake. We investigate the effect of this form of radiative feedback on the physical properties of the wake, efficiency of dynamical friction and pairing of SMBHs in galactic mergers.

Author(s): Alexander Buser[1], Tamara Bogdanovic[1], KwangHo Park[1]
Institution(s): *1. Georgia Institute of Technology*

247.15 – What is the nature of the high energy X-ray sources in the galaxy?

Finding sources of high energy "hard" X-rays allow us to probe the most extreme conditions in the Universe. Such sources include accreting black holes and neutron stars, where we find the strongest gravitational and magnetic fields, as well as pulsars and supernova remnants, where particles are accelerated to produce the hard X-rays. Over the past decade, the INTEGRAL satellite ahs been discovering new high energy sources, and this has allowed us to understand the population of bright hard X-ray sources. Over the past few years, the NuSTAR satellite, with much better sensitivity than INTEGRAL, has been allowing us to find even more hard X-ray sources, and we will present results from studies of sources discovered in the NuSTAR serendipitous source survey. We analyzed seven different potential sources looking for counterparts using NuSTAR, Chandra and ground based optical/NIR observations. Of the seven, two have confirmed counterparts and five need either an optical/NIR detection or further spectroscopy.

Author(s): Sophie Cuturilo[2], John Tomsick3, Maica Clavel3, George B Lansbury[1]
Institution(s): *1. Durham University, 2. Seattle Pacific University, 3. UC Berkeley/SSL*

248 – Dark Matter & Dark Energy Poster Session

248.01 – A Blind Search Pipeline for Dark Satellites of the Milky Way in Gamma Rays

According to current cosmological dark matter simulations, the Milky Way's halo should host several thousand dark matter subhalos, many of which are not massive enough to accrete considerable baryonic content and form stars. Because these "dark satellites" are completely dark matter dominated and contain few if any astrophysical sources, the only possibility of finding them is through observations of gamma rays from dark matter annihilation in them. The sensitivity and all-sky coverage of the *Fermi* Large Area Telescope (*Fermi*-LAT) make it uniquely capable to detect this population of dark satellites. In preparation for an all-sky blind search for dark satellites we have performed systematic studies of simulated data to establish robust choices for the energy and spatial binning used in the analysis. We have also applied a preliminary version of the analysis pipeline in the directions of confirmed and candidate dwarf spheroidal satellite galaxies using seven years of *Fermi*-LAT data and confirmed that our methodology gives upper limits compatible with previous work on these satellites.

Author(s): Nathan Ross Sandford[2], Eric Charles[1], Mattia Di Mauro[1]
Institution(s): *1. Kavli Institute for Particle Astrophysics and Cosmology, SLAC National Accelerator Laboratory, Standford University, 2. Pomona College*
Contributing team(s): Fermi-LAT Collaboration

248.02 – Searching for a 3.5-keV line in the spectrum of the deepest Chandra blank fields

We report results of our spectral analysis of ~10 Ms of data in the deep Chandra COSMOS Legacy and CDFS surveys. We discuss a possible emission feature at 3.5 keV, which has been reported in other XMM-Newton, Chandra and NuSTAR X-ray data. If due to dark matter decay, the 3.5-keV feature, together with the result from the DAMA dark matter detection experiment, is to date the only positive dark matter signature surviving experimental tests. We discuss possible instrumental contaminations, proper statistical treatment and interpretation in terms of dark matter decay or S XVII charge exchange.

Author(s): C. Megan Urry[2], Nico Cappelluti[2], Esra Bulbul[1]
Institution(s): *1. Massachusetts Institute of Technology, 2. Yale University*

248.03 – Simulating Xenon Bubble Chambers for Dark Matter Detection

Dark Matter, despite the strong theoretical and observational evidence to support its existence, continues to elude detectors. If dark matter is composed of weakly interacting massive particles (WIMPs), bubble chambers may be an effective way to detect dark matter. In order to unambiguously detect WIMPs, we must gain a better understanding of the background events present in a bubble chamber. A key step to understanding the backgrounds in the newly assembled prototype Xenon Bubble Chamber (XEBC) is accurate 3D reconstruction of bubble positions. To do this, we use a photo of the nucleation event with two separately angled mirrors to provide a stereoscopic view of each bubble. The accuracy of this 3D reconstruction relies on an optical model of the chamber, which can be tuned using features with known locations in the chamber images. We produce a goodness-of-fit function that quantifies agreement between target positions of rays and simulated position of rays, which when optimized properly can result in a 3D reconstruction that accurately reproduces chamber walls. We go over the motivation for this project and the details of the optical model that simulated the chamber and traced the rays for the goodness-of-fit function.

Author(s): Joseph Arroyo[1], Eric Dahl[1]
Institution(s): *1. Northwestern University*
Contributing team(s): PICO

248.04 – Testing Ultra-Light Dark Matter Axions Using Galaxy Surveys

The axion is a particle that has been strongly motivated by symmetry arguments in particle physics since the 1970s and has recently become promising in a cosmological context as well. Ultra-light axions are among the candidates for dark matter and would produce a characteristic suppression of the matter power spectrum at high wavenumbers. The strength of this suppression is heavily dependent on both the mass of the axion and on what fraction of the dark matter it constitutes. In this work, we forecast the sensitivity of future galaxy surveys to determine the ultra-light axion abundance at a variety of axion masses, using Fisher-matrix analysis.

Author(s): Emery Trott[1], Tristan L. Smith[2], Daniel Grin[1]
Institution(s): *1. Haverford College, 2. Swarthmore College*

248.05 – In Theory: Dark Energy as a Power Source

In theory, it is possible to use the dark energy of the universe as a power source. In practice, the amount of energy that could be liberated in a local setting is many orders of magnitude too small to be useful or even detectable. Nevertheless, in the interests of education and amusement, simple machines that could, in theory, extract local power from the gravitationally repulsive cosmological constant are discussed. The gravitational neutral buoyancy distance -- the distance where local Newtonian gravity balances cosmological dark energy in a concordance cosmology -- is computed between two point objects of low mass.

Author(s): Robert J. Nemiroff[1], David Russell[1], Matipon Tangmatitham[1]
Institution(s): *1. Michigan Technological Univ.*

249 – Starburst Galaxies Near & Far Poster Session

249.01 – GMRT HI Imaging of the Ly-α Emitting Starburst Galaxy Tololo 1924-416

The Lyman Alpha Reference Sample (LARS) and its extension (eLARS) form the most comprehensive effort to date to study the details of Lyman Alpha radiative transfer in galaxies. Direct imaging of Lyman Alpha emission from the Hubble Space Telescope is supplemented by a wealth of multi-wavelength observations designed to probe the complex processes that contribute to the escape or destruction of Lyman Alpha photons as they resonantly scatter in the neutral ISM. The 42 LARS+eLARS galaxies span a range of physical properties, including mass and star formation rate. In companion posters, we present results of HI imaging programs using the VLA and the GMRT. In this work, we present new HI imaging of the Lya-emitting starburst galaxy Tololo 1924-416; this source has a similar complement of HST imaging and spectroscopy as the LARS+eLARS galaxies. Tololo 1924-416 is known to be dramatically tidally interacting with ESO 338-IG04B; HI gas is strewn between the galaxies on scales of ~70 kpc. Our new data provide information on scales of ~2-10 kpc at the adopted distance of Tololo 1924-416 (37.5 Mpc). We study the HI morphology and dynamics of this interacting system.

Author(s): Cesar I Mendoza Davila[1], Karen Perez Sarmiento[1], John M. Cannon[1], Matthew Hayes[2], Jens Melinder[2], Göran Östlin[2], Stephen Pardy3
Institution(s): *1. Macalester College, 2. Stockholm University, 3. University of Wisconsin*
Contributing team(s): LARS Team

249.02 – GMRT HI Imaging of Selected LARS+eLARS Galaxies

The Lyman Alpha Reference Sample (LARS) and its extension (eLARS) form the most comprehensive effort to date to study the details of Lyman Alpha radiative transfer in galaxies. Direct imaging of Lyman Alpha emission from the Hubble Space Telescope is supplemented by a wealth of multi-wavelength observations designed to probe the complex processes that contribute to the escape or destruction of Lyman Alpha photons as they resonantly scatter in the neutral ISM. The 42 LARS+eLARS galaxies span a range of physical properties, including mass and star formation rate. In this work, we present new GMRT HI imaging of selected LARS+eLARS galaxies designed to study the detailed morphology and kinematics of the HI gas. HI column density images and velocity fields are compared to SDSS imaging.

Author(s): Karen Perez Sarmiento[1], Cesar I Mendoza Davila[1], John M. Cannon[1], Matthew Hayes[2], Jens Melinder[2], Göran Östlin[2], Stephen Pardy3
Institution(s): *1. Macalester College, 2. Stockholm University, 3. University of Wisconsin*
Contributing team(s): LARS Team

249.03 – VLA HI Imaging of the LARS+eLARS Galaxies: Global HI Properties

The Lyman Alpha Reference Sample (LARS) and its extension (eLARS) form the most comprehensive effort to date to study the details of Lyman Alpha radiative transfer in galaxies. Direct imaging of Lyman Alpha emission from the Hubble Space Telescope is supplemented by a wealth of multi-wavelength observations designed to probe the complex processes that contribute to the escape or destruction of Lyman Alpha photons as they resonantly scatter in the neutral ISM. The 42 LARS+eLARS galaxies span a range of physical properties, including mass and star formation rate. In this work, we present new VLA D-configuration HI imaging of 32 LARS+eLARS galaxies designed to localize the HI gas and to measure the total HI mass. HI column density images and velocity fields are compared to SDSS imaging. Most galaxies are unresolved at this angular resolution; a companion poster presents imaging of interacting galaxies that are well-resolved.

Author(s): Brian Andrew Eisner[1], Bridget Reilly[1], John M. Cannon[1], Matthew Hayes[2], Jens Melinder[2], Göran Östlin[2], Stephen Pardy3
Institution(s): *1. Macalester College, 2. Stockholm University, 3. University of Wisconsin*
Contributing team(s): LARS Team

249.04 – VLA HI Imaging of the LARS+eLARS Galaxies: Tidally Interacting Systems

The Lyman Alpha Reference Sample (LARS) and its extension (eLARS) form the most comprehensive effort to date to study the details of Lyman Alpha radiative transfer in galaxies. Direct imaging of Lyman Alpha emission from the Hubble Space Telescope is supplemented by a wealth of multi-wavelength observations designed to probe the complex processes that contribute to the escape or destruction of Lyman Alpha photons as they resonantly scatter in the neutral ISM. The 42 LARS+eLARS galaxies span a range of physical properties, including mass and star formation rate. A companion poster presents VLA HI imaging of 32 LARS+eLARS galaxies. In this work, we present new VLA D-configuration HI imaging of selected LARS+eLARS galaxies that are well-resolved or tidally interacting. HI column density and velocity field images are compared to SDSS imaging. We interpret the results in the context of tidal interactions shifting the HI gas out of resonance and increasing the likelihood of Lyman Alpha photons escaping the galaxy.

Author(s): Bridget Reilly[1], Brian Andrew Eisner[1], John M. Cannon[1], Matthew Hayes[2], Jens Melinder[2], Göran Östlin[2], Stephen Pardy3
Institution(s): *1. Macalester College, 2. Stockholm University, 3. University of Wisconsin*
Contributing team(s): LARS Team

249.05 – Too Young to Shine? *Chandra* analysis of X-ray emission in nearby primordial galaxies

The 2—10 keV X-ray emission in star-forming galaxies traces the population of high mass X-ray binaries (HMXBs) and is a function of both the star formation rate (SFR) and metallicity, according to several studies. Theoretical studies predict that stars retain more mass over their lifetimes due to weaker stellar winds in lower metallicity environments, and therefore, produce more luminous and numerous HMXBs. We present *Chandra* analysis for a local sample of primordial galaxies, Hα emitters (HAEs). Our selection is based on large Hα equivalent widths (EW(Hα)>500Å, suggestive of bursts of star formation within 6 Myr), SFR >1 $M_\odot$/yr and low metallicities ($Z < 0.25\ Z_\odot$) and offers a clean sample of the youngest, metal-poor galaxies, potentially containing the most luminous X-ray binaries. However, we find that these galaxies are less X-ray luminous than expected based on their SFRs and metallicities. We attribute their lower X-ray emission to the extreme youth (young stellar age) of the galaxies, where HMXBs may not have fully formed. Our investigation of HMXB formation as a function of stellar age, metallicity and SFR offers important refinements to the X-ray emission from the first galaxies and on predictions of black hole binaries, which are precursors of gravitational wave sources.

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249.06 – Initial Results of a Far-Ultraviolet Spectroscopic Survey of Nearby Star-forming Galaxies with the Cosmic Origins Spectrograph

We present initial results for the HST Cycle 22 proposal 13761. We proposed to observe 75 target star-forming galaxies at a redshift $0.02 < z < 0.24$ in the G140L mode of COS, spanning a bandpass of $1100 < \lambda < 2400$ angstroms, and have thus far observed 34 of them. The main thrust of this project is to provide a previously unavailable survey of star-forming galaxies in this redshift range, allowing investigation into the factors that determine the Lyman-alpha emission at these low redshifts. We have begun a statistical analysis of the relationship between Lyman-alpha emission and the morphologies of the galaxies, such as absorption line strengths of other species, including various ionization states of oxygen, silicon, and other species to probe intrinsic properties of the emitting galaxy, such as metallicity, the gas-to-dust ratio, and local velocity fields. We have acquired a very rich dataset, with enough samples to try to answer a variety of open questions regarding the far-ultraviolet spectra of bright Lyman-alpha emitters. This work is supported by a NASA Grant HST-GO-13761 to the Johns Hopkins University.

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249.07 – Toward Gas Chemistry in Low Metallicity Starburst Galaxies

Dense gas, which is intimately connected with star formation, is key to understanding star formation. Though challenging to study, dense gas in low metallicity starbursts is important given these system's often extreme star formation and their potential implications for high redshift analogs. High spatial resolution (~50 pc) ALMA observations of several key probes of gas chemistry, including HCN(1-0), HCO^+(1-0), CS(2-1), CCH(1-0;3/2-1/2) and SiO(2-1), towards the nearby super star-cluster (SSC) forming, sub-solar metallicity galaxy NGC 5253 are discussed. Dense gas is observed to be extended well beyond the current compact starburst, reaching into the apparently infalling molecular streamer. The faintness of HCN, the standard dense gas tracer, is extreme both in an absolute sense relative to high metallicity starbursts of a similar intensity and in a relative sense, with the HCO^+/HCN ratio being one of the most elevated observed. UV-irradiated molecular gas, traced by CCH, is also extended over the mapped region, not being strongly correlated with the SSC. Despite the accretion of molecular gas from the halo and the intense burst of star formation, chemical signatures of shocked gas, traced by SiO (and HNCO), are not obvious. By placing NGC 5253 in context with other local starbursts, like 30 Doradus in the Large Magellanic Clouds and the high metallicity proto-typical starburst NGC 253, it is suggested that a combination of gas excitation and abundance changes associated with the sub solar metallicity may explain these anomalous dense gas properties.

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249.08 – Hα Kinematics of High-z Dusty Star Forming Galaxies

Dusty Star Forming Galaxies (DSFGs) have the highest star formation rates in the Universe, but compared with other star forming galaxies at z > ~1 they are difficult to characterize, physically. Their low number density and extreme dust obscuration has led to very few kinematic studies of DSFGs at optical wavelengths. We present a rest-frame optical kinematic analysis of 5 DSFGs at z ~1.5 using long slit spectroscopy obtained with MOSFIRE at Keck Observatory. From our high signal-to-noise spectra we simultaneously fit Hα, [NII] λ6548, and [NII] λ6583 along each slit to generate position-velocity diagrams. We infer the kinematic disturbances and derive dynamical masses in order to compare with other derived quantities such as fractional obscuration, stellar and gas fractions, and dust characteristics.

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249.09 – The HDUV Survey: Seven Lyman Continuum Emitter Candidates at z~2 Revealed by HST UV Imaging

The fraction of ionizing photons that escape from star-forming galaxies in the early universe is a key unknown in the search for the main drivers of cosmic reionization. Despite significant efforts it has proven difficult to identify galaxies with high ionizing escape fractions (f_{esc}). So far, only a handful of galaxies have been directly detected in their ionizing continuum (λ_{rest}<912 Angstrom) in the local universe, and even fewer reliable detections exist at higher redshifts. Here we present seven new Lyman continuum (LyC) emitter candidates at z~2, which we identified in the newly acquired, deep UV imaging of the Hubble Deep UV legacy survey (HDUV) conducted with the Hubble Space Telescope (HST) WFC3/UVIS camera. At the redshift of these sources, the HDUV F275W images partially probe the ionizing continuum. By exploiting the HST multi-wavelength data available in the HDUV/GOODS fields, models of the UV continuum, and detailed Monte-Carlo simulations of the intergalactic medium absorption, we estimate the escape fractions of these galaxies to be larger than 60%. The wealth of surveys and studies in the GOODS fields, especially the near-IR grism spectra from the 3D-HST survey, enable us to discuss the candidates in detail and tentatively test some recently proposed indirect methods to probe LyC leakage--namely, the OIII/OII line ratio and the Hβ-β_{UV} diagram. High-resolution spectroscopic followup of our candidates will help constrain such indirect methods which are our only hope of studying f_{esc} at z~4-9 in the fast-approaching era of the *James Webb Space Telescope*.

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Contributing team(s): Hubble Deep UV (HDUV) Legacy Survey Team

249.10 – AGN contamination in total infrared determined star formation rates in dusty galaxies at z~2-3

Along with theoretical work that suggests feedback from active galactic nuclei (AGN) may quench star formation in massive galaxies, the temporal coincidence between the peak of cosmic star formation rates and black hole accretion rates suggests that AGN are common in star forming galaxies at z~2-3. Since star forming galaxies at these epochs are also very dusty, it is important that we correct galaxies' long-wavelength properties for the presence of dust-obscured AGN in order to accurately capture their star formation rates and gas characteristics. We present a spectral energy distribution (SED) analysis of several un-lensed z~2-3 dusty star-forming galaxies from Pope et al. (2008) and Coppin et al. (2010), which we compare to several other high-z starbursts with well sampled SEDs. We constructed dust SEDs from existing *Spitzer*, *Herschel*, and *SCUBA-2* photometry catalogues with data between 3.6 and 850 µm. For the SED fits, we used the Code Investigating GALaxy Emission (CIGALE), since it self-consistently determines the dust attenuation of stars and dust emission in the infrared in addition to determining the dust emission from obscured AGN (Noll et al. 2009; Serra et al. 2011). Our best-fit SEDs have typical reduced χ^2 values between 0.2 and ~3. We use the output from CIGALE to determine the fraction of the total infrared luminosity (L_{TIR}; 8-1000 um) from star formation and from any potential obscured AGN. In order to examine the effects of buried AGN on the integrated Schmidt-Kennicutt relation ($\log(L_{TIR})$ vs. $\log(L'_{CO})$), we compare our new L_{TIR} to recently obtained CO(1-0) line luminosities from the Karl G. Jansky Very Large Array. Unaccounted for dust emission from AGN can artificially inflate the star formation rate inferred from L_{TIR}, and may therefore offset starburst galaxies from the local Schmidt-Kennicutt relation and increase the slope of the relation, which can affect the inferred drivers of star formation.

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249.11 – Molecular Gas Content of an Extremely Star-forming *Herschel* Observed Lensed Dusty Galaxy at z=2.685

We present the results of combined deep near-infrared, far infrared and millimeter observations of an extremely star forming lensed dusty star-forming galaxy (DSFG) identified from the *Herschel* Astrophysical Terahertz Large Area Survey (H-ATLAS). The high redshift DSFG is gravitationally lensed by a massive WISE identified cluster at z~1 (spectroscopically confirmed with Keck/DEIMOS and Gemini/GMOS) producing multiply lensed images and arcs observed in the optical. The DSFG is spectroscopically confirmed at z=2.685 from CO(1-0) observations by GBT and separately from CO(3-2) observations by CARMA. We use the combined spectroscopic and imaging observations to construct a detailed lens model of the background DSFG which allowed us to study the sources plane properties of the target. Multi-band data from Keck/NIRC2, *HST*/WFC3 and *Herschel* yields star formation rate and stellar mass well above the main sequence. Observations of the dust continuum by the Sub-millimeter Array yields an observed total ISM mass of 6.5E+11 M* which is responsible for the intense observed star formation rates. Comparing the measured SFR with molecular gas measurements from CO(1-0) observations reveals that this system has relatively short gas depletion time scale which is consistent with the starburst phase observed in high redshift sub-millimeter galaxies.

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Contributing team(s): H-ATLAS

249.12 – C IV and He II line emission of Lyman α blobs: powered by shock-heated gas

Utilizing ab initio ultrahigh resolution hydrodynamical simulations, we investigate the properties of the interstellar and circumgalactic medium of Lyα blobs (LABs) at z = 3, focusing on three important emission lines: Lyα 1216 Å, He II 1640 Å and C IV 1549 Å. Their relative strengths provide a powerful probe of the thermodynamic properties of the gas when confronted with observations. By adjusting the dust attenuation effect using one parameter and matching the observed size-luminosity relation of LABs using another parameter, we show that our simulations can reproduce the observed C IV/Lyα and He II/Lyα ratios adequately. This analysis provides the first successful physical model to account for simultaneously the LAB luminosity function, luminosity-size relation and the C IV/Lyα and He II/Lyα ratios, with only two parameters. The physical underpinning for this model is that, in addition to the stellar component for the Lyα emission, the Lyα and C IV emission lines due to shock-heated gas are primarily collisional excitation driven and the He II emission line collisional ionization driven. We find that the density, temperature and metallicity of the gas responsible for each emission line is significantly distinct, in a multiphase interstellar and circumgalactic medium that is shock heated primarily by supernovae and secondarily by gravitational accretion of gas.

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249.13 – Serendipitous ALMA detections of faint submm galaxies in SERVS

We present a preliminary ALMA study of faint (<1mJy) submm galaxies with counterparts in the Spitzer Extragalactic Representative Volume Survey (SERVS). SERVS provides post-cryogenic IRAC imaging at 3.6 and 4.5 microns over an 18 deg^2 area of the sky over five famous deep fields. The depth of the survey is ~ 2 μJy, and it provides a complete census of galaxies up to z ~ 5. While it is known that bright submm galaxies are associated with dusty, ultra-luminous starforming galaxies at z ~ 2, the sub-mJy population is still not well understood. A key missing piece of information is their morphologies at rest-frame optical wavelengths, which for high-redshift submm galaxies is only accessible through ALMA observations. The high sensitivity, spatial resolution, and positional accuracy of ALMA have enabled us to probe the nature of the sub-mJy population by resolving their spatial extents and improving constraints on their SEDS and photometric redshifts. We are building a catalog of sources by searching the ALMA archive for moderate to deep observations in the area covered by SERVS. This study will help us begin to understand the contribution of obscured star formation to the total star formation rate at high redshift and guide future wide-area surveys of submm galaxies with ALMA.

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250 – AGN, QSO, Blazars Poster Session

250.01 – New quasar survey with WIRO: Color-selection of quasar candidates behind M33

We report new quasar candidates in the extended gaseous region of the Triangulum (M33) Galaxy as observed with WIRO (The Wyoming Infrared Observatory) in the ugri bands during the Summer of 2016. Our survey produced a sample of 14042 point sources to a limiting depth of g ≤ 21.7 in a region of ~16 square degrees, 34 of which are UVX-selected, known quasars with redshifts up to z < 2.2. Color-color plots were created using extinction-corrected magnitudes of ugri as well as NUV and W1 as taken from GALEX (Galaxy Evolution Explorer) and WISE (Wide-field Infrared Survey Explorer) respectively. Using a series of color cuts in NUV, u, g, r, i, and W1 bands, we recover high-quality quasar candidates. Based on optical colors alone we project ~30 new candidates per square degree. Spectroscopic follow-up of these candidates could yield new, bright quasars behind M33. This work is supported by the National Science Foundation under REU grant AST 1560461.

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250.02 – New quasar surveys with WIRO: UV variability of known quasars behind M33

Bright quasars are of particular interest when detected through the extended gaseous regions of local galaxies. Spectroscopy of UV-bright quasars, in particular, can be used to map the properties of the gas surrounding foreground galaxies in absorption. As our atmosphere absorbs UV flux, UV-bright quasars behind galaxies have been a regular target of spectroscopic campaigns with HST. The utility of such quasars is usually predicated on their UV emission at a single epoch. But, some quasars vary significantly in the UV, so objects which have shown a recent increase in UV flux may also be good candidates for spectroscopic follow-up with HST. We have analyzed the changes in u-band measurements of known quasars within a recent observational survey of quasars behind M33. Imaging in the u-band of a region around M33 containing ~35 known quasars was conducted at the Wyoming Infrared Observatory (WIRO) in the summer of 2016. We report on the known quasars which show the most u-band variability between our WIRO campaign and earlier SDSS observations. By correlating u-band observations with GALEX NUV, we determine the likelihood that an increase in u-band flux is a good indicator of an increase in flux further in the UV. This work is supported by the National Science Foundation under REU grant AST 1560461.

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250.03 – New quasar survey with WIRO: The light curves of quasars over ~15 year timescales

Quasars, a type of active galactic nuclei (AGN), are known to vary in brightness on 10 day to 7 year timescales. While it has been proposed that this variability is caused by instability in the accretion disk, Poisson processes, or microlensing, the exact cause remains mysterious. Understanding the physical mechanisms that drive quasar variability will require imaging of quasars over a wide range of timescales. In particular, the observations required to constrain longer timescales can be difficult to conduct. This summer ~1000 quasars in Stripe 82 were observed in ugriz wavelength bands using WIRO, the University of Wyoming's 2.3-meter telescope. Using these images, earlier data from the Sloan Digital Sky Survey's observations of Stripe 82, as well as various data reduction methods, the quasars' magnitude can be studied on our extended 3 day to 15 year timescale. Here, we present the light curves of ~1000 quasars in ugriz bands as observed over the last 15 years. This work is supported by the National Science Foundation under REU grant AST 1560461.

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250.04 – New Quasar Surveys With WIRO: Planning and Depth of Observations

The Wyoming Infrared Observatory (WIRO) 2.3-meter telescope is used to observe a section of sky behind the outer regions of the galaxy M33 with the goal of identifying previously undiscovered quasar candidates. We choose the regions based on visibility during the time of year the observations are taken as well as regions in which few quasars have been detected by previous surveys. DS9 and Python are used to determine the coordinates of our desired field centers for photometric observations in the u, g, r, and i Sloan filters. Exposure times are chosen such that the depth in each filter is greater than an apparent magnitude of 21. This depth allows us to identify quasar candidates which are fainter than other quasar surveys in the same vicinity. Future spectroscopic observations will be able to confirm if the candidates are indeed quasars and spectra of the confirmed quasars can be used to study the extended gaseous region of M33. This work is supported by the National Science Foundation under REU grant AST 1560461.

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250.05 – New Quasar Surveys with WIRO: Data and Calibration for Studies of Variability

Measurements of quasar variability offer the potential for understanding the physics of accretion processes around supermassive black holes. However, generating structure functions in order to characterize quasar variability can be observationally taxing as it requires imaging of quasars over a large variety of date ranges. To begin to address this problem, we have conducted an imaging survey of sections of Sloan Digital Sky Survey (SDSS) Stripe 82 at the Wyoming Infrared Observatory (WIRO). We used standard stars to calculate zero-point offsets between WIRO and SDSS observations in the urgiz magnitude system. After finding the zero-point offset, we accounted for further offsets by comparing standard star magnitudes in each WIRO frame to coadded magnitudes from Stripe 82 and applying a linear correction. Known (i.e. spectroscopically confirmed) quasars at the epoch we conducted WIRO observations (Summer, 2016) and at every epoch in SDSS Stripe 82 (~80 total dates) were hence calibrated to a similar magnitude system. The algorithm for this calibration compared 1500 randomly selected standard stars with an MJD within 0.07 of the MJD of each quasar of interest, for each of the five ugriz filters. Ultimately ~1000 known quasars in Stripe 82 were identified by WIRO and their SDSS-WIRO magnitudes were calibrated to a similar scale in order to generate ensemble structure functions.

This work is supported by the National Science Foundation under REU grant AST 1560461.

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250.06 – New Quasar Surveys with WIRO: Colors of ~1000 Quasars at $0 < z < 3$

We present the colors of quasars observed as part of an imaging campaign using the Wyoming Infrared Observatory (WIRO). A major goal of the campaign was to calibrate the magnitudes of point sources in the Sloan Digital Sky Survey (SDSS) photometric system using WIRO's new DoublePrime camera. The sample we study is comprised of approximately 1000 quasars with redshift $0 < z < 3$ that were matched to spectroscopically confirmed quasars in SDSS Stripe 82. As expected from earlier imaging surveys of quasars, we find that quasars occupy a region of u-g vs. g-r color-color space that is distinct from that of stars. The quasar u-g colors are considerably bluer than those of the stars while quasar g-r colors are only slightly bluer than the g-r colors of the majority of the observed stars. There is a noticeable correlation between the quasar redshift and the corresponding u-g color. As the redshift of a quasar increases, its u-g color becomes redder. In the g-r vs. r-i and r-i vs. i-z color-color spaces, the quasars occupy regions that overlap with the regions occupied by the majority of the stars, again in excellent agreement with the expectation from earlier surveys.

This work is supported by the National Science Foundation under REU grant AST 1560461.

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250.07 – New quasar surveys with WIRO: Searching for high redshift (z~6) quasar candidates

High redshift quasars (z~6) are of great interest to fundamental astronomy due to the information they hold about the early universe. With their low number density in the sky, however, they are elusive objects. Reported here is our search for these high redshift quasars using the Wyoming Infrared Observatory (WIRO) 2.3m telescope. We search for potential candidates that have been detected by surveys such as WISE, which have been mostly redshifted out of the optical. The main emission feature of these quasars (the Lyman-Alpha line at ~1216 Angstroms rest-frame) would be redshifted to the z-band or beyond. This means that the quasars should have very low levels of i-band flux. These objects are known as i-dropouts. By imaging the quasars in the i-band and running photometric analysis on our fields, candidates can be identified or rejected by whether or not they appear in our fields. We also provide an analysis of the colors of our candidate high-redshift quasars.
This work is supported by the National Science Foundation under REU grant AST
1560461

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250.08 – In Search Of Tiny Giants: Finding Supermassive Black Holes In Low Mass Galaxies

Most, if not all, massive galaxies have a central supermassive black hole (SMBH) with a mass of up to 1 billion times the mass of the Sun. While the properties of SMBHs and their host galaxies have been well-studied in massive galaxies, very few SMBHs have been found in galaxies with low masses and those with small bulges. This is a significant deficiency since the study of this population allows us to gain an understanding of merger-free pathways to black hole growth, and to gain insight into the origin and growth efficiency of SMBH seeds, thought to have formed at high redshift. Most studies aimed at finding SMBHs have been conducted using optical spectroscopic studies, where active SMBHs (active galactic nuclei or AGNs) display distinctive optical emission lines indicative of accreting SMBHs. However, in low mass galaxies, the SMBHs will likely be less massive. As the black hole masses decreases, the Schwartzchild radius of the black hole decreases, and in response, the temperature of the surrounding accretion disk increases. The shape of the ionizing radiation field therefore changes with black hole mass, potentially affecting the optical spectroscopic signatures generally associated with AGNs. In this work, we investigate the effect of black hole mass on the emission line spectrum from AGNs.

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250.09 – Clustering, Cosmology and a New Era of Black Hole Demographics: The Conditional Luminosity Function of AGNs

Deep X-ray surveys have provided a comprehensive and largely unbiased view of active galactic nuclei (AGN) evolution stretching back to z~5. However, it has been challenging to use the survey results to connect this evolution to the cosmological environment that AGNs inhabit. Exploring this connection will be crucial to understanding the triggering mechanisms of AGNs and how these processes manifest in observations at all wavelengths. In anticipation of upcoming wide-field X-ray surveys that will allow quantitative analysis of AGN environments, we present a method to observationally constrain the Conditional Luminosity Function (CLF) of AGNs at a specific z. Once measured, the CLF allows the calculation of the AGN bias, mean dark matter halo mass, AGN lifetime, halo occupation number, and AGN correlation function -- all as a function of luminosity. The CLF can be constrained using a measurement of the X-ray luminosity function and the correlation length at different luminosities. The method is illustrated at $z\approx0$ and 0.9 using the limited data that is currently available, and a clear luminosity dependence in the AGN bias and mean halo mass is predicted at both, supporting the idea that there are at least two different modes of AGN triggering. In addition, the CLF predicts that $z\approx0.9$ quasars may be commonly hosted by haloes with $M_h \sim 10^{14}\ M_\odot$. These `young cluster' environments may provide the necessary interactions between gas-rich galaxies to fuel luminous accretion. The results derived from this method will be useful to populate AGNs of different luminosities in cosmological simulations.

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250.10 – Improving LSST Photometric Redshifts using Differential Chromatic Refraction

We evaluate the capabilities of the Large Synoptic Survey Telescope (LSST) to estimate quasar redshifts while making use of astrometric data. The addition of astrometric information, specifically the Differential Chromatic Refraction (DCR) effect, has been shown to improve the accuracy of photometric redshift estimates of SDSS Stripe 82 quasars by breaking color-redshift degeneracies. We use the LSST Metric Analysis Framework (MAF) to evaluate the effectiveness of this method for the upcoming survey. We compare potential survey cadences and air mass limits for their effect on the accuracy of quasar redshift estimates, with a focus on redshift ranges where photometric redshifts are least dependable.

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250.12 – The Era of Monster Formation: Peering into the Heart of ULIRGs out to z ~ 1

The search for the progenitors of the most massive QSO host galaxies has been an ongoing quest for several decades. In the local Universe (to z~0.4), there is a clear progression from merger-induced star-formation (SF) to QSO activity via Ultraluminous Infrared Galaxies (ULIRGs). Although not all mergers are ULIRGs, all ULIRGs are mergers. At $0.4 < z < 1.0$ the SF rates, gas fractions, and masses appear to be significantly higher than in the local universe. ULIRGs at this epoch both dominate the SF activity, have a higher number density, are more gas-rich and have faster SF rates. Yet, at these and earlier epochs it is argued by many that ULIRGs are simply star-forming factories with no (or insignificant) merger activity, nor do they house active galactic nuclei (AGN), making them unlikely precursors to QSO host galaxies. However, nearly all studies of ULIRGs at $z > 0.4$ have selected these systems via scaling observed 24μm or 170μm Spitzer fluxes to integrated 8-1000μm fluxes and inferring masses from scaling photometric fluxes or millimeter observations of CO gas emission. These methods often rely heavily on uncertain assumptions (e.g. gas conversions, SED fitting and templates) and the supposition that galaxies in the local Universe can be used to represent systems at $z > 0.4$. Rather than risk comparing apples with oranges, we have assembled a representative sample of 13 "classically" selected ULIRGs obtained by cross correlating 60 and 100μm IRAS fluxes (supplemented by 12 and 25μm WISE fluxes) with the Faint Images of the Radio Sky at Twenty cm (FIRST) VLA catalog for $0.4 < z < 1.0$. Here, we present for the first time, optical and near-IR imaging and spectroscopy from Hubble Space Telescope, Keck, and the Large Binocular Telescope for all 13 ULIRGs in the sample. We directly measure the dynamical mass of the ULIRGs, confirm the presence of broadened and/or high-excitation lines indicative of powerful AGN, measure the properties of the host stellar populations, and begin to probe the gas-metallicities in these systems. Our results indicate that these intermediate redshift ULIRGs are dynamically similar to their local counterparts suggesting that they too are the progenitors of massive QSO host galaxies.

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250.13 – Likelihood for detection of sub-parsec supermassive black hole binaries in spectroscopic surveys

Motivated by observational searches for sub-parsec supermassive black hole binaries (SBHBs) we develop a semi-analytic model to determine the likelihood for detection of SBHBs by ongoing spectroscopic surveys. The model combines theoretical expectations for the rate of orbital evolution of SBHBs in circumbinary disks and takes into account the selection effects of spectroscopic surveys. It returns a multivariate probability density for SBHB detection in terms of the binary mass, orbital separation, mass ratio, and mass accretion rate through the circumbinary disk. This approach allows us to infer the most likely orbital parameters for observed SBHB candidates and can be used to provide constraints on the rate of orbital evolution of SBHBs, if observed candidates are shown to be genuine binaries.

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250.14 – EMPCA and Cluster Analysis of Quasar Spectra: Construction and Application to Simulated Spectra

Quasars have complex spectra with emission lines influenced by many factors. Therefore, to fully describe the spectrum requires specification of a large number of parameters, such as line equivalent width, blueshift, and ratios. Principal Component Analysis (PCA) aims to construct eigenvectors-or principal components-from the data with the goal of finding a few key parameters that can be used to predict the rest of the spectrum fairly well. Analysis of simulated quasar spectra was used to verify and justify our modified application of PCA.

We used a variant of PCA called Weighted Expectation Maximization PCA (EMPCA; Bailey 2012) along with k-means cluster analysis to analyze simulated quasar spectra. Our approach combines both analytical methods to address two known problems with classical PCA. EMPCA uses weights to account for uncertainty and missing points in the spectra. K-means groups similar spectra together to address the nonlinearity of quasar spectra, specifically variance in blueshifts and widths of the emission lines.

In producing and analyzing simulations, we first tested the effects of varying equivalent widths and blueshifts on the derived principal components, and explored the differences between standard PCA and EMPCA. We also tested the effects of varying signal-to-noise ratio. Next we used the results of fits to composite quasar spectra (see accompanying poster by Wagner et al.) to construct a set of realistic simulated spectra, and subjected those spectra to the EMPCA /k-means analysis. We concluded that our approach was validated when we found that the mean spectra from our k-means clusters derived from PCA projection coefficients reproduced the trends observed in the composite spectra.

Furthermore, our method needed only two eigenvectors to identify both sets of correlations used to construct the simulations, as well as indicating the linear and nonlinear segments. Comparing this to regular PCA, which can require a dozen or more components, or to direct spectral analysis that may need measurement of 20 fit parameters, shows why the dual application of these two techniques is such a powerful tool.

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250.15 – EMPCA and Cluster Analysis of Quasar Spectra: Sample Preparation and Validation

All quasars are fundamentally similar, powered by accretion of matter onto a super massive black hole. However, patterns of differences can be identified through the emission lines. Quasar broad absorption lines have been postulated to be responsible for feedback in galaxy evolution. Principal component analysis (PCA) quantifies trends in emission lines of quasars that can be used to predict and reconstruct the underlying continuum in broad absorption line quasars.

Richards et al. 2011 hypothesized that emission-line variance across the rest-UV spectrum is correlated with C IV blueshift and equivalent width. We fit their composite spectra, constructed based on these properties, to identify trends for the purpose of creating simulated spectra to test the weighted Expectation Maximization PCA (EMPCA; Bailey 2012) and cluster analysis method discussed in adjacent poster by Marrs et al.

More than 800 SDSS spectra from Allen et al. 2011, with a redshift range of $z = 2.2 – 2.3$, were selected for analysis, particularly spectra with high signal to noise ratios, without broad absorption lines, and without numerous narrow absorption lines. Interstellar and intergalactic absorption lines add variance that contaminates the principal components. To remove these lines, we smoothed the spectra using a Fourier transform and a low-pass filter. We then used a line-finding and -removal program to remove or flag narrow absorption lines. From the principal components that resulted from the PCA analysis we were able to reconstruct the continua of a small sample of BAL QSOs.

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250.16 – EMPCA and Cluster Analysis of Quasar Spectra: Application to SDSS Spectra

Accurate modeling of the quasar continuum is necessary to measure and analyze absorption lines. But quasar continua, in particular the emission lines, vary from object to object. Patterns in the variations allow a spectral principal component analysis (SPCA) approach using large samples of quasar spectra, e.g., from the SDSS. Then, a small number of the derived principal component spectra can be used to reconstruct an arbitrary quasar's continuum.

A problem with this approach is that the number of principal components required to model an arbitrary quasar, usually 8 to 20 in the literature, is large. One reason why so many components are required is that SPCA implicitly assumes that spectra bins are independent. Quasar emission lines are spread over a range of spectral bins, and more importantly, can sometimes be blueshifted. So while the intrinsic variability may only be a function of a few physical parameters, the nonlinearity inherent in the variations from object to object requires a large number of prinicipal components to accurately model a quasar continuum.

We present a modified approach. We perform a SPCA analysis, using an expectation-maximization algorithm by Bailey et al. 2012, which takes into account uncertainties and missing data. We project the sample spectra on the resulting eignevectors to obtain the projection coefficients. Reasoning that intriniscally similar spectra will have similar projection coefficients, we perform a cluster analysis on the projection coefficients. The results are used to divide the sample into groups of similar spectra. A second PCA analysis is then performed on each group. We find that many fewer eigenspectra are required to accurately model the spectra in each group. We apply this approach to several samples of quasars from the SDSS.

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250.17 – SimBAL: A Spectral Synthesis Approach to Analyzing Broad Absorption Line Quasar Spectra

Broad Absorption Line quasars (BALQSOs) show blueshifted absorption lines in their rest-UV spectra, indicating powerful winds emerging from the central engine. These winds are essential part of quasars: they can carry away angular momentum and thus facilitate accretion through a disk, they can distribute chemically-enriched gas through the intergalactic medium, and they may inject kinetic energy to the host galaxy, influencing its evolution.

The traditional method of analyzing BALQSO spectra involves measuring myriad absorption lines, computing the inferred ionic column densities in each feature, and comparing with the output of photonionization models. This method is inefficient and does not handle line blending well.

We introduce SimBAL, a spectral synthesis fitting method for BALQSOs, which compares synthetic spectra created from photoionization model results with continuum-normalized observed spectra using Bayesian model calibration. We find that we can obtain an excellent fit to the UV to near-IR spectrum of the low-redshift BALQSO SDSS J0850+4451, including lines from diverse ionization states such as PV, CIII*, SIII, Lyalpha, NV, SiIV, CIV, MgII, and HeI*.

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250.18 – Determining Black Hole Mass of AGN using FWHM of H-beta Emission Line and Luminosity Relations

At the center of some active galaxies are super-massive black holes and for some time the accepted method of measuring the mass of such galaxies has been the method used by Vestergaard and Peterson, among others. By using the luminosity function which is related to H-�� emission spectra from these black holes, both for cosmic redshift and for Fe-II emissions using IRAF. From there, H-�� can accurately measure the full width half max of the H-beta line in these spectrum as well as the luminosity and these paired with the O-III lines give us an estimate on the mass of the black hole. The purpose of this is to compare it to the values obtained from the Mass-Pitch Angle relation being proposed by Kennefick et al. (2016 in preparation)

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250.19 – Broad and Narrow Intrinsic Absorption in Quasars as it Relates to Outflows, Orientation, and Radio Properties

We investigate the nature of quasar outflows in the form of both broad and narrow absorption lines using data taken as part of the Sloan Digital Sky Survey (SDSS). We look for correlations of these outflows with the radio properties of the quasars, which can potentially reveal a physical connection between the quasar's accretion physics and its outflows. We also investigate how relaxing the traditional criteria for defining both radio loud and broad absorption line quasars impacts our understanding of these classes and quasars in general. We seek to demonstrate that not all BALQSOs are exactly the same; separating the extreme cases and discovering where they lie on the continuum of quasar properties could help in determining the physics underlying all quasars. Our ultimate goal is to understand how outflows from quasars change as a function of line-of-sight orientation, mass, accretion, and spin of the black holes that fuel them.

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250.20 – Correlations between different line-forming regions in quasar environments

The early stage of massive galaxy evolution can involve outflows driven by a starburst or a central quasar plus cold mode accretion (infall) adding to the mass build-up in the galaxies. We are using SDSS-BOSS DR12 database to study the nature of infall and outflows in quasar environments by examining the relationships of their narrow absorption lines (NALs) at positive and negative velocity shifts to other quasar properties such as their broad absorption line (BAL) outflows, emission line characteristics, radio-loudness, and reddening by dust. We also test for extreme high-velocity NAL outflows (with speeds 0.1-0.2c) based on relationships to low-speed NALs and quasar properties, and we perform detailed analyses of particular cases of rich multi-component NAL complexes that might result from high-speed quasar outflows shredding and dispersing interstellar clouds in the host galaxies. Our results show that low-velocity NALs and rich NAL complexes correlate strongly with BALs, suggesting a physical relationship. Infalling systems are less common in quasars with BALs, suggesting that BAL outflows can halt or disrupt gas accretion. The extreme high-velocity NALs (at 0.1-0.2c) show a weak relationship to BALs and a strong dependence on low-velocity NALs, indicating that a significant fraction of these systems is ejected from the quasars (and are *not* unrelated intervening clouds). We find no correlations between radio flux and low-velocity NALs, infalling systems, or rich complexes, which indicates that none of these features are closely tied to quasar radio properties. We analyze the relationship of the N V/C IV line strengths (a possible abundance/metallicity probe) in emission versus absorption lines and find no correlation between them.

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250.21 – Investigating the Sensitivity of Emission Line Spectra to the Incident SED in Narrow Line Seyferts and LINERs

This research investigates photoionization models of the Narrow Line Region (NLR) of Seyfert galaxies and Low-Ionization Nuclear Emitting Region (LINER) galaxies with the use of the astrophysical code CLOUDY. Groves et al. 2004 attempted to resolve the apparent uniformity of emission line ratios in the NLR through introducing dusty, radiation pressure-dominated photoionization models of AGN. This model assumed a simple power law relation for the Spectral Energy Distribution (SED). Grupe et al. 2010 found a correlation between α_{uv} and α_x, and by constraining α_{uv} as a function of α_x we developed a photoionization model for the ionizing spectrum of a typical Seyfert Narrow Line Region. The incident SED is based upon the spectral indices α_{uv}, α_x, α_{ox} , and the blackbody accretion disk temperature T_{bb} . We set the value of α_{ox} based on the average of data collected in Grupe et al. 2010, and fix the value of α_{uv} to α_x based on their linear correlation. To check the validity of our model, simulations were run across a range of blackbody accretion disk temperatures and α_x, while fixing the hydrogen density, ionization parameter, and elemental abundance of clouds in the NLR. The emission lines produced by these simulations were plotted using standard diagnostic diagrams and compared to emission line data obtained from the Sloan Digital Sky Survey. Our model produces emission lines without significant variation between simulations with α_x = 1.42, 1.17, and 2.19, with T_{bb} ranging from 104 K to 107 K, except with regard to [O I] λ6300/Hα, where our simulated spectra started to fall on the boundary between Seyferts and LINERs. This leads us to examine the ability of our photoionization model to create emission line spectra that are typical of LINERs, as debate still continues over the primary excitation mechanism for LINERs. To adjust our model to fit LINERs, we lower the value of the ionization parameter and discuss the preliminary results within the context of literature involving the nature of LINERs.

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250.22 – Identifying Evolutionary Patterns of SMBHS Using Characteristic Variables of the Quasar AGNs of eBOSS

We investigate the redshift distribution and environmental conditions of quasar AGNs. The importance of studying these relationships is to use the evolutionary patterns of QSOs (features with many quantifiable characteristics) to gain insight into the evolutionary paths and environmental dependencies of their host super massive black holes (SMBHs), which are more difficult to study directly. We employ specific redshift bins within Data Release 13 of the Sloan Digital Sky Survey's (SDSS) Extended Baryonic Oscillation Spectroscopic Survey (eBOSS) and begin with a sample of 595,025 QSOs. We then incorporate overlapping data sets: The Very Large Array Faint Images of the Radio Sky at Twenty-Centimeters (FIRST) which provides the HI detected QSOs in our sample, along with the galaxy group and cluster sample from Tempel, Tago, Liivamägi 2012 which we cross referenced with our QSO sample to see which of them exist in group environments. The addition of these data sets allows us to create a more holistic view of the processes at work within our sample of QSOs. Understanding the HI presence in different evolutionary phases will allow us to draw conclusions on potential star formation rates or quenching, and by understanding the populations of QSOs in galaxy groups we can determine if QSOs exist overwhelmingly in one particular environment and how environmental conditions effect the other characteristics of QSOs. Overall we provide a multi-faceted analysis of some of the evolutionary patterns and cycles of the eBOSS Data Release 13 QSOs and their implications on the evolutionary paths of SMBHs. This work was supported by the SDSS Research Experience for Undergraduates program, which is funded by a grant from Sloan Foundation to the Astrophysical Research Consortium.

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250.23 – Statistical Analysis of Quasar Light Curves from Pan-STARRS1

We present a statistical analysis of variable quasars in the Pan-STARRS1 Medium Deep Survey (PS1 MDS). PS1 MDS obtained multi-epoch images of 10 fields, each 8 square degrees in size, over 4 years, starting in May 2010. The MDS fields were observed in 5 filters (gp1, rp1, ip1, zp1, and yp1) during their season of visibility, with a typical cadence per filter of 3 days. We extracted the light curves of 670 color-selected quasars in the PS1 MDS using Point Spread Function photometry from the Image Processing Pipeline data products. From the quasar sample, we selected 104 quasars whose variability was at least 2 standard deviations higher than the non-variable reference star sample. We performed a statistical analysis of the light curves of the selected quasars in the g,r,i and z bands using a maximum likelihood method to find the best-fit Damped Random Walk parameters (sigma and tau – also incorporating the Zoghbi et al. 2013 method for uneven sampling). The resulting distributions for sigma and tau were similar to those found in previous studies of quasars.

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250.24 – Infrared Reverberation Mapping of 17 Quasars from the SDSS Reverberation Mapping Project

The Spitzer Space Telescope Cycle 11/12 proposals allowed observations over a 20 month long period which opened up a new window for long term reverberation monitoring of high luminosity active galactic nuclei (AGN). Previous Spitzer reverberation monitoring projects looking for UV/optical light absorbed and re–emitted in the IR by dust had been limited to AGN that could potentially show reverberation within a single cycle (~1 year). This had narrowed the sample of sources to low luminosity AGN which would have a small dust sublimation radius thus having their dust close enough so that the light travel time from the UV/optical emitting region of the accretion disk to the IR emitting region of the dust would be on the 1–2 month timescale. With this new opportunity we monitored 17 quasars from the Sloan Digital Sky Survey Reverberation Mapping (SDSS–RM) project. This sample has photometric monitoring for 849 quasars starting in 2010 combining data from the Pan–STARRS, CFHT, and Steward Observatory telescopes. By combining these ground based observations with Spitzer data we can, for the first time, detect dust reverberation in high luminosity AGN.

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250.25 – Powerful Quasar Outflows at High Redshifts

Powerful quasar outflows can be driven by radiation pressure or radio jets, and they are capable of effecting the evolution of their host galaxies, particularly at high-redshifts (z~2)) when the quasar density peaks. We present a multi-wavelength analysis of 131 quasar outflows at high-redshifts (0.8<z<1.6) selected from the Sloan Digital Sky Survey (SDSS) based on double peaked narrow emission lines. Our goal is to understand the mechanisms driving the outflows, their impact on the host galaxies, and their environments. We find that a subsample of 32 are detected by FIRST with 21 of them showing evidence for extended radio emission that suggests the outflows may be driven by the mechanical energy of radio jets in up to one-third of the sample. For the remaining two thirds of the sample, radiation pressure from the accretion disk is likely the driving mechanism. For those sources, we use the spatial information from long-slit spectra to estimate the energy of the outflowing gas, finding that one hundredth of the quasar energy is coupled with the energy being emitted by the radiation pressure from the accretion disk. Three of the quasars are found in the Hubble Space Telescope archives, with two of them showing clear signs of galaxy interactions/mergers, and a fraction of 0.4 show evidence of interactions from SDSS imaging. These combined results suggests that galaxy interactions may be the triggers of enhanced accretion onto the nuclear supermassive black holes of this sample, with the corresponding enhanced radiation pressure driving the outflows. Furthermore, the high-redshift nature of this sample has pushed the systematic study of quasar outflows closer to the epoch in which quasar feedback is likely to have been important in galaxy evolution.

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250.26 – Cross-Correlating the Cosmic Infrared and Cosmic X-Ray Background Fluctuations

Studying unresolved (i.e., undetected) sources is a way to probe the faintest, and thus the least understood, source populations. In particular, such studies have suggested a population of high redshift accreting black holes. We present cross-power spectra and coherence between the cosmic infrared and cosmic x-ray background fluctuations, using infrared images from Spitzer Space Telescope and x-ray images from XMM-Newton of the ~2 square degree area of the COSMOS field. We first masked all known sources and subtracted model images of the masked x-ray sources' PSF tails so as to isolate the unresolved cosmic backgrounds. We have considered infrared data from two bands, 3.6 and 4.5 µm, and x-ray data from five bands, [0.3-0.5], [0.5-1], [1-2], [0.5-2], and [2-10] keV. We find strong correlation between the cosmic infrared and cosmic x-ray backgrounds, which suggests an origin in a common population, i.e., stars and/or growing black holes.

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250.27 – Luminous, High-z, Type-2 Quasars are Still Missing

A simple unified model suggests that there should be roughly equal numbers of type-1 (unobscured) and type 2 (obscured) quasars. However, we argue that the expected population of luminous, high-z, type-2 quasars are still missing. While large numbers of type-2 AGNs have now been identified (both via spectroscopy and through color-based arguments in the optical, IR, and X-ray), the vast majority of these are low-luminosity objects at z<1, whereas only handfuls of bonafide type-2 quasars are confirmed at redshifts z~2 with bolometric luminosities that are comparable to the typical luminosity of SDSS type-1 quasars. Although some analyses find the density of high-z, type-2 candidates to be much higher than the type-1 population (at similar bolometric luminosity), our revisiting of the problem through an archival spectroscopic search reveals that the confirmed high-z, type-2 population is only a fraction of the high-z, type-1 quasar population to a depth of WISE W4<8. As most interpretations of the "unified model" predict similar numbers of type-1 and type-2 quasars, this conspicuous lack of luminous type-2 quasars at high-redshift constitutes a major unsolved problem. To uncover these missing type-2 quasars, we explore a candidate selection algorithm that utilizes the sky area of AllWISE, the depth/resolution of large-area Spitzer-IRAC surveys, and optical data from the SDSS.

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250.28 – Discovery of a New Quasar: SDSS J022155.26-064916.6

We report the discovery of a new quasar: SDSS J022155.26-064916.6. The object was selected as a white dwarf candidate for a sample of spectrophotometric standards for the Dark Energy Survey. It was imaged by SDSS and classified as a star with a cosmic ray hit, but the quasar was not selected as a spectroscopic target for SDSS-III. WISE data place the object in the QSO/Seyfert range; however, no spectroscopic confirmation of the object as a quasar previously existed. In the investigation of this object as a potential white dwarf, the object was identified by its spectrum to be a quasar. The spectrum is presented with MgII, OII, Hb, and OIII identified, and the average redshift is determined to be $z \approx 0.799 \pm 0.0086$. The luminosity distance is $D_L = 5074.7$ Mpc. The Spectral Energy Distribution and a comparison with objects from the SDSS DR7 quasar catalog are also presented.

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250.29 – Multiwavelength and Polarimetric Analysis of the Flat Spectrum Radio Quasars 3C 273 and 3C 279

This poster presents results of multiwavelength analyses of 3C 273 and 3C 279. The main goals were to identify the gamma-ray emission region and dominant high-energy emission processes. Our methodology consisted of analyzing light curves from radio to gamma-rays over 6 - 8 years and polarimetric, spectral and line emission behavior.

In 3C 279, we found that the emission from millimeter to ultraviolet was simultaneous and therefore co-spatial. We identified two active states where different high-energy emission processes were dominant. We found multiwavelength flaring events consistent with component ejections and shocks. We proposed that the gamma-ray emission region changed over time based on observations of both simultaneous and delayed gamma-rays emission with respect to low-energy emission during different time-frames.

In 3C 273, we identified a non-thermal flare related to a component ejection and a thermal flare related to accretion. From reverberation mapping we found that the broad line region dynamical behavior over time possibly affects the derived supermassive black hole mass.

In both objects we found that the gamma-ray spectral index was variable, and a trend of harder spectral index with higher gamma-ray luminosity. From the identification of different dominant high-energy emission processes, we concluded that the dominant high-energy emission mechanism changes with time. Overall, we concluded that similar results from both objects points to behavior that is potentially common to flat spectrum radio quasars. Increasing the sample size of objects analyzed with similar methodologies will provide more results to confirm or refine our conclusions.

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250.30 – Associated TeV Emission from the Double-Synchrotron Model for Large-Scale Quasar Jets

When the Chandra X-ray telescope launched, it discovered that the radio jets sometimes produced by active galactic nuclei (AGN) were anomalously bright in the X-ray band. The dominant model for explaining this X-ray emission is presently that the synchrotron-emitting electrons in the jet are Compton-scattering Cosmic Microwave Background photons (IC/CMB). This model requires highly relativistic bulk jet speeds far from the core of the AGN and a cutoff of the electron energy distribution in the jet below TeV energies. Based on recent results ruling out the IC/CMB model for anomalous X-ray jets, we consider instead that X-rays from a second electron energy distribution reaching up to TeV energies. As a mandatory process, IC/CMB emission at TeV energies will result from these jets, at a level dependent on the magnetic field and Doppler boosting factor. Using publicly available multi-wavelength observations of around three dozen anomalously X-ray bright jets, we predict the TeV gamma ray production of each jet subject to these unknowns. This will allow us to construct a catalog of potential TeV-producing active galaxies to observe with TeV telescopes currently being constructed. Such observations could be used to determine which, if either, of these two models is correct in explaining the X-ray emission of these jets.

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250.31 – On the Time Scales of Optical Variability in Radio-Quiet Quasar PDS 456

We present new results from the ongoing multi-year monitoring of the radio-quiet, luminous, near-by ($z = 0.184$) quasar PDS 456 in two narrow-band filters using the 17-inch CCD telescope at the Maria Mitchell Observatory. We observed 19 nights in the summer of 2016, and over five summer seasons we have 63 nights of data. The filters are centered on the redshifted H-alpha line ($\lambda = 777$ nm) and the nearby red continuum ($\lambda = 850$ nm). We detected small-amplitude (< 0.2 m) variations in both the emission line and the continuum on all time scales from years to days, and quite probably, rare intra-night variations in both the continuum and the emission line. The reality of intra-night variations, with amplitudes of up to a few per cent, was corroborated by the F-test. Since they were detected on rare nights, the duty cycle of such variations must be small, probably less than 5%. If confirmed, the intra-night variations of the emission line will require a much closer proximity of the broad-line region to the black hole than it was considered before. This project was supported in part by the NSF REU grant AST-1358980, the MA Space Grant, and by the Nantucket Maria Mitchell Association.

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250.32 – Periodic Variability of MRK501 in Optical Light

We present data for Mrk501 from 2009-2016 taken by ROVOR and WMO in Johnson B, V, and R filters. An aperture of radius 5" was used for all data. Photometry was referenced to the same ensemble of stars in all frames. We find strong evidence for a regular light curve that is the combination of a sine wave of amplitude around 0.08mag in V and R with a period of ~2000±200 days and a linear combination of sine waves having periods of ~113±3days and ~70±5 days both with amplitudes of approximately 0.03mag. These amplitudes tend to be larger in the B filter. These results are consistent with X-ray data and are qualitatively similar to the light curve found for NGC5548 (Bon et al, 2016).

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250.33 – The Dramatic June 2016 Optical Outburst and Micro-Variability of the Blazar 3C 454.3

We present the optical (Johnson-Cousins *R* filter) light curve of the blazar 3C 454.3 from May to August 2016 obtained at the Colgate University Foggy Bottom Observatory (FBO) as part of our twenty-eight year blazar variability monitoring program. In June 2016 the blazar underwent an extremely rare, quick, and powerful outburst with a duration of ~2 weeks, flaring from 15.5 to 13.0 magnitude, then back to 15.5, with multiple timescales of variations. The optical outburst appears to be correlated with gamma-ray activity as seen by the *Fermi*-LAT mission during a similar time period. In this outburst, several nights exhibited intraday optical variability of several tenths of a magnitude over the course of five hours. On June 25, 2016 (UT), the flux from 3C 454.3 decreased exponentially from 10.5 to 6 mJy (R = 13.7 to 14.3 magnitude) over 3.5 hours, with micro-variability in the form of damped sinusoidal oscillations with a period of 35 minutes. The amplitude of these oscillations was 7% of the intensity of the flaring component. We place the June 2016 event in a historical context with other outbursts (Balonek, Weaver, et al. 2017, at this conference). We gratefully acknowledge support through Colgate University's Justus and Jayne Schlichting Student Research and NASC Division funds.

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250.34 – The Optical Variability of the Blazar 3C 454.3 over Three Decades from the Colgate University Foggy Bottom Observatory

Using images from the ongoing quasar monitoring program at Colgate University's Foggy Bottom Observatory (FBO), we present a twenty-eight year light curve of the blazar 3C 454.3 in Johnson-Cousins *V, R,* and *I* filters. Using additional data from several sources, we construct an historic light curve going back to 1899. We compare the variations in several outbursts beginning with the great outburst of 2005. Following its historic minimum in 2012 (R=16.4 magnitude), 3C 454.3 has exhibited several outbursts, always remaining above a base level of 15.8 magnitude. Short timescale activity with duration of hours to days and brightness range of a magnitude or smaller are superposed on the longer-term events. We investigate the characteristic timescales and intensities of these events. We observe V-R and R-I color index variations that are correlated with brightness. The most recent flare, June 2016, has been studied by Weaver & Balonek (2017, at this conference). We gratefully acknowledge support through Colgate University's Justus and Jayne Schlichting Student Research and NASC Division funds, a National Science Foundation REU grant (AST-1005024) to the Keck Northeast Astronomy Consortium, and the NASA / New York Space Grant.

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250.35 – Searching for X-Ray Variability in Resolved Jets from Radio-Loud AGN

Nearly all large galaxies host a super-massive black hole (SMBH) at their centers, featuring an accretion disk that may become so luminious that it outshines the host galaxy. In some cases, accreting SMBH may also produce bipolar jets of fully-ionized relativistic plasma. The origin of these jets is not fully understood; however, they are large enough to be resolved by high-resolution telescopes such as the Hubble Space Telescope and the Chandra Space Telescope. Through multi-wavelength observations it has been shown that these jets produce synchrotron (ST) radiation; still, the nature of X-ray emission from the jets is a long-standing mystery. We propose that any variability observed would conclusively rule out one of the two competing models for the X-ray emission, namely, the inverse-Compton (IC) model where relativistic electrons in the jet upscatter ambient CMB photons to produce electrons. In this case, the flux of the jet should remain steady over time. On the other hand, by detecting significant variability, the ST radiation model would be preferred. By measuring the flux in jet knots over multiple observations of a single source, we tested variability in the X-ray emission of jets. Observations were obtained using Chandra's open-source archive of X-ray imaging data, and processed using the open-source processing package CIAO.

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250.36 – AGN Variability: Probing Black Hole Accretion

We combine the long temporal baseline of Sloan Digital Sky Survey (SDSS) for quasars in Stripe 82 with the high precision photometry of the Kepler/K2 Satellite to study the physics of optical variability in the accretion disk and supermassive black hole engine. We model the lightcurves directly as Continuous-time Auto Regressive Moving Average processes (C-ARMA) with the Kali analysis package (Kasliwal et al. 2016). These models are extremely robust to irregular sampling and can capture aperiodic variability structure on various timescales. We also estimate the power spectral density and structure function of both the model family and the data. A Green's function kernel may also be estimated for the resulting C-ARMA parameter fit, which may be interpreted as the response to driving impulses such as hotspots in the accretion disk. We also examine available spectra for our AGN sample to relate observed and modelled behavior to spectral properties. The objective of this work is twofold: to explore the proper physical interpretation of different families of C-ARMA models applied to AGN optical flux variability and to relate empirical characteristic timescales of our AGN sample to physical theory or to properties estimated from spectra or simulations like the disk viscosity and temperature. We find that AGN with strong variability features on timescales resolved by K2 are well modelled by a low order C-ARMA family while K2 lightcurves with weak amplitude variability are dominated by outliers and measurement errors which force higher order model fits. This work explores a novel approach to combining SDSS and K2 data sets and presents recovered characteristic timescales of AGN variability.

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250.37 – Searching for Short Term Variable Active Galactic Nuclei: A Vital Step Towards Using AGN as Standard Candles

Current models for accretion disk sizes of active galactic nuclei (AGN) do not match the limited observational data available, so there is an active need from the modeling community for many more accretion disk/dusty torus reverberation mapping campaigns with which to better calibrate models. Since short term variable AGN can be more easily monitored for reverberation mapping than long term variable AGN, they can begin to provide data more quickly. This project looked for short term variable AGN in the Young Stellar Object Variability (YSOVAR) survey conducted using the Spitzer Space Telescope. The YSOVAR survey targeted 12 nearby star forming regions for repeated observations. Potential AGN from the YSOVAR data were first selected by color ([3.6] – [4.5] > 0.4) and then by magnitude (m < 14) based on previous Spitzer surveys of known AGN. Since AGN share some similar color characteristics with young stars, images of each YSOVAR region were viewed to remove potential objects near concentrations of known young stellar objects since these were likely also YSOs. The spectral energy distribution (SED) for each remaining potential AGN was then examined for AGN like characteristics. Several potential short term variable AGN were found.

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250.39 – The bursting behavior of the blazar PKS 1130+009 from K2 and ground based photometry

PKS 1130+009 (EPIC 201510350) is a z=1.64 blazar, observed as part of our continuing observations of WiBRAL blazars with the K2 mission. During the K2 observations, PKS 1130+009 exhibited repeated outbursts of up to 50% in flux, with one larger, rapid outburst well in excess of 100% flux variation detected. The outbursts were semi-regular, but did not occur with any rigorous periodicity. Ground based optical R band observations were obtained with the 1.3 Robotically Controlled Telescope at KPNO to determine if this behavior is episodic and restricted to the time of the K2 observations, or if this behavior is typical of this source. The slope and nature of the source power spectral density are discussed.

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250.40 – A Comparison of Two Methods for Estimating Black Hole Spin in Active Galactic Nuclei

The angular momentum, or spin, is one of the fundamental properties of black holes (BHs), yet it is much more difficult to estimate than mass or accretion rate (for actively accreting black holes). In recent years, high-quality X-ray observations have allowed for detailed measurements of the Fe Kα emission line in nearby AGN, where relativistic line broadening allows constraints on the spin parameter (the X-ray reflection method). Another method, commonly used for stellar-mass accreting BHs and recently applied to super-massive BHs (Capellupo et al. 2016), is the continuum-fitting (CF) method. A detailed comparison of the two methods in AGN is necessary because neither method can be applied to all AGN. We apply the CF method to two AGN that already have X-ray reflection measurements. For the high-mass AGN H1821+643, we find results that are consistent with the reflection method, unless the BH mass is at the lower end of current estimates. For the Seyfert 1 NGC 3783, a large range in spin is consistent with the data, including the very high spin predicted by the reflection method. However, this high spin is more probable when a disk wind is added to the continuum model, which is consistent with other studies that find evidence of an AGN outflow in this source.

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250.41 – B-FlaP: Classifying Gamma-ray Blazars Using Machine Learning

In the Third Fermi Large Area Telescope Catalog of high-energy gamma-ray sources, 573 are listed as Blazar Candidates of Uncertain type (BCU), or sources without a conclusive classification. Blazar Flaring Patterns (B-FlaP) uses Empirical Cumulative Distribution Function and Artificial Neural Network machine-learning techniques for a fast method of screening and classification of BCUs based on gamma-ray data only, when rigorous multiwavelength analysis is not available. In this study radio analysis and direct observations by ground-based optical observatories are used to validate the B-FlaP method. Tests indicate that the method is effective, suggesting that 342 sources are likely BL Lac objects, 154 are likely Flat Spectrum Radio Quasars, with only 77 remaining uncertain. 53 of the BCUs appear to be High Synchrotron Peaked blazars, a class of particular interest to ground-based imaging atmospheric Cherenkov telescopes.

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250.42 – Searching for Hard X-Ray Emission from Radio-Loud Gamma-Ray Quiet Blazars

While the Swift BAT AGN source catalog is dominated by radio-quiet Seyfert AGN, around 15% of the sample are radio galaxies or blazars (Ajello et al., 2009). There is an overlap of about 40 sources between the Fermi LAT and Swift BAT detected AGN populations, only a few percent of the Fermi total. These small numbers are presumably a result of selection bias as the SSC peak often falls squarely within the Fermi LAT bandpass while the Swift BAT sensitivity is highest in the spectral region straddling the synchrotron and SSC components.
Recently however, a significant sample of bright (F 15GHz >1.5 Jy), radio selected AGN was found, surprisingly, to overlap with Fermi at only the ~80% level (Lister et. al., 2015). This could be a result of selection bias as well as the gamma-ray quiet objects of that survey having synchrotron peak frequencies of 10^13.4 Hz or less. On the other hand it could be due to deficient Doppler boosting among that ~20%. One can, in principle, test the former possibility by assessing emission from the low-energy wings of putative sub-GeV peaked SSC components. We describe our ongoing joint Swift BAT analysis project that attempts to address this possibility. Initial results, comparisons with INTEGRAL observations, and conclusions are presented.

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250.43 – Spectral and Temporal Analysis of 1H1934-0617: Observing an “Eclipsed” AGN with XMM-Newton and NuSTAR

1H1934-0617 is a low-mass (3×10^6 $M_\odot$) NLS1 which was ranked as 7^{th} in excess variance among AGN comprising the CAIXA catalogue (Ponti 2012). Similar to its high-ranking and oft-studied counterparts, this AGN is extremely time-variable, luminous, and displays strong reflection features. We present spectral and temporal analyses of concurrent XMM-Newton and NuSTAR observations (120 ks), during which we explore a dramatic dip in flux, similar to that of Fairall 9 (Lohfink 2012, 2016). The transit-like dip appears in the NuSTAR band, and the spectral shape of the 0.3-2 keV band remains constant throughout the flux varied observation, ruling out a strong absorber. XMM-Newton’s large effective area and NuSTAR’s constraints on the 10-79 keV band combine to inform us about the source geometry, black hole spin, and emission/absorption processes as we speculate on the nature of the variability of this scarcely-studied AGN. Preliminary spectral modeling indicates that the dip in flux can be understood as a decrease in the height of the corona, and preliminary timing analysis shows hints of an iron K reverberation lag.

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250.44 – Fermi Observations of Resolved Large-Scale Jets: Testing the IC/CMB Model

It has been observed with the *Chandra* X-ray Observatory since the early 2000s that many powerful quasar jets show X-ray emission on the kpc scale (Harris & Krawczynski, 2006). In many cases these X-rays cannot be explained by the extension of the radio-optical spectrum produced by synchrotron emitting electrons in the jet, since the observed X-ray flux is too high and the X-ray spectral index too hard. A widely accepted model for the X-ray emission first proposed by Celotti et al. 2001 and Tavecchio et al. 2000 posits that the X-rays are produced when relativistic electrons in the jet up-scatter ambient cosmic microwave background (CMB) photons via inverse Compton scattering from microwave to X-ray energies (the IC/CMB model). However, explaining the X-ray emission for these jets with the IC/CMB model requires high levels of IC/CMB γ-ray emission (Georganopoulos et al., 2006), which we are looking for using the *FERMI/LAT* γ-ray space telescope. Another viable model for the large scale jet X-ray emission favored by the results of Meyer et al. 2015 and Meyer & Georganopoulos 2014 is an alternate population of synchrotron emitting electrons. In contrast with the second synchrotron interpretation; the IC/CMB model requires jets with high kinetic powers which can exceed the Eddington luminsoity (Dermer & Atoyan 2004 and Atoyan & Dermer 2004) and be very fast on the kpc scale with a $\Gamma \sim 10$ (Celotti et al. 2001 and Tavecchio et al. 2000). New results from data obtained with the *Fermi/LAT* will be shown for several quasars not in the *Fermi/LAT* 3FGL catalog whose large scale X-ray jets are attributed to IC/CMB. Additionally, recent work on the γ-ray bright blazar AP Librae will be shown which helps to constrain some models attempting to explain the high energy component of its SED, which extends from X-ray to TeV energies (e.g., Zacharias & Wagner 2016 & Petropoulou et al. 2016).

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250.45 – Testing for Shock-Heated X-Ray Gas around Compact Steep Spectrum Radio Galaxies

We present Chandra and XMM-Newton X-ray, VLA radio, and optical observations of two CSS radio galaxies. B3 1445+410 is a low excitation emission line galaxy with possibly a hybrid FRI/II (or Fat Double) radio morphology. The Chandra observations are point-like and well fit with a power-law consistent with emission from a Doppler boosted core. PKS B1017-325 is a galaxy with a bent double radio morphology. The XMM-Newton observations are consistent with an ISM with a contribution from hot shocked gas. We compile selected radio and X-ray properties of the nine CSS radio galaxies with X-ray detections so far. We find that 1/3 show evidence for hot shocked gas. We note that the counts in the sources are low and the properties of the 3 sources with evidence for hot shocked gas are typical of the other CSS radio galaxies. We suggest that hot shocked gas may be typical of CSS radio galaxies due to their propagation through their host galaxies.

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250.46 – Properties of the optical line-emitting gas in the radio galaxy, 4C+29.30

Theoretical simulations and observations of galaxies point towards a paradigm in which they grow through mergers and interactions, and this growth is regulated by powerful feedback from star formation, AGN winds or jets. The details of these feedback processes are not well understood; however in radio galaxies the influence of the radio activity on the interstellar medium is suggested by the similar morphologies of the regions of optical line emitting gas and the radio emission. The nearby radio galaxy, 4C+29.30, (z=0.0647; 1 arcsec = 1.227 kpc) has X-ray (Chandra ACIS-S, 0.5-7 keV; Siemiginowska et al. 2012) as well as VLA imaging (van Breugel et al. 1986) which both reveal a jet, hot spots and lobes, and provides an excellent opportunity for detailed studies of feedback processes.

To investigate a faint filament that was seen in previous narrow-band optical imaging and spectroscopic data and believed to be associated with the radio jet (van Breugel et al. 1986), we obtained a deep image through a narrow band filter centered at redshifted Halpha using the imager/spectrograph OSMOS at the Hiltner 2.4-m telescope of the MDM Observatory, and a long-slit spectrum covering the range 3200-10000 Angstroms using the Multi-Object Double Spectrograph (MODS) at the Large Binocular Telescope (LBT). The spectrum reveals a complex velocity structure, with well-detected extended Halpha+[NII], [SII], Hbeta, [OIII] and [OII] emission, concentrated into clumps, two of which correspond to 'wisps' in the Halpha image and may coincide with the filament. We discuss the new imaging and spectroscopic data, analyzed together with the X-ray and radio maps, in a study of the properties of the line-emitting gas and its relation to the radio emission.

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250.47 – HST Polarimetry of the 3C 273 Jet

We present preliminary results using HST polarimetry of the jet of 3C 273. Polarization is a critical parameter for understanding jet flows, and has proven essential in characterizing the physics of FR I jets; high-quality HST polarimetry has been done for just two other FR II jets previously. Our recent work on two quasar jets, where we measured high optical polarization in the brightest X-ray knots, has favored the synchrotron emission model over the alternative IC/CMB model for their optical to X-ray emission. These new observations of 3C 273 allow for the determination of the magnetic field structure and confirmation of which emission mechanisms are operating to create its optical to X-ray emission, and will allow us to greatly advance modeling efforts for this jet and nail down its kinetic power, a key unknown parameter for understanding quasars and their cosmological effects.

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250.48 – A Hubble Space Telescope Survey of Intrinsic Absorption in Nearby AGN

We present a survey of the intrinsic UV absorption lines in active galactic nuclei (AGN). We limit our study to the ultraviolet spectra of type 1 AGN with a redshift of $z < 0.15$ as a continuation of the Dunn et al. (2007, 2008) and Crenshaw et al. (1999) studies of smaller samples. We identify approximately 90 AGN fit our redshift specifications in the Mikulski Archive for Space Telescopes (MAST) database with Cosmic Origin Spectrograph (COS) observations. We download and co-add all of the COS spectra. We find that about 80 of these are type 1 AGN. We normalize the COS spectra and identify all of the intrinsic Lyman-alpha, N V, Si IV, and C IV intrinsic absorption features. From these data, we determine the fraction of type 1 AGN with intrinsic absorption in this redshift range and find the global covering factors of the absorbers. We also identify low ionization species as well as excited state lines. A number of objects have multiple epoch COS and/or Space Telescope Imaging Spectrograph (STIS) observations, which we use to investigate the absorption variability.

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250.49 – Exploring the Vertical Structure of Nuclear Starburst Disks: A Possible Source of AGN Obscuration at Redshift ~ 1

Nuclear starburst disks (NSDs) are star-forming regions that could be present at high redshift (z~1) in the vicinity of active galactic nuclei (AGNs). One dimensional analytical models by Thompson et al. (2005) show that, under certain conditions, these disks can be geometrically thick on parsec scales which make them a possible source for AGN obscuration. We construct a 2D model of NSDs where an iterative method is used to obtain vertical solutions for a given annulus. These solutions coherently satisfy the equations of energy balance, hydrostatic, radiative transfer, and the Toomre stability criteria. In comparison to 1D model, a more robust 2D calculation shows the higher scale-height at the outer part of a NSD, but predicts a lower expansion of an atmosphere at the parsec/sub-parsec scale**.** A total of 96 NSD models are computed under various physical conditions (black hole mass, size of a disk, and a gas fraction) in order to predict the column density distribution along a line of sight. Assuming a random distribution of input parameters, the statistics yield 59% of Type 1, 24% of Compton-thin (CTN), and 17% of Compton-thick (CTK) AGNs. The distribution of obscured AGNs fraction peaks near $N_H = 10^{23.5}$ cm^{-2}. Depending on a viewing angle (θ) of a given NSD, the line of sight N_H can vary from 10^{22} to 10^{28} cm^{-2}. This supports the unification theory of AGNs as our results show an AGN can appear to be obscured by a CTK ($N_H > 10^{24}$ cm^{-2}) or CTN (10^{22} cm$^{-2} < N_H < 10^{24}$ cm^{-2}) gas depending on a viewing angle. Using 2D structure, we show any θ is possible for CTN AGNs; however, the maximum allowed θ for CTK AGN is restricted to approximately 60 degrees.

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250.50 – Optical to extreme ultraviolet reddening curves for normal AGN dust and for dust associated with high-velocity outflows

We use mid-IR (WIRE), optical (SDSS), and ultraviolet (GALEX) photometry of over 80,000 AGNs to derive mean attenuation curves from the optical to the rest frame extreme ultraviolet (EUV) for (i) "normal" AGN dust dominating the optical reddening of AGNs and (ii) "BAL dust" – the dust causing the additional extinction in AGNs observed to have broad absorption lines (BALs). Our method confirms that the attenuation curve of "normal" AGN dust is flat in the ultraviolet, as found by Gaskell et al. (2004). In striking contrast to this, the attenuation curve for BAL dust is well fit by a steeply-rising, SMC-like curve. We confirm the shape of the theoretical Weingartner & Draine (2001) SMC curve out to 700 Angstroms but the drop in attenuation to still shorter wavelengths (400 Angstroms) seems to be less than predicted. We find identical attenuation curves for high-ionization and low-ionization BALQSOs. We suggest that attenuation curves appearing to be steeper than the SMC are due to differences in underlying spectra and partial covering by BAL dust. This work was This work was performed under the auspices of the Science Internship Program (SIP) of the University of California at Santa Cruz performed under the auspices of the Science Internship Program (SIP) of the University of California at Santa Cruz.

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250.51 – Tracing the Far-Infrared Roles of AGN in Dusty Star-Forming Galaxies

Active galactic nuclei (AGNs) are suggested to play an important role in quenching their host galaxy's star formation rate (SFR) by heating up and/or consuming the cool gas necessary to create stars. This mechanism is theorized as a critical step in AGN evolutionary models. The efforts to study this effect suffer in part from low-number statistics at high x-ray luminosities ($L_{XR} > 10^{44}$ ergs/s) for AGNs at z≈1-3, and a lack of separately estimated SFRs for AGN in dusty, star-forming galaxies (DSFGs). In this work, we extend our analysis to build a more complete picture using the variety of available multi-wavelength data in the XBoötes region. The Chandra XBoötes Survey is a 5-ks X-ray survey of the 9.3 square degree Boötes Field of the NOAO Deep Wide-Field Survey, a survey imaged from the optical to the near-IR. We estimate AGN spectral energy distributions and SFRs for ~400 x-ray sources using available data in all four Spitzer IRAC bands, the Spitzer MIPS 24μm band, all five Herschel SPIRE and PACS bands, along with NEWFIRM optical bands. Preliminary results show an exponential correlation between x-ray luminosity and star formation. As a comparison, we will use a stacking technique for the ~500 x-ray sources that were not detected at submillimeter wavelengths, where sources are binned by x-ray luminosity. We will compare these two samples and expect to see a difference in slope. Using these techniques, we hope to place tighter constraints on the mean SFRs of high-luminosity AGNs inside DSFGs, and determine if x-ray luminosities are independent of average SFRs for our sample in the Boötes field.

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250.52 – Circumnuclear Star Formation in Seyfert Galaxies

We examine a group of Seyfert 1 and Seyfert 2 galaxies to determine whether there exists a correlation between the circumnuclear starburst age and the luminosity of the active galactic nucleus. Using data from the Keck OSIRIS Nearby AGN (KONA) survey, we have a sample size of 40 Seyfert galaxies (split between Seyfert 1s and 2s), in which we measure the circumnuclear properties down to a few tens of parsecs. We determine the age of the most recent episode of circumnuclear star formation by analyzing the equivalent width of the Br Gamma 2.16 micron emission line and further constrain the age using measurements of the K-band mass to light ratio. The results of these analyses will be presented, including a comparison of the Seyfert 1 and Seyfert 2 subsamples.

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250.53 – Disentangling the NLR Structure in Mrk 573 with Integral Field Spectroscopy

We present near-infrared emission-line kinematics of the Seyfert 2 galaxy Mrk 573 using the Near-Infrared Field Spectrograph (NIFS) at Gemini North. By obtaining 2D kinematic maps of the infrared ionized and molecular gas in the circumnuclear region of Mrk 573, we find that kinematics within and surrounding the spatially-resolved Narrow-Line Region (NLR) are largely due to a combination of both rotation and radiative, in situ acceleration of material originating in the host disk. From this analysis, we find that outflowing gas extends to distances less than 1 kpc, suggesting that outflows in this Seyfert galaxy may not be powerful enough to evacuate its entire bulge.

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250.54 – An Extended Look at the Narrow-Line Region of the Seyfert 2 Galaxy Mrk 573

Active galactic nuclei (AGN) are supermassive black holes found in the centers of galaxies which accrete matter from their surroundings and subsequently produce AGN feedback in the form of ionized and molecular gas outflows. These outflows are largely contained within the Narrow-Line Region (NLR), a low density sector that extends froms tens to thousands of parsecs away from the nucleus. In order to clarify the relationship between the AGN and its host galaxy at these various distances, we present this study on Mrk 573, a Seyfert 2 AGN, based on long-slit spectroscopy from the Dual Imaging Spectrograph (DIS) on the ARC 3.5-meter telescope at Apache Point Observatory. We find that the dominant ionization mechanism of the gas up to a radius of 2 kpc can be attributed to the AGN and that the ionized gas kinematics are dominated by galactic rotation at distances larger than 750 pc.

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250.55 – NGC 3393: multi-component AGN feedback as seen by *CHEERS*

Due to its low density, moderate ionization, and weak kinematics, the narrow line region (NLR) of active galactic nuclei (AGN) provides poweful diagnostics for investigating AGN feedback. The *CHandra Extended Emission line Region Survey* (*CHEERS*) is the ultimate investigation into resolved feedback in the NLR. We present results from our *CHEERS* investigations of NGC 3393. By imaging extended X-ray line emission of NGC 3393 with *Chandra* and optical line emission with *Hubble's* narrow-band filters, we are able to map out the simultaneous impact of photoionization, jets and an AGN disk-wind. When resolved on scales of ~10s of parsecs, the NLR of NGC 3393 shows a complex multi-component medium. Diagnostic line mapping indicates a Low-ionization Emmision Line Region (LINER) cocoon surrounding the outflow-evacuated cavities (in optical) and surrounding the supports the presence of collisional plasma (in X-rays). These physically distinct constituent regions can only be resolved by the high-resolution imaging that *Chandra* and *HST* enable.

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250.56 – A Search for H2O Maser Emission from Wide-Angle Outflows in Nearby AGN

As part of large surveys for 22 GHz water maser emission in external galaxies, the Green Bank Telescope has made over 4000 distinct observations resulting in nondetections. Most of these observations are 10-minute integrations toward nearby active galaxies, often as part of the Megamaser Cosmology Project. We have grouped the observed galaxies according their nuclear activity type and made stacked averages of the nondetections, searching for low-level, ubiquitous maser emission. Such emission might be expected, for example, if there is faint maser emission from a wide-angle outflow component in the nuclei of AGNs. We detected no maser emission in our stacked averages of Seyfert 1s and Seyfert 2s, or in the sum of all nondetections. We explore the significance of this result in the context of clumpy outflow models.

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Contributing team(s): Megamaser Cosmology Project

250.57 – Probing the Physical Properties and Origins of Ultra-fast Outflows in AGN

Approximately half of Type 1 AGN possess intrinsic absorption and high resolution UV and X-ray spectroscopy have revealed that the absorbing gas is radially outflowing, with velocities of 100s to 1000s km/sec. X-ray ("warm") absorbers, originally revealed by the presence of bound-free edges of O~VII and O~VIII, are more highly ionized than their UV counterparts, and photo-ionization modeling studies have determined that they have ionization parameters of logU ~ -1 to 1. Recently, much more highly ionized gas, with logU > 2, has been detected in XMM-Newton spectra, as evidenced by absorption lines from H- and He-like Fe. Some of these absorbers, ``Ultra Fast Outlows (UFOs)", have radial velocities up to 0.2c. We have undertaken a detailed photo-ionization study of high-ionization Fe absorbers, both UFOs and non-UFOs, in a sample of AGN observed by XMM-Newton. We find that the UFOs are completely Compton-cooled, unlike the non-UFOS. Both types are too highly ionized to be radiatively accelerated, hence they are more likely driven via Magneto-Hydrodynamic processes. Their large column densities and velocity gradients are consistent with flows along magnetic streamlines emanating from accretion disks. Open questions include: the temporal stability of the UFOs, the apparent lack of non-UFOs in UFO sources, and their relationship to warm absorbers.

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250.58 – Possible Superluminal Components in the Nearest Tidal Disruption Event

Tidal disruption events (TDEs) are believed to occur when a star or sub-stellar objects pass close enough to a supermassive black hole for the object to be disrupted by tidal forces. NGC 4845 (d=17 Mpc) was host to a TDE, IGR J12580+0134, that was detected by INTEGRAL in the X-rays and later in the radio by the JVLA. Its proximity offers us a so far unique close-up of the TDE and its aftermath. Here we discuss new VLBA and JVLA observations, obtained in 2015, which show that the radio flux from the active nucleus created by the TDE has decayed in a manner consistent with predictions from a jet-circumnuclear interaction model. But more excitingly, they also contain evidence of ejecta, in the form of a resolved component located 52 milliarcsec (4.1 pc) from the nucleus which, if ejected in 2010 as a result at the TDE, is moving superluminally at 2.4c. The milliarcsecond-scale core is seen to be circularly polarized in our L-band observations only. We discuss the implications of these observations.

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250.59 – AGN-halo Mass Assembly Connection in Galaxy Clusters: Investigation Using the Splashback Radius

The splashback radius (also known as the last density caustic or the second turnaround radius) is a sharp dark matter halo edge that corresponds to the location of the first orbital apocenter of satellite galaxies after their infall. This definition of a halo boundary is more physical compared to the traditional definitions of halo boundaries which tend to be quite arbitrary. The splashback radius responds to the mass assembly history of clusters. For dark matter halos of the same mass, a large mass accretion rate results in a smaller splashback radius, since its deeper halo potential well has a closer apocenter. Using two cluster samples which had the same mass, but different splashback radii, we set out to check if the incidences of active galactic nuclei (AGN) in the member galaxies of these clusters are affected by their mass assembly history. Using SDSS spectroscopic data, we determined metallicity of galaxies and constructed a BPT diagram to classify each galaxy member in each cluster (Seyfert, Liner, Composite, etc.) and determined if an AGN was likely to be present. We compared the samples and determined that the rapidly assembling sample did have a larger AGN presence.

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300 – SPD George Ellery Hale Prize: Magnetic Energy Release in Solar Flares, Terry Forbes (University of New Hampshire)

300.01 – Magnetic Energy Release in Solar Flares

Solar flares are the result of a rapid release of magnetic energy stored in the solar corona. An ideal-MHD process, such as a loss of magnetic equilibrium, most likely initiates the flare, but the non-ideal process of magnetic reconnection quickly becomes the dominant mechanism by which energy is released. Within the last few years EUV and X-ray instruments have directly observed the kind of plasma flows and heating indicative of magnetic reconnection. Relatively cool plasma is observed moving slowly into the reconnection region where it is transformed into two high-temperature, high-speed outflow jets moving in opposite directions. Observations of the flow in these jets suggest that they are accelerated to the ambient Alfvén speed in a manner that resembles the reconnection process first proposed by H. E. Petschek in 1964. This result is somewhat surprising because Petschek-type reconnection does not occur in most numerical simulations of magnetic reconnection. The apparent contradiction between the observations and the simulations can be understood by the fact that most simulations assume a uniform resistivity model that is unlikely to occur in reality. Recently, we have developed a theory that shows how the type of reconnection is related to the plasma resistivity. The theory is based on a form of the time-dependent, MHD-nozzle equations that incorporate the plasma resistivity. These equations are very similar to the equations used to describe magnetized plasma flow in astrophysical jets.

Author(s): Terry G. Forbes[1]
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301 – Extrasolar Planets: Characterization & Theory IV

301.01D – A Model of the Hα Transmission Spectrum of HD 189733b

The hot gas in the upper thermosphere of hot Jupiter sets the boundary condition for understanding the rate of gas escape. Among current detections, Hα transmission spectrum may play an important role in understanding the conditions in the planet's thermosphere. I present a detailed atmosphere model and comparison of Hα model transmission spectra to the data, with the goal of constraining the temperature and particle densities in the region where the absorption line is formed.
A hydrostatic atmosphere is constructed over the pressure range 10^{-4} —10 μbar. Ionization equilibrium and balance of heating and cooling processes are enforced at each level of the atmosphere. The Lyα radiation intensity is computed using a Monte-Carlo code which includes resonant scattering, as well as photon destruction. Both the incident stellar Lyα and internal sources due to recombination cascade and collisional excitation are included. The atomic hydrogen level population is computed including both collisional and radiative transition rates.
The model transmission spectra are in broad agreement with the HD 189733b observation data by Jensen et al and Cauley et al. The combination of large Lyα excitation rates and increasing hydrogen density with depth give rise to a nearly flat at $n = 2$ state density over two decades in pressure. This layer is optically thick to Hα, and temperature is in the range 3000 ~ 6000 K. Additional models computed for a range of stellar EUV flux find transit depth changes with EUV level, suggesting that the variability in transit depth may be due to variability in the stellar EUV. Since metal lines provide the dominant cooling of this part of the atmosphere, the atmosphere structure is sensitive to the density of species such as Mg and Na which may themselves be constrained by observations.

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301.02 – Unveiling exoplanetary atmospheres through LBT spectrophotometry

The Large Binocular Telescope (LBT), with its 12-m equivalent double mirror, high efficiency and cutting-edge technology, offers a unique opportunity to probe planetary atmospheres. Our group already exploited the dual-channel cameras (LBC-B, LBC-R) mounted at the prime foci of LBT to gather simultaneous transit light curves of GJ3470b and GJ1214, and to detect or constrain Rayleigh scattering signatures on their transmission spectrum. We pushed this approach further by taking advantage of a newly-available instrumental setup, i.e. observing the same transit with MODS (intermediate-resolution spectra) through the blue channel, and with LBC-R (broad-band photometry) trough the red one. We present preliminary results from our first observing runs.

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301.03 – VLT FORS2 comparative transmission spectral survey of clear and cloudy exoplanet atmospheres

Thousands of transiting exoplanets are known today but not many have been studied in transmission. While observations with the Hubble Space Telescope (HST) have started to reveal a diversity of atmosphere types, drawing robust conclusions about the underlying population is hampered by the small sample size. This can be greatly aided by ground-based telescopes, equipped with multi-object spectrographs by their unprecedented access to the abundance of fainter systems that HST cannot observe. We have initiated a ground-based, multi-object transmission spectroscopy of a handful of hot gas-giants, covering the wavelength range 360-850nm, using the recently upgraded FOcal Reducer and Spectrograph (FORS2) mounted on the Very Large Telescope (VLT). These exoplanets were selected for a comparative follow-up as their transmission spectra showed evidence for alkali metal absorption, based on the results of HST observations. Here we will discuss first results from the program, demonstrating an excellent agreement between the transmission spectra measured from VLT and HST and detections of Na and K absorption and scattering by clouds/hazes in the atmospheres of several exoplanets. More details will be discussed on the narrow alkali features obtained with FORS2 at higher resolution, revealing its high potential in obtaining optical transmission spectra, which can greatly aid comparative exoplanet studies.

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301.04 – Exploring an Earth-sized neighbor: ground-based transmission spectroscopy of GJ1132b, a rocky planet transiting a small nearby M-dwarf

The terrestrial planets of the Solar System are rocky worlds that did not accrete envelopes of hydrogen and helium, but instead possess thin secondary atmospheres, or no atmosphere at all. Until recently, most exoplanet atmospheric studies have centered around hot Jupiters, for which high planet-to-star radius ratios and short orbital periods allowed for observable transmission spectra. Now we have the opportunity to probe the atmosphere of a small, rocky exoplanet. GJ1132b has a radius of 1.2 Earth radii and a mass of 1.6 Earth masses, and orbits an M-dwarf 12 parsecs away. Determining the composition of GJ1132b's atmosphere is essential to understanding the nature of atmospheric evolution on terrestrial planets. We observed five transits of GJ1132b using the Magellan

Clay telescope with the LDSS3C multi-object spectrograph. We compare the transit depth of GJ1132b in wavelength bins ranging from 0.65 -- 1.04 microns to infer whether or not GJ1132b has maintained its primordial hydrogen-dominated atmosphere. Should we find evidence of a hydrogen-dominated atmosphere, this would imply that a terrestrial planet is able to accrete and retain a low mean-molecular weight atmosphere from the planetary nebula. Coupled with recent UV spectra of the host star, our results can clarify the process of atmospheric escape on terrestrial worlds, with implications for formation histories of M-dwarf planets and the potential for habitability in these systems. If instead GJ1132b possesses a low mean-molecular weight atmosphere, we look to future observations with JWST and the ground-based extremely large telescopes to characterize its atmosphere.

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301.05 – Emission Spectroscopy of the Super-Earth 55 Cnc e

Recent surveys have revealed an extraordinary and unexplained diversity of low-mass exoplanets. The main frontier for constraining the nature and origins of these planets is atmospheric characterization to reveal their detailed physical properties. Previous spectroscopic observations of small exoplanets have been focused on transmission measurements, but these studies are often limited by clouds. We are turning small exoplanet characterization in a new direction with multi-wavelength observations (Warm Spitzer and HST WFC3) of the dayside of 55 Cnc e, a quintessential super-Earth in a tight orbit and transiting a nearby star. We will present the first dayside emission spectrum of a super-Earth, which we use to distinguish between different atmospheric compositions and constrain the vertical temperature structure of the atmosphere. Our results for 55 Cnc e will guide JWST emission spectroscopy of a much larger sample of small close-in transiting exoplanets.

Author(s): Diana Dragomir3, Jacob Bean5, Laura Kreidberg[2], Kevin B. Stevenson4, Michael R. Line[1]
Institution(s): *1. Arizona State University, 2. Harvard, 3. MIT, 4. Space Telescope Science Institute, 5. University of Chicago*

301.06 – Challenges to Constraining Exoplanet Masses via Transmission Spectroscopy

MassSpec, a method for determining the mass of a transiting exoplanet from its transmission spectrum alone, was proposed by deWit and Seager (2013). The premise of this method relies on the planet's surface gravity being extracted from the transmission spectrum via its affect on the atmospheric scale height, which in turn determines the depth of absorption features. Here, we further explore the applicability of *MassSpec* to low-mass exoplanets – specifically those in the super-Earth size range for which radial velocity determinations of the planetary mass can be extremely challenging and resource intensive. Determining the masses of these planets is of the utmost importance because the nature of these planets is otherwise highly unconstrained. Without knowledge of the mass, these planets could be rocky, icy, or gas-dominated. To investigate the effects of planetary mass on transmission spectra, we present simulated observations of super-Earths with atmospheres made up of mixtures of water and H_2 both with and without clouds. We model their transmission spectra and run simulations of each planet as it would be observed via JWST with the NIRISS, NIRSpec, and MIRI instruments. We find that significant degeneracies exist between transmission spectra of planets with different masses and compositions, making it impossible to unambiguously determine the planet's mass in many cases.

Author(s): Eliza Kempton[1], Natasha Batalha[2], Rostom Mbarek3
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301.07 – The ACCESS Transiting Exoplanets Spectroscopy Survey and the Impact of Heterogeneous Stellar Atmospheres on Transit Spectroscopy

We present results from the ACCESS survey, a large optical transmission spectroscopy survey of transiting planets. With over 40 transits observed using the IMACS multi-object spectrograph on Magellan, ACCESS is building up the most comprehensive spectral database for transiting exoplanets. The goals of ACCESS are to probe the composition of exoplanet atmospheres as a function planet mass and insolation and stellar properties.
We will present a brief overview of the survey and highlight results on multiple targets, including hot jupiters and the sub-nepture GJ1214. I will also report on our study of how stellar heterogeneity impact the transmission spectrum of transiting exoplanets and discuss approaches to correct for this important effect to improve the diagnostic power of transit spectroscopcy.

Author(s): Daniel Apai[6], Benjamin V. Rackham[6], Mercedes Lopez-Morales3, Nestor Espinoza[1], Andres Jordan[1], David Osip4, Nikole K. Lewis5, Florian Rodler[2], Jonathan Fraine[6], Caroline Morley7, Jonathan J Fortney7, Alex Bixel[6]
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Contributing team(s): ACCESS Team; Earths in Other Solar Systems Team

301.08 – FINESSE: A Dedicated Transiting Exoplanet Spectroscopy Mission

FINESSE (Fast INfrared Exoplanet Spectroscopy Survey Explorer) is a proposed space mission dedicated to performing a statistical census of transiting exoplanet atmospheres. The objectives of FINESSE are to test theories of planetary origins and climate, enable comparative planetology, and open up discovery space on atmospheric chemistry, planetary evolution, and other topics. The baseline design for FINESSE is a 75 cm telescope observing from L2. The FINESSE instrument is a high throughput spectrometer with continuous coverage from 0.5 to 5.0 microns in a single shot. FINESSE will survey on order of 1000 exoplanets with a combination of transmission, dayside emission, and phase-resolved emission spectroscopy during a two year mission. As of this writing FINESSE will be proposed for the NASA Medium-Class Explorers (MIDEX) announcement of opportunity in December 2016. I will present an overview of FINESSE, including the mission concept, science drivers, and expected results from extensive simulations.

Author(s): Jacob Bean[1]
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Contributing team(s): FINESSE Science Team

302 – AGN, QSO, Blazars: Jets, Outflows, & Winds

302.01 – Polarization Signatures distinguish the kinetic- and the magnetic-driven blazar jet models

Blazars are a type of active galaxies whose jets direct close to our line of sight. They exhibit strong variability across the entire electromagnetic spectrum, from radio up to TeV gamma-rays. The radio to optical polarization signatures, which originate from synchrotron emission in a partially ordered magnetic field, show strong variability as well. Two scenarios have been advanced to explain the blazar variability. The kinetic-driven model argues that the emission region can drain kinetic energy through shocks to accelerate nonthermal particles and generate flares. The magnetic-driven model suggests that the magnetic energy can dissipate through current-driven instabilities to fuel the variability. Both models have their merits in understanding blazar spectra and light curves during flares, thus they cannot be distinguished. We perform comprehensive polarization-dependent radiation modeling of shocks and kink instabilities in the blazar emission region, based on detailed relativistic magnetohydrodynamic (RMHD) simulations. Our approach involves self-consistent magnetic field evolution, nonthermal particle injection based on the energy release from the RMHD simulation, and detailed radiation transfer including all light travel time effects. Hence our method offers the self-consistent time-dependent radiation and polarization signatures from first principles. By comparing the shock and the kink models, we find that while both can interpret the light curves well, the shock model generally produce too strong polarization variations compared to observations. On the other hand, the kink model well fits the general polarization fluctuations and polarization angle swings. We conclude that by coupling first-principle simulations and detailed polarization-dependent radiaiton modeling, polarization signatures can probe the origin of the blazar jet variability, and offer a general diagnostic of the jet physics, including the energy composition, the particle acceleration, and the magnetic field evolution in the emission region.

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302.02 – The remarkable optical jet in 4C +00.58

A recent HST program on X-ray detected kpc-scale jets has revealed an infrared/optical jet in the very nearby moderate-power quasar 4C+00.58. At a redshift of only 0.058, it is closer than 3C 273 and also represents a moderate-power analog to that source and the well-studied M87. I will discuss the implications of the multiwavelength data we have on hand, including very recent UV observations with WFC3. In particular, we see evidence of an X-ray excess which may be relevant to the synchrotron/IC origin debate for X-rays in large-scale jets generally.

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302.03D – The link between quasar broad-line region and galaxy-scale outflows and accurate CIV-based black hole masses

Accurate black-hole (BH) mass estimates for high-redshift (z>2) quasars are essential for better understanding the relationship between super-massive BH accretion and star formation. Progress is currently limited by the large systematic errors in virial BH-masses derived from the CIV broad emission line, which is often significantly blueshifted relative to systemic, most likely due to outflowing gas in the quasar broad-line region. We have assembled Balmer-line based BH masses for a large sample of 230 high-luminosity ($10^{45.5}$-10^{48} ergs^{-1}), redshift 1.5<z<4 quasars, which, for the first time, span the entire range of CIV blueshifts seen in the quasar population. We find the CIV-based BH-masses to be larger than the corresponding Balmer line-based masses by almost an order of magnitude at the most extreme blueshifts (~5000 kms^{-1}). An empirical correction to the CIV BH-masses is derived, which depends only on the properties of the CIV line itself (i.e. blueshift and FWHM). We show that this new correction now enables the derivation of un-biased CIV-based virial BH masses for the majority of high-luminosity, high-redshift quasars.

In the same high-luminosity quasar sample, we find the narrow [OIII] emission to be weaker and more asymmetric than is generally found in lower-luminosity AGN and that a significant fraction of our quasars have exceptionally broad (FWHM > 3000 kms^{-1}), blueshifted [OIII] emission. We find a strong correlation between the CIV and [OIII] blueshifts. This correlation holds even for quasars at fixed luminosity and suggests that broad line region outflows in quasars are connected to galaxy-scale winds.

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302.04 – Determining the Spatially Resolved Mass Outflow Rate in Markarian 573

We report on current progress in calculating the narrow line region (NLR) mass outflow rate in the Seyfert 2 galaxy Markarian 573. Our goal is to determine the mass outflow rate as a function of distance from the nucleus in 10 nearby Active Galactic Nuclei (AGN) with spatially resolved NLRs. These nearby AGN allow us to study the feeding and feedback of supermassive black holes (SMBHs) that may play an important role in understanding large scale structure, enrichment of the interstellar medium, and coevolution of SMBHs with their host galaxies. Utilizing archival spectra from the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope (HST) we measured emission line ratios from a wide range of ionized species. Next we used the line ratios to find a reddening correction and determined the physical conditions in the ionized gas using the photoionization code Cloudy. Specifically, we derived the mass of the ionized gas and then estimate the total mass outside of the spectral slit using HST [O III] images. Combined with kinematic models of the outflows we will determine the mass outflow rate and kinetic luminosity as a function of distance from the central AGN. Ultimately, we aim to determine if NLR outflows are effective in regulating AGN feedback by comparing our observed outflow rates with theoretical models.

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302.05 – Composite Spectra of Broad Absorption Line Quasars in SDSS-III BOSS

We present preliminary results from a study of broad absorption line (BAL) quasars in the SDSS-III BOSS survey. We're particularly interested in BALs because they arise from quasar outflows, which may be a source of feedback to the host galaxy. We analyze median composite spectra for BOSS QSOs in the redshift range 2.1 to 3.4 sorted by the strength of the BAL absorption troughs, parameterized by the Balnicity Index (BI), to study trends in the emission and absorption properties of BAL quasars. The wavelength coverage and high number of quasars observed in the BOSS survey allow us to examine BALs in the Lyman forest. Our main preliminary results when sorting the quasars by BI are **1)** doublet absorption lines such as P V 1128A show a 1:1 ratio across all BI, indicating large column densities at all BI. This suggests that weaker BAL troughs result from smaller covering fractions rather than lower column densities. **2)** The He II emission line, which is a measure of the far-UV/near-UV hardness of the ionizing continuum, is weaker in the larger BI composite spectra, indicating a far-UV spectral softening correlated with BI. This is consistent with the radiatively-driven BAL outflows being helped by intrinsically weaker ionizing continuum shapes (e.g., Baskin, Laor, and Hamann 2013). We also find a trend for slightly redder continuum slopes in the larger BI composite spectra, suggesting that the slope differences in the near-UV are also intrinsic.

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302.06 – The LBT/WISSH quasar survey: revealing

powerful winds in the most luminous AGN

The systematic, multi-frequency investigation of hyper-luminous quasars shining at the golden epoch of AGN activity offers the unique opportunity of studying the power and the effect of AGN feedback at its extreme.
The WISE/SDSS selected hyper-luminous (WISSH) quasar survey is an extensive multi-band observing program (from millimeter wavelengths to hard X rays) designed to accurately probe the role of nuclear activity in SMBH-galaxy self-regulated growth via extended outflows.
Our on-going project aims at constraining both AGN and host galaxy ISM and star-formation properties in a large sample of ~ 90 broad-line quasars at the brightest end of the AGN luminosity function (L_bol > 1e14 L_sun), and at the peak of their number density (z ~ 2.5 - 3.5).

I will review the most important results of the near-IR spectroscopic follow-up of WISSH quasars (available for ~40% of the total sample) performed with the LUCI at LBT. These observations were carried out to obtain a reliable Hbeta-based estimate of the SMBH masses and a census of the ionized outflows in these hyper-luminous quasars.
We found that WISSH AGN are typically powered by highly accreting (0.3-3 Ledd), ten billion solar masses SMBHs, demonstrating that WISSH provides a simple and valuable tool to complete the census of the extreme SMBH population in the universe.
We also succeeded in discovering [OIII] emission lines with a broad, skewed profile and exceptional luminosities (> 6e44 erg/s), tracing very powerful ionized outflows (up to ~4% of L_bol) in ~30% of the sample.
Remarkably, the remaining 70% of quasars lacks [OIII] emission but shows strong winds traced by 3,000-8,000 km/s blueshifts of the high-ionization (CIV) with respect to low-ionization (Hbeta) broad emission lines, revealing strong radiatively driven winds that dominate the BLR kinematics.
I will discuss the possible origins of this intriguing dichotomy which involves fundamental parameters such as bolometric luminosity, SMBH mass, Eddington ratio and shape of the UV-X-ray spectrum.

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302.07D – Probing Quasar Winds Using Intrinsic Narrow Absorption Lines

Quasar outflows are important for understanding the accretion and growth processes of the central black hole. Furthermore, outflows potentially have a role in providing feedback to the galaxy, and halting star formation and infall of gas. The geometry and density of these outflows remain unknown, especially as a function of ionization and velocity. Having searched ultraviolet spectra at both high redshift (VLT/UVES; 1.4<z<5) and low redshift (HST/COS; z<0.45), we have located narrow absorption lines (NALs) that are intrinsic to (physically associated with) the quasar. We identify intrinsic NALs with a wide range of properties, including ejection velocity, coverage fraction, and ionization level. We also consider the incidence of intrinsic absorbers as a function of quasar properties (optical, radio and X-ray fluxes), and find that radio properties and quasar orientation are influential in determining if a quasar is likely to host an intrinsic system. We find that there is a continuum of properties within the intrinsic NAL sample, rather than discrete families, ranging from partially covered CIV systems with black Lya and with a separate low ionization gas phase to partially covered NV systems with partially covered Lya and without detected low ionization gas. Additionally, we construct a model describing the spatial distributions, geometries, and varied ionization structures of intrinsic NALs.

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303 – Extrasolar Planets Detection: Imaging

303.01D – Using direct imaging to investigate the formation and migration histories of gas giant exoplanets

Gas giant exoplanets are found around their host stars at orbital separations spanning more than four orders of magnitude (0.01 to 100 AU). However, it is not known whether the planets at the extreme ends of this range could have formed in situ or if they instead formed closer to ice lines between 1-10 AU and then migrated to their present day locations. In this study, we use two direct imaging surveys to explore the potential origins of hot Jupiters and to characterize the population of gas giant planets beyond the ice line. In our first survey, we focus on the role of stellar companions in hot Jupiter formation and migration. We determine that less than 20% of hot Jupiters have stellar companions capable of inducing migration via Kozai-Lidov oscillations. In addition, we find that hot Jupiter hosts are three times more likely to have a stellar companion between 50-2000 AU than field stars, suggesting that binary star systems may be favorable environments for gas giant planet formation. In our second study, we present the results from the first year of a two-year direct imaging planet survey of 200 young M-dwarf stars. By imaging in L-band (3.8 micron) and taking advantage of the new 80 milliarcsecond inner working angle "vortex" coronagraph on Keck NIRC2, we are sensitive to young planets with masses between 1-10 Jupiter masses with projected separations between 1-10 AU. We can compare the semi-major axis distribution of directly imaged planets beyond 10 AU to that of intermediate period gas giants from radial velocity surveys and determine whether or not these two populations form a continuous distribution. If so, this would imply these populations share common formation (core accretion) and migration channels.

Author(s): Henry Ngo[1]
Institution(s): *1. California Institute of Technology*

303.03D – Imaging Protoplanets: Observing Transition Disks with Non-Redundant Masking

Transition disks - protoplanetary disks with inner, solar system sized clearings - may be shaped by young planets. Directly imaging protoplanets in these objects requires high contrast and resolution, making them promising targets for future extremely large telescopes. The interferometric technique of non-redundant masking (NRM) is well suited for these observations, enabling companion detection for contrasts of 1:100 - 1:1000 at or within the diffraction limit. My dissertation focuses on searching for and characterizing companions in transition disk clearings using NRM. I will briefly describe the technique and present spatially resolved observations of the T Cha and LkCa 15 transition disks. Both of these objects hosted posited substellar companions. However multi-epoch T Cha datasets cannot be explained by planets orbiting in the disk plane. Conversely, LkCa 15 data taken with the Large Binocular Telescope (LBT) in single-aperture mode reveal the presence of multiple forming planets. The dual aperture LBT will provide triple the angular resolution of these observations, dramatically increasing the phase space for exoplanet detection. I will also present new results from the dual-aperture LBT, with similar resolution to that expected for next generation facilities like GMT.

Author(s): Stephanie Sallum[1]
Institution(s): *1. University of Arizona*

303.04 – Directly Imaging Planets with SCExAO: First Results

We present the first science results from the newly commissioned Subaru Coronagraphic Extreme Adaptive Optics project, an experimental system dedicated to image faint jovian planets around nearby stars. SCExAO is now achieving true extreme AO capability. We describe the typical performance of SCExAO, the first images of benchmark exoplanets and planet-forming disks, and SCExAO's first science results. Finally, we briefly chart the path forward for

SCExAO to achieve its full scientific capability, including imaging mature planets in reflected light.

Author(s): Thayne M. Currie[2], Olivier Guyon[2], Nemanja Jovanovic[2], Julien Lozi[2], Motohide Tamura[3], Tomoyuki Kudo[2], Taichi Uyama[3], Eugenio Garcia[1]
Institution(s): *1. Lawrence Livermore National Laboratory, 2. NAOJ/Subaru Telescope, 3. University of Tokyo*

303.05 – Illuminating Free-floating Planet Demographics with Keck AO

The frequency and mass function of free-floating planets (FFPs) are unknown. Gravitational microlensing is able to explore the demographics of FFPs, which are identifiable as short-timescale microlensing events, lasting of-order 1 day for Jupiter-mass planets. In 2011, the MOA ground-based microlensing survey group announced the discovery of an excess of short-timescale microlensing events over what was expected from Galactic models that incorporate stellar densities and kinematics. They account for this excess by positing a population of Jupiter-mass FFPs that outnumbers stars by a ratio of nearly 2:1. However, there are several other possible astrophysical explanations for short-timescale microlensing events, including bound planets on wide orbits and high-velocity stars. Although the specific events identified by MOA lack mass measurements, high-resolution imaging can determine whether the lens systems are luminous, which would exclude the FFP conclusion through proof by contradiction. We have taken H-band adaptive optics (AO) observations of the MOA FFP candidates using NIRC2 on Keck II in order to test this result. Here I will present preliminary results from these AO observations, which will help inform our understanding of the demographics of FFPs.

Author(s): Calen B. Henderson[1]
Institution(s): *1. JPL/Caltech*

303.06 – Laboratory Demonstration of High Contrast Imaging in Multi-Star Systems

We show laboratory results advancing the technology readiness of a method to directly image planets and disks in multi-star systems such as Alpha Centauri. This method works with almost any coronagraph (or external occulter with a DM) and requires little or no change to existing and mature hardware. Because of the ubiquity of multistar systems, this method potentially multiplies the science yield of many missions and concepts such as WFIRST, Exo-C/S, HabEx, LUVOIR, and potentially enables the detection of Earth-like planets (if they exist) around our nearest neighbor star, Alpha Centauri, with a small and low-cost space telescope such as ACESat.
We identified two main challenges associated with double-star (or multi-star) systems and methods to solve them. “Multi-Star Wavefront Control” (MSWC) enables the independent suppression of starlight from more than one star, and Super-Nyquist Wavefront Control (SNWC) enables extending MSWC to the case where star separation is beyond the Nyquist limit of the deformable mirror (DM).
Our lab demonstrations were conducted at the Ames Coronagraph Experiment (ACE) laboratory and proved the basic principles of both MSWC and SNWC. They involved a 32x32 deformable mirror but no coronagraph for simplicity. We used MSWC to suppress starlight independently from two stars by at least an order of magnitude, in monochromatic as well as broadband light as broad as 50%. We also used SNWC to suppress starlight at separations as far as 100 λ/D from the star, surpassing the Nyquist limit of the DM.

Author(s): Ruslan Belikov[2], Eduardo Bendek[2], Eugene Pluzhnik[2], Dan Sirbu[2], Sandrine Thomas[1]
Institution(s): *1. LSST, 2. NASA Ames Research Center*

303.07 – Technologies Required to Image Earth 2.0 with a Space Coronagraph

NASA's Exoplanet Exploration Program (ExEP) guides the development of technology that enables the direct imaging and characterization of exo-Earths in the habitable zone of their stars for future space observatories. Here we present the coronagraph portion of the 2017 ExEP Technology Gap List, an annual update to ExEP's list of of technologies, to be advanced in the next 1-5 years. A coronagraph is an internal occulter that allows a space telescope to achieve exo-Earth imaging contrast requirements (more than 10 billion) by blocking on-axis starlight while allowing the reflected light of off-axis exoplanets be detected. Building and operating a space coronagraph capable of imaging an exo-Earth will require new technologies beyond those of WFIRST, the first high-contrast conronagraph in space. We review the current state-of-the-art performance of space coronagraphs and the performance level that must be achieved for a coronagraph..

Author(s): Nicholas Siegler[1]
Institution(s): *1. Jet Propulsion Laboratory*

304 – Properties of Nearby Galaxies

304.01 – The SAMI Galaxy Survey: Publicly Available Spatially Resolved Emission Line Data Products

The SAMI Galaxy Survey is collecting optical integral field spectroscopy of up to 3400 nearby ($z<0.1$) galaxies with a range of stellar masses and in a range of environments. The first public data release contains nearly 800 galaxies from the Galaxy And Mass Assembly (GAMA) Survey. In addition to releasing the reduced data cubes, we also provide emission line fits (flux and kinematic maps of strong emission lines including Halpha and Hbeta, [OII]3726,29, [OIII]4959,5007, [OI]6300, [NII]6548,83, and [SII]6716,31), extinction maps, star formation classification masks, and star formation rate maps. We give an overview of the data available for your favorite emission line science and present a few early science results. For example, a sample of edge-on disk galaxies show enhanced extraplanar emission related to SF-driven outflows, which are correlated with a bursty star formation history and higher star formation rate surface densities. Interestingly, the star formation rate surface densities of these wind hosts are 5-100 times lower than the canonical threshold for driving winds (0.1 $M_{Sun}/yr/kpc^2$), indicating that galactic winds may be more important in normal star-forming galaxies than previously thought.

Author(s): Anne Medling[3], Andrew W. Green[1], I-Ting Ho[4], Brent Groves[2], Scott Croom[5]
Institution(s): *1. Australian Astronomical Observatory, 2. Australian National University, 3. California Institute of Technology, 4. Max Planck Institute for Astronomy, 5. University of Sydney*
Contributing team(s): the SAMI Galaxy Survey Team

304.02D – The Dragonfly Nearby Galaxies Survey: A Census of the Stellar Halos of Nearby Luminous Galaxies

The Dragonfly Telephoto Array, comprised of 48 individual Canon telephoto lenses operating together as a single telescope, is an innovative approach to low surface brightness imaging and the study of galactic stellar halos in particular. Sub-nanometer coatings on each optical element reduce scattered light from nearby bright stars and compact galaxy centers - typically a key obstacle for integrated light observations - by an order of magnitude, and Dragonfly's large field of view (2x2.6 degrees for a single frame) provides a large-scale view of stellar halos free from substructure biases. Using extremely deep (>30 mag/arcsec^2) optical imaging in g and r bands from the Dragonfly Nearby Galaxies Survey (DNGS), we have characterized the stellar halos of a sample of ~20 nearby luminous galaxies. I will present measurements of the stellar halo mass fractions of these galaxies as a function of stellar mass, morphology, and environment, and discuss the scatter in halo fractions in the context of the galaxies' individual accretion histories.

Author(s): Allison T. Merritt[1]
Institution(s): *1. Yale University*

304.03 – The Shocked POststarburst Galaxy Survey

Modern day galaxies are found to be in a bimodal distribution, both in terms of their morphologies, and in terms of their colors, and these properties are inter-related. In color space, there is a genuine dearth of intermediate colored galaxies, which has been taken to mean that the transition a galaxy undergoes to transform must be rapid. Given that this transformation is largely one-way (at z=0), identifying all initial conditions that catalyze it becomes essential. The Shocked POststarburst Galaxy Survey (http://www.spogs.org) is able to pinpoint transitioning galaxies at an earlier stage of transition than other traditional searches, possibly opening a new door to identifying new pathways over which galaxies transform from blue spirals to red ellipticals.

Author(s): Katherine A. Alatalo[1]
Institution(s): *1. Carnegie Observatories*
Contributing team(s): The SPOGS Team

304.04D – Resolved Ammonia Thermometry, Water and Methanol Masers from the “Survey of Water and Ammonia in Nearby Galaxies (SWAN)”

We present Karl G Jansky Very Large Array (VLA) molecular line observations of the nearby star forming galaxies NGC 253 and IC 342. These galaxies are close enough to be resolved with a few tens of pc resolution with the VLA. At this resolution we are well matched to the physical scales of Giant Molecular Clouds (GMCs) and therefore sensitive to the dominant processes therein. We have selected metastable inversion transitions of NH_3 from (1,1) to (5,5) and the (9,9), the 22.2 GHz H_2O (6_{16}-5_{23}) maser, and the 36.1 GHz CH_3OH (4_{14}-3_{03}) maser. We use the metastable NH_3 transitions to calculate rotation temperatures of the gas, and apply LVG models to estimate kinetic temperatures. Our selected masers are collisionally pumped and reveal the locations of shocked material. We find that the molecular gas is well described by cool 57K and warm 130K components, and there is no significant temperature variation over the central kpc. The result suggests that neither PDRs nor superbubbles significantly heat the molecular gas, but superbubbles likely increase the bulk motion of GMCs. We also report the discovery of H_2O masers associated with the large-scale biconical outflow for the first time, indicating the presence of shocked dense gas. Finally, we find CH_3OH masers, indicative of weak shocks, coincident with superbubble walls.

Author(s): Mark Gorski[4], Juergen Ott[2], Richard J. Rand[4], David S. Meier[3], Emmanuel Momjian[2], Fabian Walter[1], Eva Schinnerer[1]
Institution(s): *1. Max Planck Institut für Astronomie, 2. National Radio Astronomy Observatory, 3. New Mexico Institute of Mining and Technology, 4. University of New Mexico*

304.05 – Analyzing Extragalactic Magnetic Fields Using Faraday Rotation Measure Synthesis

Extragalactic magnetic fields are a poorly understood element of galaxies that are likely to play an important role in galaxy formation and evolution. Until recently, however, there was no way to observe these fields to a high level of detail, making it difficult to map the spatial distribution of these fields to any high degree of accuracy. Fortunately, a new technique known as Faraday Rotation Measure Synthesis allows for a more precise analysis of galactic magnetism. This technique uses the observed Faraday rotation of polarized emission from background sources to map the magnetic field of a foreground galaxy. This Faraday rotation occurs when the polarized emission encounters ionized, magnetized gas within the galaxy, causing the emission to be rotated by an amount proportional the magnetic field subjected to the ionized gas. Working as part of CHANG-ES (Continuum HAlos in Nearby Galaxies – an EVLA Survey), we have applied this technique in order to learn about the distribution of magnetic fields in the disks and halos of edge-on spiral galaxies. We will present maps of the galactic magnetic fields of CHANG-ES galaxies using this technique, indicating the potential of this technique in successfully mapping these distant fields.

Author(s): Dylan Pare[1], Q. Daniel Wang[1], Patrick Kamieneski[1], Kendall Sullivan[1]
Institution(s): *1. University of Massachusetts, Amherst*

304.06D – A New Perspective on Galaxy Evolution from the Low Density Outskirts of Galaxies

In order to investigate the nature of galaxy outskirts, we carried out a deep imaging campaign of several nearby ($D\lesssim$10Mpc) galaxies, across a range of environments. We found that most of the galaxies we imaged show red and non-star-forming outer disks, implying evolved stellar populations. Such populations in outer disks are expected as the result of radial migration, yet through Fourier analysis we found no evidence of extended spiral structure in these galaxies. Without star formation or outer spiral structure, it is difficult to determine how these outer disks formed. To investigate the effects of interactions on outer disks, we also observed the Leo I Group; however, while group environments are expected to promote frequent interactions, we found only three extremely faint tidal streams, implying a calm interaction history. As Leo I is fairly low density, this implies that loose groups are ineffective at producing intragroup light (IGL). In the famous interacting system M51, we found that its extended tidal features show similarly red colors as the typical outer disks we observed, implying that M51 had a similar outer disk prior to the interaction, and that the interaction induced no extended star formation, including in the system's HI tail. Therefore, to investigate the nature of star formation in low-density environments, we carried out deep narrow-band Hα imaging of M101 and M51.

Author(s): Aaron Emery Watkins[1]
Institution(s): *1. Case Western Reserve University*

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305 – Galactic Archaeology with Kepler and K2

The exquisite lightcurves of the Kepler and K2 missions have been an unexpected boon to the field of near-field cosmology. Ages and evolutionary states can now be derived for field red giants, by combining asteroseismology with spectroscopic data. Red giants, far more luminous than the main-sequence turnoff stars usually used, allow us to probe the evolution of the whole Galaxy. Originally these investigations were restricted to a single line of sight of the Kepler field. With the failure of two of the reaction wheels and the start of the K2 program to observe many fields along the ecliptic, we now probe distinctly different Galactic populations, including the inner and outer disks, the bulge-halo interface, and far more of the Galactic halo. In K2, the Galactic Archaeology Program has been awarded the second largest number of targets, with over 50,000 stars targeted to understand the formation of the Milky Way. The data from the Kepler field has already been used to calibrate the largest age map yet made of the Galaxy, and we are just beginning to explore this vast dataset. The ongoing release of Kepler/K2 light curves and the public availability of follow-up spectra for thousands of targets over the last year alone indicates that this is an ideal time to discuss the most recent breakthroughs in the rapidly evolving field of Galactic archeology In this special session, we will discuss the extensive follow-up work underway to make Galactic archaeology possible, discuss how Kepler/K2 data in stellar clusters reveals the history of stellar activity, and present the pioneering results of Galactic archaeology. These include investigations of the age spread in the Galactic halo, examination of the vertical and radial age gradients in the thick and thin disk, measurement of the timescales for chemical evolution, calibration of age indicators for even larger age maps, and discussion of synergies with Gaia.

305.01 – Overview of Galactic Archaelogy with Kepler and K2

The exquisite lightcurves of the Kepler and K2 missions have been an unexpected boon to the field of near-field cosmology. Ages and evolutionary states can now be derived for field red giants, by combining seismic and granulation signatures with spectroscopic data. Red giants, far more luminous than the main-sequence turnoff stars usually used, allow us to probe the evolution of the whole Galaxy. Originally these investigations were restricted to a single line of sight in the direction of Cygnus. With the failure of the reaction wheels and the start of the K2 program, we now probe distinctly different Galactic populations, including the inner and outer disks, the bulge-halo interface, and far more of the Galactic halo. I will present an overview of some of the Galactic archaeology efforts underway with Kepler and K2 data, focusing on our calibration of absolute ages. I will also present results on Galactic chemical evolution and the timescales for the formation of the elements.

Author(s): Jennifer Johnson[1]
Institution(s): *1. Ohio State Univ.*
Contributing team(s): APOKASC Team, APO-K2

305.02 – Synergies between spectroscopic and time-series photometric surveys – LAMOST observations for the *Kepler* field and *K*2 fields

Synergies between spectroscopic and time-series photometric surveys can provide valuable information for studies in Galactic archaeology. The *Kepler* satellite has provided unprecedented high duty-cycle, high-precision time-series photometric observations for a large number of stars. After a continuous monitoring of the *Kepler* field for 4 years, it started to observe *K*2 fields, which include multiple stellar populations, for about 80 days each. These observed fields are all good targets for Galactic archaeology, provided that spectroscopic observations can be made for hundreds of thousands of stars within these fields in a homogeneous way.
In 2010, we initiated the LAMOST-*Kepler* project with the aim to collect low-resolution spectra for as many objects from the KIC10 catalogue as possible with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST). This is a 4-m telescope equipped with 4,000 optical fibers covering a circular field of view with a diameter of 5 degrees on the sky. The observations since 2012 have resulted in 150,567 low-resolution spectra with the Signal-Noise-Ratio in *r* larger than 20. The stellar atmospheric parameters were derived and calibrated with the values determined from either high-resolution spectroscopy or asteroseismology.
Since the end of 2015, five *K*2 fields have been observed with LAMOST and the qualified spectra were used to derive the stellar atmospheric parameters for 59,213 stars.
In this presentation we introduce the LAMOST-*Kepler* project, whose data have a great potential for Galactic archaeology. It includes an update on the progress and a summary of the existing scientific works based on the data provided by this project.

Author(s): Jianning Fu[1], Peter De Cat[2], Martin Smith3
Institution(s): *1. Beijing Normal University, 2. Royal Observatory of Belgium, 3. Shanghai Astronomical Observatory*

305.03 – K2 red giant asteroseismology using Bayesian Asteroseismology data Modeling (BAM)

The re-purposed Kepler mission, K2, boasts an impressive panoramic view of tens of thousands of red giants along the ecliptic, zooming in on clusters of various ages and metalliticies and probing Galactic sight lines inaccessible to the original Kepler field of view. However, its compromised pointing has introduced spurious features in stellar light curves and has reduced its photometric quality compared to that of the original Kepler mission. Enhanced data processing techniques above and beyond those used for Kepler are therefore required in order to translate observed K2 stellar light curves in to reliable fundamental parameters like surface gravity, radius, and mass with asteroseismology. I will present results from one such effort -- the Bayesian Asteroseismology data Modeling (BAM) pipeline. I will discuss the state of science with red giants in K2, with particular emphasis on a sample of red giants analyzed with the BAM. Implications for Galactic population studies using K2 red giants will be presented, with an eye toward completeness and contamination.

Author(s): Joel Zinn[1], Dennis Stello[2], Marc H. Pinsonneault[1]
Institution(s): *1. Ohio State University, 2. University of New South Whales*

305.04 – Activity and age from Kepler and K2 observations of field and cluster stars

Kepler and K2 are providing key insights into activity-related phenomena on late-type stars. Kepler observations showed that highly energetic flares can be seen on many more types of stars than the M dwarfs that have been the traditional focus of flare studies. Some stars similar to the Sun have been seen to exhibit flares with $\sim10^4$ times the energy of the largest solar flares ever seen, for example. The K2 extension of Kepler has been especially valuable by providing data for several open clusters, including the Pleiades, Praesepe, Hyades, and M67.

In this review I will summarize the flaring behavior seen with Kepler and K2, from A stars through Ms and from the pre-main sequence to solar age. The Pleiades and M67 provide useful examples to illustrate what is seen and not seen.

Other aspects of Kepler and K2 light curves have been studied as indicators of activity, and some results from that will be presented. Finally, these indicators of activity will be placed into an age context using indicators and measurements of age from Kepler/K2.

Author(s): David R. Soderblom[1]
Institution(s): *1. STScI*

305.05 – APOKASC 2.0: Asteroseismology and Spectroscopy for Cool Stars

The APOGEE survey has obtained and analyzed high resolution H band spectra of more than 10,000 cool dwarfs and giants in the original Kepler fields. The APOKASC effort combines this data with asteroseismology and star spot studies, resulting in more than 7,000 stellar mass estimates for dwarfs and giants with high quality abundances, temperatures, and surface gravities. We highlight the main results from this effort so far, which include a tight correlation between surface abundances in giants and stellar mass, precise absolute gravity calibrations, and the discovery of unexpected stellar populations, such as young alpha-enhanced stars. We discuss grid modeling estimates for stellar masses and compare the absolute asteroseismic mass scale to calibrators in star clusters and the halo Directions for future efforts are discussed.

Author(s): Marc H. Pinsonneault[1], Yvonne P Elsworth[2]
Institution(s): *1. Ohio State Univ., 2. University of Birmingham*
Contributing team(s): APOKASC

305.07 – Disentangling the stellar components of the metal-poor Milky Way

Some studies of the Milky Way halo and all studies of the thick disk populations suffer from difficulties cleanly separating out one galactic component from another. This is largely due to magnitude limitations, which produces a bias towards local solar neighborhood samples, where the separation of the thick disk from the halo populations of the Milky Way is problematic. Most studies have relied on metallicity or kinematics to attempt to disentangle halo samples from thin and thick disk samples. Using the new large data sets from the ESA Gaia mission, the NASA Kepler mission, the SDSS/APOGEE survey and knowledge of stellar interiors we explore the candidate halo and thick disk giants using Galactic position, kinematics, mass, age, and chemistry. We explore the correlations with chemical abundance ratios such as mass and [C/Fe] and how these may inform future efforts to make clean samples of Milky Way stellar components.

Author(s): Matthew D. Shetrone3, Jennifer Johnson[2], Giuseppina Battaglia[1], Dennis Stello4, Joel Zinn[2], Sanjib Sharma[2]
Institution(s): *1. Instituto de Astrofisica De Canarias, 2. Ohio State University, 3. Univ. of Texas, 4. University of New South Wales*
Contributing team(s): APOGEE Team

306 – Cosmology II

306.01 – The SDSS-IV Extended Baryon Oscillation

Spectroscopic Survey: The Clustering of Luminous Red Galaxies Using Photometric Redshifts

SDSS-IV/eBOSS survey will allow a ~1% measurement of the Baryon Acoustic Oscillation (BAO) scale and a 4.0% Redshift Space Distortion (RSD) measurement using a relatively uniform set of luminous, early-type galaxies in the redshift range $0.6 < z < 1$. In this talk, I will present the 3D real space clustering of a sample of ~600,000 LRGs measured by the SDSS/eBOSS, using photometric redshifts. These galaxies have accurate photometric redshifts with an average error of $z = 0.028$. These LRGs range from redshift $z = 0.6$ to 1.0 over 10,000 deg2 of the sky, making it the largest volume ever used for galaxy clustering measurements. We measure the angular clustering power spectrum in different redshift slices and use well-calibrated redshift distributions to combine these into a high precision 3D real space clustering. i will present an evidence for BAO in the 2-point correlation function. The detection of BAO also allows the measurement of the comoving distance to $z = 1.0$. Traditionally, spectroscopic redshifts are used to estimate distances to the galaxies and, in turn, to measure galaxy clustering. However, acquiring spectroscopic redshifts is a time consuming and expensive process even with modern multi-fiber spectrographs. Although photometric redshifts are less accurate, they are signicantly easier to obtain, and for a constant amount of time, one can image both wider areas and deeper volumes than would be possible with spectroscopy, allowing one to probe both larger scales and larger volumes. The ability to make precise clustering measurements with photometric data has been well demonstrated by Padmanabhan et al. (2007).

Author(s): Abhishek Prakash[1]
Institution(s): *1. University of Pittsburgh*
Contributing team(s): SDSS-IV/eBOSS

306.02 – Strong New Evidence for Oscillation of the Cosmological Scale Factor Observed in the Large Scale Structure

We have analyzed SDSSIII-BOSS, DR9 galaxy number count data using 2 independent approaches, a relativistic expanding space model based on work by Ostriker and direct Fourier analysis, and found incontrovertible evidence for a scale factor oscillation at 7 Hubble-Hertz (HHz) in both methods, where we define 1 HHz as 1 cycle over 1 Hubble-time. The number count of galaxies on these scales should be relatively smooth. However, a DR9 plot of galaxy number count per 0.01 redshift bin as a function of redshift shows significant bumps to redshift 0.5. We take the SDSSIII data (about ¼ of the sky) to be a fair representation of the entire sky when using number count. Our model fits essentially all bumps at a 99.8% R-squared goodness level if and only if the 7 HHz oscillation (plus 2nd and 3rd harmonics at 14 HHz and 21 HHz) is included. These are the same frequencies observed by us in AJ 149, 137 (2015) using SNe data. Since the SDSSIII data set only goes to redshift 0.8, only one cycle of oscillation is included compared to 2-3 in our earlier work. Thus a Fourier analysis performed on the SDSS redshift data converted to equal-time binning leaves a broadened spectrum over the range where harmonics would normally reside but nevertheless peaked at 7 HHz. A scalar field model presented in the AJ paper describes the oscillation and enters the Friedmann equations by replacing the LCDM dark matter density parameter with the scalar field density. Thus, LCDM dark matter is the median of the wave which appears to act like a fluid with a changing equation-of-state. The oscillation may be a longitudinal gravitational wave originating with the Big Bang and requiring a massive graviton. 7 HHz is consistent with a graviton mass of 10^ -32 eV.

Author(s): Harry I. Ringermacher[1], Lawrence R Mead[1]
Institution(s): *1. U. of Southern Mississippi*

306.04 – The Properties of Primordial Stars and Galaxies measured from the 21-cm Global Spectrum using the Dark Ages Radio Explorer (DARE)

DARE is a mission concept designed to observe the formation of primordial stars, black holes, and galaxies (z=11-35) by measuring their spectral effects on the redshifted 21-cm hydrogen line. The UV and X-ray radiation emitted by these first objects ionized and heated the intergalactic medium and imprinted characteristic features in the 21-cm spectrum. The 1.4 GHz signal is redshifted into the radio band 40–120 MHz. DARE will take advantage of the quietest RF environment in the inner solar system by using the Moon as a shield from human radio frequency interference and solar emissions via observations on the lunar farside. DARE's science objectives are to determine: when the first stars turned on and their properties, when the first black holes began accreting and their masses, the reionization history of the early Universe, and if evidence exists for exotic physics in the Dark Ages such as Dark Matter decay. Wideband crossed-dipole antennas, pilot tone stablized radiometric receivers, a polarimeter, and a digital spectrometer constitute the science instrument. DARE's radiometer is precisely calibrated with a featureless spectral response, controlled systematics, and heritage from CMB missions. Models for the instrument main beam and sidelobes, antenna reflection coefficient, gain variations, and calibrations will be validated with electromagnetic simulations, laboratory and anechoic chamber measurements, and verified on-orbit. The unique frequency structure of the 21-cm spectrum, its uniformity over large angular scales, and its unpolarized state are unlike the spectrally featureless, spatially-varying, polarized emission of the bright Galactic foreground, allowing the signal to be cleanly separated from the foreground. The 21-cm signal will be extracted in the presence of foregrounds using a Bayesian framework with a Markov Chain Monto Carlo (MCMC) numerical inference technique. The DARE data analysis pipeline enables efficient, simultaneous, and self-consistent explorations of multi-parameter models with non-Gaussian probability distributions, while properly accounting for all systematic astrophysical and instrumental uncertainties. DARE was recently proposed to NASA for its MIDEX program.

Author(s): Jack O. Burns[8], Judd D. Bowman[1], Richard F. Bradley[5], Anastasia Fialkov[3], Steven R. Furlanetto[7], Dayton L. Jones[6], Justin Kasper[9], Abraham Loeb[2], Jordan Mirocha[7], Raul A. Monsalve[8], David Rapetti[8], Keith Tauscher[8], Edward Wollack[4]
Institution(s): *1. Arizona State University, 2. Harvard University, 3. Harvard-Smithsonian Center for Astrophysics, 4. NASA GSFC, 5. NRAO, 6. Space Science Institute, 7. UCLA, 8. Univ. of Colorado at Boulder, 9. University of Michigan*

306.05 – Lyman-alpha radiation hydrodynamics of galactic winds before cosmic reionization

Radiation from the first stars and galaxies initiated the dramatic phase transition marking an end to the cosmic dark ages. The emission and absorption signatures from the Lyman-alpha transition of neutral hydrogen have been indispensable in extending the observational frontier for high-redshift galaxies into the epoch of reionization. Lyman-alpha radiative transfer provides clues about the processes leading to Lyman-alpha escape from individual galaxies and the subsequent transmission through the intergalactic medium. Cosmological simulations incorporating Lyman-alpha radiative transfer enhance our understanding of fundamental physics by supplying the inferred spectra and feedback on the gas. We discuss the dynamical impact of Lyman-alpha radiation pressure on galaxy formation throughout cosmic reionization with the first fully coupled Lyman-alpha radiation-hydrodynamics simulations. We self-consistently follow the chemistry, cooling, self-gravity, and ionizing radiation in protogalaxies and find that Lyman-alpha radiation pressure turns out to be dynamically important in several spherically symmetric simulations. As a case in point we apply our model to the COSMOS redshift 7 (CR7) galaxy at $z = 6.6$, which exhibits a +160 km/s velocity offset between the Lyman-alpha and HeII line peaks. We find that a massive black hole with a nonthermal Compton-thick spectrum is able to reproduce the observed Lyman-alpha signatures as a result of higher photon trapping and longer potential lifetime. We conclude with a general discussion of Lyman-alpha radiation in the first galaxies by considering simulations that cover the expected range of halo and source properties.

Author(s): Aaron Smith[2], Volker Bromm[2], Abraham Loeb[1]
Institution(s): *1. Harvard University, 2. University of Texas at Austin*

306.06 – Cosmological consistency tests of gravity theory and cosmic acceleration

Testing general relativity at cosmological scales and probing the cause of cosmic acceleration are among the important objectives targeted by incoming and future astronomical surveys and experiments. I present our recent results on consistency tests that can provide insights about the underlying gravity theory and cosmic acceleration using cosmological data sets. We use statistical measures, the rate of cosmic expansion, the growth rate of large scale structure, and the physical consistency of these probes with one another.

Author(s): Mustapha B. Ishak-Boushaki[1]
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306.07 – Cosmology with Independently Varying Neutrino Temperature and Number

We consider Big Bang nucleosynthesis and the cosmic microwave background in a model in which both the neutrino temperature and neutrino number are allowed to vary from their standard values. The neutrino temperature is assumed to differ from its standard model value by a given factor from Big Bang nucleosynthesis up to the present. In this scenario, the effective number of relativistic degrees of freedom, N_{eff}, derived from observations of the cosmic microwave background is not equal to the true number of neutrinos, N_{ν}. We determine the element abundances predicted by Big Bang nucleosynthesis as a function of the neutrino number and temperature, converting the latter to the equivalent value of N_{eff}. We find that a value of $N_{eff} \approx 3$ can be made consistent with $N_{\nu} = 4$ with a decrease in the neutrino temperature of ~5%, while $N_{\nu} = 5$ is excluded for any value of N_{eff}. No observationally-allowed values for Neff and Nν can solve the lithium problem.

Author(s): Richard Galvez[1]
Institution(s): *1. Vanderbilt University*

307 – Merging Galaxies & Gravitational Waves: From Mpc to mpc

This Special Session will highlight advancements in astrophysics in the low frequency gravitational waveband. Galaxy mergers are key to galaxy assembly and dynamics, as large galaxies in the local Universe are thought to undergo multiple mergers during their development. It is also established that most, if not all, large galaxies in the local Universe host a supermassive black hole (SMBH). During a merger SMBHs sink, through dynamical friction, to the center of the merger product; this simple dynamical evolution model can replicate a variety of galaxy and quasar properties, including the M_BH-sigma relation, the quasar luminosity function, and the central brightness of galaxies. The two SMBHs will form a bound *binary* when their separation is of order 10 pc. Further interactions with stars in the central region, and possibly gas interactions, may drive the binary to a point at which gravitational wave emission dominates its dynamics. The nanohertz gravitational waves emitted by a binary SMBH should be detectable by precise timing of radio pulsars. The sensitivity of pulsar timing arrays has now breached the strength of gravitational-wave signals expected from the known population of merging galaxies. The upper limits on nanohertz gravitational waves have a number of implications for galaxy dynamics: (i) masses of SMBH binaries could be systematically over-estimated, such that their gravitational waves are too; (ii) SMBH binaries could "stall," remaining at pc-scale separations and never emit gravitational waves; or (iii) Binaries could evolve rapidly through the nanohertz regime because they couple strongly to the galactic environment. This session will review what is known about the SMBH mass function, black hole-host relations, the galaxy merger process, and the influence of these on the expected gravitational wave signals. We will explore potential resolutions of the emerging mismatch between observed galaxy mergers and their not-yet-detected gravitational waves.

307.01 – AGN Triggering in Kpc-scale Separation Merging Galaxies

As supermassive black holes in galaxy mergers evolve from Mpc to mpc separations, the kpc-scale separations are pivotal for igniting AGN activity. At these separations the galaxy mergers drive central inflows of gas, which can trigger AGN activity in one or both supermassive black holes, in systems known as offset AGN and dual AGN, respectively. Offset and dual AGN are direct tracers of the connection between galaxy mass growth (via galaxy mergers) and supermassive black hole mass growth (via gas accretion). These systems are also the smallest separation supermassive black hole pairs that have been observationally confirmed, offering the last glimpse of supermassive black hole pair dynamics before gravitational wave emission dominates and drives the coalescence of the supermassive black holes. I will present multiwavelength approaches to building catalogs of offset AGN and dual AGN, and show the results of our observing campaigns with HST, Chandra, VLA, and Keck. Finally, I will discuss what our results show about whether galaxy mergers preferentially fuel the most luminous AGN, which supermassive black hole in a merger is more efficient at accreting gas, and where in a merger the AGN fueling occurs.

Author(s): Julia M. Comerford[1]
Institution(s): *1. University of Colorado, Boulder*

307.02 – Gravitational waves from binary supermassive black holes in galactic nuclei

Pulsar timing arrays (PTAs) will eventually detect the gravitational wave (GW) background produced by a cosmological population of binary supermassive black hole (SBHs). In this talk, I review the ways in which the formation and evolution of the binary population determine the amplitude and form of the GW spectrum. A major source of systematic uncertainty is the mass function of SBHs; in the past, SBH masses have often been overestimated, and the number of SBHs with trustworthy mass estimates is still very small. The presence of gas and stars around the binaries accelerates the evolution at large separations, reducing the amplitude of the GW spectrum at low frequencies. I will highlight two recent developments in our theoretical understanding of binary evolution. (1) Slight departures from axi-symmetry in a galaxy imply a sustained supply of stars to the very center, thus overcoming the “final-parsec problem”. (2) In the generic case of a rotating nucleus, the plane of the binary’s orbit evolves predictably toward alignment with the symmetry plane of the nucleus; the binary’s eccentricity also evolves in tandem with the orientation, sometimes reaching values close to one. These processes should leave distinct imprints on the stochastic GW spectrum, and have important implications for the likelihood of GW detection in the near future.

Author(s): David Merritt[1]
Institution(s): *1. Rochester Inst. of Technology*

307.03 – Implications of gravitational-wave observations observations for supermassive binary black holes

Pulsar timing arrays can be used to detect nanohertz frequency gravitational waves. The NANOGrav Physics Frontiers Center is reaching unprecedented sensitivities and we expect to make a detection soon. In this region of the gravitational-wave spectrum the most promising sources are supermassive binary black holes that form and coalesce when galaxies merge. In this talk I will discuss the implications of gravitational-wave observations for black-hole and galaxy co-evolution, galactic merger rates, and possible environmental effects.

Author(s): Xavier Siemens[1]
Institution(s): *1. University of Wisconsin -- Milwaukee*
Contributing team(s): NANOGrav Physics Frontiers Center

307.04D – Evolution of massive black hole binaries in

rotating galactic nuclei: implications for gravitational wave detection

The subject of our study is a binary supermassive black hole (BSBH) in the center of a galactic nucleus. We model the evolution of its orbit due to interactions with the stars of the galaxy by means of 3-body scattering experiments. Our model includes a new degree of freedom - the orientation of the BSBH's orbital plane - which is allowed to change due to interaction with the stars in a rotating nucleus. The binary's eccentricity also evolves in an orientation-dependent manner. We find that the dynamics are qualitatively different compared with non-rotating nuclei: 1) The BSBH's orbital plane evolves toward alignment with the plane of rotation of the nucleus; 2) The BSBH's eccentricity decreases for aligned BSBHs and increases for counter-aligned ones.

We then apply our model to calculate the effects of stellar environment on the gravitational wave background spectrum produced by BSBHs. Using the results of recent N-body/Monte-Carlo simulations we account for different rates of stellar interaction in spherical, axisymmetric and triaxial galaxies. We also consider the possibility that SBH masses are systematically lower than usually assumed. The net result of the new physical mechanisms included here is a spectrum for the stochastic gravitational wave background that has a significantly lower amplitude than in previous treatments, which could explain the discrepancy that currently exists between the models and the upper limits set by pulsar timing array observations.

Author(s): Alexander Rasskazov[1], David Merritt[1]
Institution(s): *1. Rochester Institute of Technology*

307.05 – Gravitational Wave Multi-Messenger Prospects for Pulsar Timing Arrays

Pulsar Timing Array (PTA) experiments are now setting limits on the gravitational wave (GW) emission in the nanohertz frequency band. The primary source of GW emission in this band is expected to be a population of binary supermassive black holes (SMBHs) that form following galactic mergers. This population of binary supermassive black holes are representative of a crucial step in galaxy formation theories. During the extended interaction between SMBHs and their host galaxy throughout inspiral, there is the potential for many electromagnetic tracers to accompany the binary's evolution. Using results from a suite of simulations, I will present an investigation of the potential for jointly detecting a binary's electromagnetic and gravitational radiation. The detection of a single 'multi-messenger' source would provide a unique window into a pivotal stage of galaxy evolution, and would revolutionize the understanding of late-stage galaxy evolution.

Author(s): Joseph Simon[1], Sarah Burke-Spolaor[2]
Institution(s): *1. University of Wisconsin Milwaukee, 2. West Virginia University*

307.06 – Nanohertz gravitational wave sources in the local universe

We look at the 2MASS galaxy catalog to identify potential supermassive black hole binary host galaxies, assess the likelihood of detecting one or more of these sources, and how much they might contribute to the nanohertz gravitational-wave (GW) background (GWB) and its anisotropy. We find that over 10,000 realizations of the local universe, out to 225 Mpc, that the number of sources per realization emitting GWs with f > 1 nHz can be described by a normal distribution with a mean of 130. We find that the detection of these sources is hampered by the small chirp mass of such binaries, and that with current best upper limits from the EPTA for continuous GW sources, the detection probability is < 1%. However, in the next 5-6 years we will begin to probe a region of the parameter space which is rich in sources, making a detection much more likely. Finally we find that a continuous GW source contributes < 1% to the isotropic GWB, but that some may contribute to the level of anisotropy by a few to 10%.

Author(s): Chiara M. F. Mingarelli[1], Steve Croft5, Justin Ellis[2], Jenny E. Greene4, Joseph Lazio[2], Chung-Pei Ma5, Alberto Sesana[6], Sarah Burke-Spolaor3, Stephen R Taylor[2]
Institution(s): *1. Max Planck Institute for Radio Astronomy, 2. NASA Jet Propulsion Laboratory, 3. National Radio Astronomy Observatory, 4. Princeton University, 5. UC Berkeley, 6. University of Birmingham*

308 – Supernovae

308.01 – On Variations Of Pre-Supernova Model Properties

We explore the variations in the progenitors of supernovae due to changes in the number of isotopes in a fully-coupled nuclear reaction network and adjustments in the mass resolution. We explore single, non-rotating, solar metallicity stars using MESA, in the mass range of 15-30 solar masses. We discuss the changes in the evolution of the star and the final state of the pre-supernovae star. The choice of network size and numerical resolution is found to have larger impacts on the stellar structure on the from the MS up and to core collapse. We find that up to carbon burning the choice of numerical resolution has the largest impact. After carbon burning the choice of nuclear network plays a larger role in determining the final state of the star. Variations of ~30% in the central electron fraction can be found in the supernovae progenitor as well as changes in the iron core of up to ~10% are possible. We find a minimum mass resolution of ~0.01 solar masses is necessary to achieve convergence in the helium core mass at the 5% level. For the choice of nuclear network, we find a minimum of 127 isotopes, in a fully coupled nuclear network, is needed to attain convergence at the 10% level.

Author(s): Robert Farmer[1], Carl Fields3, Ilka Petermann[1], Luc Dessart4, Matteo Cantiello[2], Bill Paxton[2], Francis Timmes[1]
Institution(s): *1. Arizona State University, 2. KITP, UC Santa Barbra, 3. Michigan State University, 4. Universite C\^ote d'Azur*

308.02 – The Fate of Exploding Carbon-Oxygen Chandrasekhar-Mass White Dwarfs: The Production of Stable Iron-Peak Elements in the Type Ia Supernova Remnant 3C 397

Type Ia supernovae are important across many astrophysical domains, serving as standardizable candles for cosmology, sources of cosmic rays, turbulence, and enriched isotopes for the interstellar medium, and endpoints of binary evolution. Yet, the nature of their stellar progenitors remains elusive. For decades, the leading model to explain the relative uniformity of Type Ia supernovae properties consisted of carbon-oxygen white dwarfs accreting material to near-Chandrasekhar mass from a stellar companion, in the single-degenerate channel. It has slowly become apparent that there are likely several diverse ways in which carbon-oxygen white dwarfs may explode and produce a range of outcomes, including both normal and peculiar Type Ia supernovae. Indeed, it is only very recently that strong observational evidence supporting the single-degenerate channel has emerged, and that numerous questions surrounding it have begun to be unraveled.

In this talk, I will focus upon the use of multidimensional numerical simulations in modeling the stable iron-group elemental abundances inferred from the hard X-ray spectrum of the galactic supernova remnant 3C 397. Because the electron capture rates involved in the production of these stable iron-group abundances are very sensitive functions of density, we now have an exquisite probe into the internal structure and composition of the progenitor near-Chandrasekhar mass white dwarf, as well as of the physics of the ignition and detonation, which gave rise to the observed remnant. I will conclude with an outlook on some of the many exciting prospects for future observational and theoretical investigation, which will have the potential of helping crack the mystery of the Type Ia supernovae progenitors.

Author(s): Robert Fisher3, Pranav Dave3, Rahul Kashyap3, Francis Timmes[1], Dean Townsley[2]
Institution(s): *1. Arizona State University, 2. University of Alabama, 3. University of Massachusetts Dartmouth*

308.03 – The Type Ia Supernova Color-Magnitude Relation and Host Galaxy Dust: A Simple Hierarchical Bayesian Model

Inferring peak optical absolute magnitudes of Type Ia supernovae (SN Ia) from distance-independent measures such as their light curve shapes and colors underpins the evidence for cosmic acceleration. SN Ia with broader, slower declining optical light curves are more luminous ("broader-brighter") and those with redder colors are dimmer. But the "redder-dimmer" color-luminosity relation widely used in cosmological SN Ia analyses confounds its two separate physical origins. An intrinsic correlation arises from the physics of exploding white dwarfs, while interstellar dust in the host galaxy also makes SN Ia appear dimmer and redder. Conventional SN Ia cosmology analyses currently use a simplistic linear regression of magnitude versus color and light curve shape, which does not model intrinsic SN Ia variations and host galaxy dust as physically distinct effects, resulting in low color-magnitude slopes. We construct a probabilistic generative model for the dusty distribution of extinguished absolute magnitudes and apparent colors as the convolution of an intrinsic SN Ia color-magnitude distribution and a host galaxy dust reddening-extinction distribution. If the intrinsic color-magnitude (M_B vs. B-V) slope β_{int} differs from the host galaxy dust law R_B, this convolution results in a specific curve of mean extinguished absolute magnitude vs. apparent color. The derivative of this curve smoothly transitions from β_{int} in the blue tail to R_B in the red tail of the apparent color distribution. The conventional linear fit approximates this effective curve near the average apparent color, resulting in an apparent slope β_{app} between β_{int} and R_B. We incorporate these effects into a hierarchical Bayesian statistical model for SN Ia light curve measurements, and analyze a dataset of SALT2 optical light curve fits of 277 nearby SN Ia at $z < 0.10$. The conventional linear fit obtains $\beta_{app} \approx 3$. Our model finds a $\beta_{int} = 2.2 \pm 0.3$ and a distinct dust law of $R_B = 3.7 \pm 0.3$, consistent with the average for Milky Way dust, while correcting a systematic distance bias of ~0.10 mag in the tails of the apparent color distribution. This research is supported by NSF grants AST-156854, AST-1211196, and NASA grant NNX15AJ55G.

Author(s): Kaisey Mandel[1], Daniel Scolnic4, Hikmatali Shariff[2], Ryan Foley3, Robert Kirshner[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Imperial College London, 3. UCSC, 4. University of Chicago*

308.04 – Progressive Red Shifts in the Late-Time Spectra of Type Ia Supernovae

We examine the evolution of late-time, optical nebular features of Type Ia supernovae (SNe Ia) using a sample consisting of 160 spectra of 27 normal SNe Ia taken from the literature as well as unpublished spectra of SN 2008Q and ASASSN-14lp. Particular attention is given to nebular features between 4000–6000 Ang in terms of temporal changes in width and central wavelength. Analysis of the prominent late-time 4700 Ang feature shows a progressive central wavelength shift from ~4600 Ang to longer wavelengths out to at least day +300 for our entire sample. We find no evidence for the feature's red-ward shift slowing or halting at an [Fe III] blend centroid ~4700 Ang as has been proposed. Two weaker adjacent features at around 4850 and 5000 Ang exhibit similar red shifts to that of the 4700 Ang feature. We conclude that the ubiquitous red shift of these common late-time SN Ia spectral features is not mainly due to a decrease in line velocities of forbidden Fe emissions, but the result of decreasing line velocities and opacity of permitted Fe absorption lines.

Author(s): Christine Black[1], Robert Fesen[1], Jerod Parrent[2]
Institution(s): *1. Dartmouth College, 2. Harvard CFA*

308.05D – Simulation of compact circumstellar shells around Type Ia supernovae and the resulting high-velocity features

For Type Ia supernovae that are observed prior to B-band maximum (approximately 18-20 days after the explosion) Ca absorption features are observed at velocities of order 10,000 km/s faster than the typical photospheric features. These high velocity features weaken in the first couple of weeks, disappearing entirely by a week after B-band maximum. The source of this high velocity material is uncertain: it may be the result of interaction between the supernova and circumstellar material or may be the result of plumes or bullets of material ejected during the course of the explosion. We simulate interaction between a supernova and several compact circumstellar shells, located within 0.03 solar radii of the progenitor white dwarf and having masses of 0.02 solar masses or less. We use FLASH to perform hydrodynamic simulations of the system to determine the structure of the ejecta and shell components after the interaction, then use these results to generate synthetic spectra with 1 day cadence for the first 25 days after the explosion. We compare the evolution of the velocity and pseudo-equivalent width of the Ca near-infrared triplet features in the synthetic spectra to observed values, demonstrating that these models are consistent with observations. Additionally, we fit the observed spectra of SN 2011fe (Parrent 2012, Pereira 2013) prior to B-band maximum using these models and synthetic spectra and provide an estimate for Ca abundance within the circumstellar material with implications for the mechanism by which the white dwarf explodes.

Author(s): Brian W. Mulligan[1], J. Craig Wheeler[1]
Institution(s): *1. University of Texas at Austin*

308.06 – Short-Lived Circumstellar Interaction in a Low-Luminosity Type IIP Supernova

While interaction with circumstellar material is known to play an important role in Type IIn supernovae, analyses of the more common Type IIP and IIL supernovae have not traditionally included interaction as a significant power source. However, recent campaigns to observe supernovae within days of explosion have revealed narrow emission lines of high-ionization species in the earliest spectra of luminous Type II supernovae of all subclasses. These "flash spectroscopy" features indicate the presence of a confined shell of material around the progenitor star. Here we present the first low-luminosity supernova to show flash spectroscopy features, SN 2016bkv. This supernova peaked at M_V = -16 mag and has expansion velocities around maximum light of < 2000 km s^{-1}, placing it at the faint/slow end of the distribution of Type IIP supernovae (similar to SN 2005cs). The detection of flash spectroscopy features in this event demonstrates that circumstellar interaction plays a role even in a low-luminosity Type IIP supernovae. Conversely, it implies that the range of luminosities of Type II supernovae is not solely driven by the presence of circumstellar material.

Author(s): Griffin Hosseinzadeh[1], Stefano Valenti[2], Iair Arcavi3, Curtis McCully[1], Dale Andrew Howell[1]
Institution(s): *1. Las Cumbres Observatory, 2. University of California, Davis, 3. University of California, Santa Barbara*

308.07D – Time Lapse Spectropolarimetry: Constraining the Nature and Progenitors of Interacting CCSNe

SNe Type IIn are among the brightest supernova explosions due to strong circumstellar interaction, but the category is not well defined. The heterogeneous nature of the class implies that any number of different progenitors can give rise to a IIn event so long as there is appreciable mass loss prior to explosion. Examining the geometric and optical properties of the circumstellar material (CSM) can help to identify the progenitors of individual IIn SNe. Polarimetry is the optimal method for constraining CSM characteristics as polarimetric signals depend on and preserve geometric information from unresolved sources.

I present results of an ensemble of three-dimensional simulations of the polarized H alpha emission-line profiles of interacting SNe using a Monte Carlo radiative transfer code called SLIP. A novel feature of these simulations is their ability to emit photons from a distributed shock region as well as from a central source. This allows us to investigate two different illumination scenarios as well as CSM properties. We present results for how these different models best match multi-epoch observed polarized spectra of the IIn SNe 1997eg, and all IIn from the the SNSPOL collaboration database. I will use the results to investigate relationships among SNe IIn based on viewing angle and consider whether the IIn category should be subdivided based on physical properties of the CSM and/or progenitor.

Author(s): Leah N. Huk[1]
Institution(s): *1. University of Denver*
Contributing team(s): SNSPOL

309 – Space Missions: X-ray Instruments

309.01 – Status of the Micro-X Sounding Rocket Telescope

Micro-X is a sounding rocket borne X-ray telescope that uses Transition Edge Sensor microcalorimeters to provide superior energy resolution. Micro-X has a variety of applications with plans to observe the Puppis A supernova remnant during its first flight, as well as future observations of the Milky Way to search for X-ray signals from decaying dark matter. Commissioning and functionality testing are complete and this project is now in the calibration and performance optimization phase. We present an overview of the instrument and an update on ongoing progress in preparation for the upcoming launch.

Author(s): David Goldfinger[4], Joseph D Adams[2], Bob Baker[2], Simon Bandler[2], Meredith E. Danowski[3], Randy Doriese[5], Megan Eckart[2], Enectali Figueroa-Feliciano[6], Sarah N. Heine[4], Gene Hilton[5], Antonia Hubbard[6], Richard L. Kelley[2], Caroline Kilbourne[2], Renée Manzagol[6], Dan McCammon[7], Takashi Okajima[2], Frederick Scott Porter[2], Carl Reintsema[5], Peter J. Serlemitsos[2], Stephen J Smith[2], Patrick Wikus[1]
Institution(s): *1. Bruker BioSpin AG, 2. Goddard Space Flight Center, 3. L-3, 4. Massachusetts Institute of Technology, 5. NIST, 6. Northwestern University, 7. University of Wisconsin*
Contributing team(s): Micro-X Collaboration

309.02 – Prospects for Sterile Neutrino Observations with the Micro-X Sounding Rocket

The Micro-X sounding rocket uses a Transition Edge Sensor (TES) array to make X-ray observations. The improved energy resolution of TESs compared to traditional space-based X-ray detectors brings new precision to both supernova observations and the X-ray search for sterile neutrino dark matter. Current X-ray observations disagree over the potential presence of a 3.5 keV X-ray line consistent with a sterile neutrino interaction, and Micro-X is in a unique position to establish or refute the presence of this line. We present the design considerations of the instrument and expectations for flight observations, with special emphasis given to the prospects of sterile neutrino studies.

Author(s): Antonia Hubbard[6], Joseph D Adams[4], Bob Baker[4], Simon Bandler[4], Meredith E. Danowski[2], Randy Doriese[5], Megan Eckart[4], Enectali Figueroa-Feliciano[6], Sarah N. Heine[3], Gene Hilton[5], David Goldfinger[3], Richard L. Kelley[4], Caroline Kilbourne[4], Renée Manzagol[6], Dan McCammon[7], Takashi Okajima[4], Frederick Scott Porter[4], Carl Reintsema[5], Peter J. Serlemitsos[4], Stephen J Smith[4], Patrick Wikus[1]
Institution(s): *1. Bruker BioSpin AG, 2. L-3, 3. Massachusetts Institute of Technology, 4. NASA Goddard Space Flight Center, 5. NIST, 6. Northwestern University, 7. University of Wisconsin*
Contributing team(s): Micro-X Collaboration

309.03 – NICER ground verification: as-built timing, spectroscopy, and throughout performance of NASA's next X-ray timing astrophysics mission

The Neutron star Interior Composition Explorer (NICER) Mission of Opportunity will fly to the International Space Station (ISS) in 2017 aboard a SpaceX resupply vehicle. Once installed as an external attached payload, NICER will provide an unprecedented soft X-ray timing spectroscopy capability for neutron stars and other phenomena. In June 2016, the NICER payload was delivered from NASA Goddard Space Flight Center to Cape Canaveral to await launch processing. We present measurements made as part of NICER's preship testing to verify performance of its X-ray Timing Instrument and associated subsystems; these measurements demonstrate that NICER meets or surpasses its design requirements in the areas of photon time-tagging resolution, energy resolution, effective collecting area, and high-rate throughput.

Author(s): Keith Gendreau[1], Zaven Arzoumanian[1]
Institution(s): *1. NASA/GSFC*
Contributing team(s): NICER Team

309.04 – STROBE-X: X-ray Timing & Spectroscopy on Dynamical Timescales from Microseconds to Years

We describe a proposed probe-class mission concept that will provide an unprecedented view of the X-ray sky, performing timing and spectroscopy over a broad band (0.2-30 keV) probing timescales from microseconds to years. The Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X) comprises two primary instruments. The soft band (0.2-12 keV) will be covered by an array of lightweight optics (3-m focal length) that concentrate incident photons onto small solid state detectors with CCD-level (85-130 eV) energy resolution, 100 ns time resolution, and low background rates. This technology, fully developed for NICER, would be scaled up with enhanced optics to take advantage of the longer focal length of STROBE-X. The harder band (2 to at least 30 keV) would be covered by large-area collimated silicon drift detectors,developed for the European LOFT mission concept. Each instrument would provide an order of magnitude improvement in effective area compared with its predecessor (NICER in the soft band and RXTE in the hard band). A sensitive sky monitor would act as a trigger for pointed observations, provide high duty cycle, high time resolution, high spectral resolution monitoring of the X-ray sky with ~20 times the sensitivity of the RXTE ASM, and enable multi-wavelength and multi-messenger studies on a continuous, rather than scanning basis.

The broad coverage will enable thermal components, non-thermal components, iron lines, and reflection features to be studied simultaneously from a single platform for the first time in accreting black holes at all scales. The enormous collecting area will enable studies of the dense matter equation of state using both soft thermal emission from rotation-powered pulsars and harder emission from X-ray burst oscillations. Revolutionary science, such as high quality spectroscopy of clusters of galaxies and unprecedented timing investigations of active galactic nuclei, would also be obtained.

We describe the mission concept and the planned trade studies that will optimize the mission to maximize the science return. This mission is being developed in collaboration with members of the European LOFT team, and a hardware contribution from Europe is expected.

Author(s): Colleen A. Wilson-Hodge[5], Paul S. Ray[7], Keith Gendreau[4], Deepto Chakrabarty[3], Marco Feroci[2], Tom Maccarone[9], Zaven Arzoumanian[1], Ronald A. Remillard[3], Kent Wood[8], Christopher Griffith[6]
Institution(s): *1. CRESST/GSFC, 2. INAF-IASF/INFN, 3. MIT, 4. NASA's GSFC, 5. NASA's MSFC, 6. NRC/NRL, 7. NRL, 8. Praxis/NRL, 9. Texas Tech*
Contributing team(s): STROBE-X Collaboration

309.05 – Diffraction efficiency of a replicated, flight-like off-plane reflection grating baselined for future X-ray missions

Future soft X-ray spectroscopy missions have science requirements that demand higher instrument throughput and higher resolution than currently available technology. A key element in such spectrometers are dispersive elements such as diffraction gratings. Our group at Penn State University develops and fabricates off-plane reflection gratings in an effort to achieve the level of performance required by future missions. We present here efficiency measurements made in the 0.3 – 1.5 keV energy band at the Advanced Light Source (ALS) synchrotron at Lawrence Berkley National Laboratory for one such grating, which was replicated using UV-nanoimprint techniques from a grating master fabricated using electron-beam lithography, plasma etching, and potassium hydroxide etching. These results represent the first successful demonstration of off-plane grating replicas produced via these fabrication techniques and provide baseline efficiency measurements for flight-like replicated gratings.

Author(s): Drew Miles[2], Randall McEntaffer[2], Jake McCoy[2], James Tutt[2], Casey DeRoo[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Penn State University*

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310 – Planets & Planetesimals in Circumstellar Disks

310.01 – Using Disk Eclipsing Systems to Understand Planet Formation and Evolution

The circumstellar environments of young stellar objects (YSOs) involve complex dynamical interactions between dust and gas that directly influence the formation of planets. However, our understanding of the evolution from the material in the circumstellar disk to the thousands of planetary systems discovered to date, is limited. One means to better constrain the size, mass, and composition of this planet-forming material is to observe a YSO being eclipsed by its circumstellar disk. Unfortunately, such events are rare but have already led to such insights as dense planet-forming structures within the tidally disrupted disk of a young binary star system, Saturn-like rings and gaps in the disk surrounding a young planet, stratified dust coagulation within a young protoplanetary disk, and an evolved binary star system with remnant planet-building material. Fortunately, the advent of wide-field time domain surveys provides a ideal tool to search for rare eclipse events. Using time-series photometry from the KELT project we are conducting the Disk Eclipse Search with KELT (DESK) survey to look for disk eclipsing events, specifically in young stellar associations. In addition, we are collaborating with the SuperWASP and ASAS-SN surveys which have already led to additional discoveries. This survey has already doubled the number of “disk eclipsing” systems known and will provide a framework for discovering such systems in future surveys such as LSST. I will describe a few of our recent discoveries and their impact on our understanding of circumstellar evolution.

KELT is a joint collaboration between the Ohio State University, Vanderbilt University, and Lehigh University. This work was partially supported by NSF CAREER grant AST-1056524. J.E.R. is supported by a Harvard Future Faculty Leaders Postdoctoral Fellowship.

Author(s): Joseph E. Rodriguez[2], Hugh P. Osborn3, Benjamin John Shappee[1]
Institution(s): *1. Carnegie Observatories, 2. Harvard-Smithsonian Center for Astrophysics, 3. Warwick University*
Contributing team(s): KELT Collaboration

310.02D – Studying the inner regions of young stars and their disks with aperture masking interferometry

High resolution aperture masking interferometry complements coronagraphic imagers to provide a unique perspective on star and planet formation at more moderate contrast. By targeting young stars, especially those with disks, we aim to understand complex protoplanetary environments. Ground-based non-redundant masking (NRM) paired with spectrographs and polarimeters probes both thermally emitting young companions, possibly embedded in the disk or gap and scattered light in protoplanetary disks. And soon the community will have access to the most stable NRM conditions yet, with the Near Infrared Imager and Slitless Spectrograph (NIRISS) Aperture Masking Interferometry (AMI) mode on the James Webb Space Telescope. I will present my thesis work commissioning the Gemini Planet Imager’s NRM, highlighting results through both its spectroscopy and polarimetry modes, which set the stage for future space-based imaging. I will also give an overview of NIRISS-AMI capabilities and performance predictions for imaging young low-mass companions and disks, and how it will complement other instruments on JWST.

Author(s): Alexandra Greenbaum[2], Anand Sivaramakrishnan[1]
Institution(s): *1. Space Telescope Science Institute, 2. University of Michigan*
Contributing team(s): GPI Instrument Team, NIRISS Instrument Team

310.03 – The First 40 Million Years of Circumstellar Disk Evolution: The Signature of Terrestrial Planet Formation

We characterize the first 40 Myr of evolution of circumstellar disks through a unified study of the infrared properties of members of young clusters and associations with ages from 2 Myr up to ~40 Myr. Our work features: 1.) a filtering technique to flag noisy backgrounds; 2.) a method based on the probability distribution of deflections, P(D), to obtain statistically valid photometry for faint sources; and 3.) use of the evolutionary trend of transitional disks to constrain the overall behavior of bright disks. We find that the fraction of optically thick disks three or more times brighter than the stellar photospheres at 24 μm decays relatively slowly initially and then much more rapidly by ~10 Myr. However, there is a continuing component until ~35 Myr, probably due primarily to massive clouds of debris generated in giant impacts during the oligarchic/chaotic growth phases of terrestrial planets. If the contribution from primordial disks is excluded, the evolution of the incidence of these oligarchic/chaotic debris disks can be described empirically by a log-normal function with the peak at 12 - 20 Myr, including ~13% of the original population, and with a post-peak mean duration of 10 - 20 Myr.

Author(s): Huan Meng[1], George Rieke[1], Kate Y.L. Su[1], Andras Gaspar[1]
Institution(s): *1. University of Arizona*

310.04D – Illuminating the Role of Spiral Waves in Circumstellar Disks

The transport of angular momentum and mass, and the generation of turbulence, play a crucial role in the evolution of a variety of astrophysical disks. Spiral waves, driven for instance by companion bodies or instabilities, have long been recognized as an important means for the aforementioned two processes. In this dissertation talk, I will discuss an instability of spiral waves that I have recently come across. I will begin by presenting the results from a three-dimensional global hydrodynamic simulation which described the growth and saturation of the instability. The spiral wave instability (SWI) arises as inertial modes, natural oscillations in rotating systems, amplify when they resonantly couple to and extract energy from the background spiral waves. This leads to break down of the spiral waves into turbulence when the velocity perturbations caused by unstable inertial modes reach a similar magnitude to those induced by the spiral waves. As an implication of the instability, I will present numerical results and discuss the consequence of the SWI when it acts on the spiral waves driven by a Jupiter-mass planet in a protoplanetary disk. I find that the planet-driven spiral arms are destabilized via the SWI, generating hydrodynamic turbulence and sustained vertical flows that are associated with long wavelength inertial modes. The associated vertical diffusion rate measured from the simulations is such that solid particles with sizes up to a few centimeters are vertically mixed within the first scale height in a protosolar nebula-like disk. Since circumstellar disks are believed to remain laminar, and thus to induce no or very little particle stirring as suggested by recent magnetocentrifugal wind models, the results imply that the SWI can be the mechanism controlling the degree of vertical settling of solid particles in planet-hosting disks. In particular, if accretion of mm- to cm-sized pebbles dominates the growth of terrestrial bodies, the stirring of solid particles by a giant planet (e.g. Jupiter in the protosolar nebula) can limit the accretion efficiency and affect sculpting the population of terrestrial planets and their precursor embryos as initial conditions for the late-stage gas-free evolution.

Author(s): Jaehan Bae[1], Lee W. Hartmann[1]
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310.06 – The highly varying circumstellar debris disk of HD 183324

The 140 Myr-old A0IV-type star HD 183324 possesses many of the same physical characteristics as the stars Beta Pictoris and 49 Ceti, whose circumstellar gas and dust disks are the two best-studied debris disk systems. Here, we compare spectral observations of HD 183324 collected (and archived) in 2009 and 2010 to similarly high-resolution spectral observations of HD 183324 that we collected in 2013. An inspection of these spectra (recorded at visible wavelengths) reveals a remarkably high level of variable circumstellar absorption activity around the star. Such behavior is typical of a stellar system in which gas and dust is being sporadically added to a circumstellar disk due to the evaporation of planetesimal-like objects ("exocomets") as they fall towards the central star.

We present spectral data that show levels of absorption variability of greater than 100% in both the circumstellar CaII-K (3933Å) and FeI (3860Å) line profiles as measured throughout the 5-year period of observations. Such high levels of circumstellar absorption variability may be indicative of an as-yet undetected exoplanet, whose gravitational forces are perturbing the planetesimals orbiting HD 183324.

Author(s): Barry Welsh[2], Sharon Lynn Montgomery[1]
Institution(s): *1. Clarion University, 2. UC, Berkeley*

310.07 – Spectroscopic Evolution of Disintegrating Planetesimals: Minutes to Months Variability in the Circumstellar Gas Associated with WD 1145+017

With the recent discovery of transiting planetary material around WD 1145+017, a critical target has been identified that links the evolution of planetary systems with debris disks and their accretion onto the star. We present a series of observations, five epochs over a year, taken with Keck and the VLT, which for the first time show variability of circumstellar absorption in the gas disk surrounding WD 1145+017 on timescales of minutes to months. Circumstellar absorption is measured in more than 250 lines of 14 ions among ten different elements associated with planetary composition, e.g., O, Mg, Ca, Ti, Cr, Mn, Fe, Ni. Broad circumstellar gas absorption with a velocity spread of 225 km s^{-1} is detected, but over the course of a year blue shifted absorption disappears while redshifted absorption systematically increases. A correlation of equivalent width and oscillator strength indicates that the gas is not highly optically thick (median $\tau \approx 2$). We will present simple models of an eccentric disk coupled with magnetospheric accretion to explain the basic observed characteristics of these high resolution and high signal-to-noise observations. Variability is detected on timescales of minutes in the two most recent observations, showing a loss of redshifted absorption for tens of minutes, coincident with major transit events and consistent with gas hidden behind opaque transiting material. This system currently presents a unique opportunity to learn how the gas causing the spectroscopic, circumstellar absorption is associated with the ongoing accretion evidenced by photospheric contamination, as well as the transiting planetary material detected in photometric observations.

Author(s): Seth Redfield4, Jay Farihi[1], Paul W. Cauley4, Steven Parsons[2], Boris T Gaensicke3, Girish Manideep Duvvuri4
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311 – Molecular Clouds, HII Regions, PDRs

311.01 – Measurements of Molecular Cloud Ages using the HI/ H_2 Ratio

We utilize a new chemical evolution model in conjunction with the HI and H_2 mass measurements of 9 nearby molecular clouds in order to place lower limits on their chemical ages (the time since the cloud first attained sufficient self-shielding for molecules to persist). HI masses are measured using HI Narrow Self-Absorption (HINSA) features with data taken with the GBT. H_2 masses are estimated using ^{13}CO emission data obtained with FCRAO.
Since the clouds' geometry (and volume density) are unknown, we examine each cloud under a range of assumptions. Under conditions that favor the lowest age limits, where each cloud is assumed to resemble a sheet and has the highest reasonable volume density, we arrive at age lower limits between 0.3 and 1.5 Myrs. Assuming that the clouds have no preferential orientation yields age lower limits of 4.4 Myrs or older. HI/H_2 cloud mass ratios between 0.13x10^{-3} and 3.8x10^{-3} were observed. The lack of any observed clouds with higher HI/H_2 ratios leaves open the question of why the youngest clouds are not observed. Our models reveal that the clouds studied here should reach a steady-state, where the only remaining HI is due to cosmic ray dissociation, within approximately 7 to 15 Myrs.
We determine the HI/H_2 ratio, and age lower limit for all clumps and velocity components within each cloud. Though individual clumps within a single cloud, and even along the same line of sight may exhibit very different HI/H_2 ratios, they most often exhibit similar ages. This would indicate that the mixing timescale for different clumps within cloud are generally longer than the cloud ages.
Ultimately we conclude that the cloud collapse timescale is at least on the order of 10Myrs.

Author(s): Marko Krco[1], Di Li[1]
Institution(s): *1. National Astronomical Observatories of China*

311.02D – Physical properties of CO-dark molecular gas with C^+ and OH observations

The lifecycle of interstellar medium (ISM) is critical for understanding galaxy evolution. The transition between atomic neutral medium and dense molecular gas, however, cannot be traced adequately by either HI or CO emission. Results from dust observations of Planck all-sky mission and gamma-ray observations of Energetic Gamma Ray Experiment Telescope (EGRET) have revealed the existence of "CO dark molecular gas" (DMG) - molecular gas without CO emission. The physical conditions of DMG including density, temperature, and molecular composition are basis of understanding the ISM evolution. We analyzed physical properties of DMG with HI-self absorption and C^+ fine line emission at 158 um toward the lines of sight of Galactic Observations of Terahertz C+ (GOTC+). DMG clouds have a median excitation temperature of 56 K and median volume density of 230 cm^2, showing intermediate physical properties between atomic and molecular gas. Sixteen DMG clouds with high visual extinction (A_V>=2.7 mag) were found. CO abundance compared to H_2 in these clouds is two orders magnitude smaller than the cannonical value in the Milky Way and cannot be explained by the chemical evolutionary model. They may be formed through the agglomeration of pre-existing molecular gas in the Milky Way. We have finished a follow up survey of OH 18 cm lines toward 51 sightlines of GOTC+ including sightlines with DMG clouds through Arecibo telescope. DMG may result in the absence of correlation between CO and OH column density. A possible correlation was found between C^+ and OH column density in tracing DMG.

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Contributing team(s): ISM group in National Astronomical Observatories, CAS

311.03 – Spectral Classification of Heavily Reddened

Stars by CO Absorption Strength

The nature of dust grains in dense molecular clouds can be explored by obtaining spectra of giant stars located behind the clouds and examining the wavelength-dependent attentuation of their light. This approach requires the intrinsic spectra of the background stars to be known, which can be achieved by determining their spectral types. In the K-band spectra of cool giant stars, several temperature-sensitive CO absorption bands serve as good spectral type indicators. Taking advantage of the SpeX Infrared Telescope Facility Spectral Library, near-infrared spectra collected with TripleSpec and the 3.5-meter ARC Telescope at Apache Point Observatory, and a previously constructed CO spectral index, we make precise spectral determinations of 20 giant stars located behind two dense cloud cores: CB188 and L429C. With spectral types in hand, we then utilize Markov Chain Monte Carlo techniques to constrain extinctions along these lines of sight. The spectral typing method will be described and assessed as well as its success at finding a couple of incorrectly spectral typed stars in the SpeX Library. Funding for this program was provided by a NSF REU grant to the Keck Northeast Astronomy Consortium and a grant from the NASA Astrophysics Data Analysis Program.

Author(s): Christopher Garling[2], Jeffrey S. Bary[1], Tracy L. Huard3
Institution(s): *1. Colgate University, 2. Haverford College, 3. University of Maryland*

311.04D – Quantifying the Multiphase Galactic Outflows Driven by Supernovae

Galactic outflows are ubiquitously observed in star-forming disk galaxies and are critical for galaxy formation. Supernovae (SN) play a key role in driving the outflows, but there is no consensus as to how much energy, mass and metals they can launch out of the disk. We perform 3D, high-resolution hydrodynamic simulations to study SN-driven outflows from stratified media. We study various conditions along the Kennicutt-Schmidt relation, and examine the loading factors of energy, mass and metals as a function of the star formation rate. We find that the hot phase, being fast and metal-enriched, would have a broad impact on the circum-galactic medium. We explore how various physical processes, including SN scale height, photoelectric heating, external gravitational field and SN rate, affect the loading factors. We find that the mass loading factor can achieve unity for a gas surface density similar to the solar neighborhood, but is lower for higher densities. The mass loading is in general a factor of a few smaller than what is currently adopted in cosmological simulations. SN-driven outflows are expected to efficiently transport out of the galaxies both energy and metals.

Author(s): Miao Li[1], Greg Bryan[1], Jeremiah P. Ostriker[1]
Institution(s): *1. Columbia University*

311.05 – Striae and MHD Waves in Molecular Clouds

The origin of molecular striae aligned along the local magnetic field in the envelope of the Taurus molecular cloud is examined with new observations of ^{12}CO and ^{13}CO J=2-1 emission obtained with the 10m submillimeter telescope of the Arizona Radio Observatory. These data identify a periodic pattern of excess blue and redshifted emission that is responsibe for the striae features. For both ^{12}CO and ^{13}CO, spatial variations of the J=2-1 to J=1-0 line ratio are small and are not spatially correlated with the striae locations. A medium comprised of small, unresolved cells of CO emission with a filling factor less than 1 is required to explain the average line ratios and brightness temperatures. We propose that the striae features result from the modulation of the velocities and the beam filling factor of the cells, as a result of magnetosonic waves propagating through the envelope of the Taurus molecular cloud. Such waves are likely a common feature of molecular clouds that are sub-Alfvenic and may explain low column density, cirrus-like features that are observed to be aligned along the magnetic field direction.

Author(s): Paul Goldsmith[2], Mark H. Heyer3, Umut Yildiz[2], Ronald L. Snell3, Edith Falgarone[1], Jorge L. Pineda[2]
Institution(s): *1. ENS, 2. JPL, 3. University of Massachusetts*

311.06D – Probing the conditions within Photo-dissociation Regions with high resolution near-infrared spectroscopy of UV-excited molecular hydrogen

UV radiation regulates the energetics, ionization, and chemistry in much of the ISM. Regions between hot ionized and cool molecular gas where non-ionizing far-UV radiation dominates the state of the gas are called Photo-Dissociation or Photon-Dominated Regions (PDRs). PDRs are found in regions of high-mass star formation, planetary nebulae, and other environments that contain strong far-UV radiation fields. Hydrogen molecules (H_2) are pumped by far-UV photons into excited rotational-vibrational levels of the ground electronic state, which give rise to a rich array of transitions in the near to mid-infrared. These transitions make an excellent probe of the physical conditions within a PDR. I will present near-IR spectra taken with the Immersion GRating Infrared Spectrometer (IGRINS; Park et al. 2014, Proc. SPIE, 9147), a novel, sensitive spectrometer with high spectral resolving power (R~45000) and instantaneous broad wavelength coverage (1.45-2.45 μm). Using IGRINS, I obtained deep spectra and measured up to 100 H_2 rotational-vibrational transitions in the well-studied Orion Bar PDR, four other star formation complexes, and over a dozen planetary nebulae. Measurements of many lines from a wide range of vibrational states (v=1 to 13), rotational states (J=1 to 13), and excitation energies provides leverage for constraining the overall level populations and discerning the state of and physical processes within the gas. This combination of high spectral and spatial resolution enables us to distinguish previously unresolved spatio-kinematical components with distinct intrinsic spectra and excitation mechanisms (e.g. shocks vs. radiative excitation) within some individual planetary nebulae. I use the plasma simulation code Cloudy (Ferland et al. 2013, ApJ, 757, 79) as a tool for interpreting the observed H_2 line ratios. Some sources are well fit by models with a single temperature and density, consistent with emission from a narrow region of the overall PDR structure. Populations of certain levels are more sensitive than others to specific physical parameters such as gas kinetic temperature or density.

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Author(s): Kyle Kaplan[1], Harriet L. Dinerstein[1], Daniel Thomas Jaffe[1]
Institution(s): *1. The University of Texas at Austin*

312 – Perspectives in Research Software: Education, Funding, Reproducibility, Citation, & Impact

Software is of vital importance to scientific research. Indeed, a recent informal survey found that all astronomers use software in their research(1). All disciplines, including astronomy, struggle with funding for developing and maintaining software, and with methods for sustaining, sharing, discovering, and citing software. Further, scientists are often not taught how to program well, efficiently, and in a sustainable manner, and software-related activities are frequently not rewarded in academic and research institutions. Given the importance of software to research, improving all aspects of research codes will result in even better science. This session, organized by the Astrophysics Source Code Library (ASCL) and the Moore-Sloan Data Science Environment (DSE) at NYU, builds on previous AAS special sessions and brings together experts from other fields and within astronomy. They will present information on activities and projects that are addressing some of the challenges the astronomy community and the scientists who write software face and will share lessons learned in other disciplines that have direct applicability to astronomy. After the presentations, the floor will be open for discussion and questions. (1)https://www.authorea.com/users/10533/articles/18046

312.01 – Software not as a service

With the expansion in the variety, velocity and volume of data being produced, computing and software development has become a crucial element of astronomy research. However, while we value the research, we place less importance on the development of the software itself, viewing software as a service to research. By viewing software as a service, we derate the effort and expertise it takes to produce, and the training required, for effective research computing. We also don't provide support for the people doing the development, often expecting individual developers to provide systems administration, user support and training and produce documentation and user interfaces. With our increased reliance on research computing, accurate and reproducible research requires that software not be separate from the act of conducting research, but an integral component - a part of, rather than a service to research. Shifts in how we provide data skills and software development training, integrate development into research programs and academic departments and value software as a product can have an impact on the quality, creativity and types of research we can conduct.

Author(s): Tracy Teal[1]
Institution(s): *1. Data Carpentry*

312.02 – Funding Research Software Development

Astronomical software is used by each and every member of our scientific community. Purpose-build software is becoming ever more critical as we enter the regime of large datasets and simulations of increasing complexity. However, financial investments in building, maintaining and renovating the software infrastructure have been uneven. In this talk I will summarize past and current funding sources for astronomical software development, discuss other models of funding and introduce a new initiative for supporting community software at STScI. The purpose of this talk is to prompt discussion about how we allocate resources to this vital infrastructure.

Author(s): Ivelina G. Momcheva[1]
Institution(s): *1. Space Telescope Science Institute*

312.03 – Reproducibility and reusability of scientific software

Information science and technology has been becoming an integral part of astronomy research, and due to the consistent growth in the size and impact of astronomical databases, that trend is bound to continue. While software is a vital part information systems and data analysis processes, in many cases the importance of the software and the standards of reporting on the use of source code has not yet elevated in the scientific communication process to the same level as other parts of the research. The purpose of the discussion is to examine the role of software in the scientific communication process in the light of transparency, reproducibility, and reusability of the research, as well as discussing software in astronomy in comparison to other disciplines.

Author(s): Lior Shamir[1]
Institution(s): *1. Lawrence Technological University*

312.04 – Finding the right wheel when you don't want to reinvent it

The increasing amount of software being developed in all areas of science brings new capabilities as well as new challenges. Two of these challenges are finding potentially-relevant software, and being able to reuse it. The notion that "surely someone must have written a tool to do XYZ" often runs into the reality of thousands of Google hits with little detail about capabilities and status of different options. Software directories such as ASCL can add tremendous value by helping to improve the signal-to-noise ratio when searching for software; in addition, developers themselves can also act to make their work more easily found and understood. In this context, it can be useful to know what people do in practice when they look for software, and some of the factors that help or hinder their ability to reuse the software they do find. The results point to some simple steps that developers can take. Improved findability and reusability of software has broad potential impact, ranging from improved reproducibility of research results to better return on investment by funding agencies.

Author(s): Michael Hucka[1]
Institution(s): *1. California Institute of Technology*

312.05 – Update on research software citation efforts

Research software citation has received a lot of attention the past few years, as evidenced by numerous efforts that have discussed it, including WSSSPE, Force11 Software Citation Working Group, the Center for Open Science's Transparency and Openness Promotion (TOP) Guidelines, a workshop on Engineering Academic Software, and the CodeMeta project. This presentation briefly covers recent broad efforts to improve research transparency across disciplines through software availability and citation, and the Software Citation Principles that have recently been published as a result of the work done through Force11.

Author(s): Alice Allen[1]
Institution(s): *1. Astrophysics Source Code Library*

312.06 – Capturing the impact of software

Research software is undervalued in funding and tenure decisions because its impact is poorly evaluated within the traditional paper-based ecosystem. The talk presents the NSF-funded Depsy project (http://depsy.org) -- a proof-of-concept system designed to address this problem by tracking the impact of software in software-native ways. Depsy finds mentions of software itself in the literature, rather than just counting citations to a wrapper paper about the software. It discovers how software gets reused by other software, even when it's not cited at all. And finally Depsy attempts to represent the full complexity of software authorship, where one project can involve hundreds of contributors in multiple roles that don't map to traditional paper authorship.

Author(s): Heather Piwowar[1]
Institution(s): *1. Impactstory*

312.07 – The relationships between software publications and software systems

When we build software systems or software tools for astronomy, we sometimes do and sometimes don't also write and publish standard scientific papers about those software systems. I will discuss the pros and cons of writing such publications. There are impacts of writing such papers immediately (they can affect the design and structure of the software project itself), in the short term (they can promote adoption and legitimize the software), in the medium term (they can provide a platform for all the literature's mechanisms for citation, criticism, and reuse), and in the long term (they can preserve ideas that are embodied in the software, possibly on timescales much longer than the lifetime of any software context). I will argue that as important as pure software contributions are to astronomy—and I am both a preacher and a practitioner—software contributions are even more valuable when they are associated with traditional scientific publications. There are exceptions and complexities of course, which I will discuss.

Author(s): David W. Hogg[1]
Institution(s): *1. New York University*

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313 – Exploring the Optical Time Domain with the Intermediate Palomar Transient Factory

The Intermediate Palomar Transient Factory (iPTF) has conducted a range of time-domain surveys since 2013, including high-cadence searches for fast transients, targeted followup of Fermi gamma-ray bursts and Advanced LIGO triggers, and an extensive variability survey of the Northern Galactic Plane. As the survey concludes, we review the scientific returns from these surveys as well as implications for next-generation surveys such as the Zwicky Transient Facility and LSST. Finally, we provide an overview of the public data products being released.

313.01 – An Overview of the The Intermediate Palomar Transient Factory Surveys

The Intermediate Palomar Transient Factory (iPTF) has conducted a range of time-domain surveys since 2013. As iPTF concludes, I will review the these goals of surveys, their on-sky performance, and implications for next-generation surveys such as the Zwicky Transient Facility and LSST. Finally, I will describe the public data products being released.

Author(s): Eric Christopher Bellm[1], Shrinivas R. Kulkarni[1]
Institution(s): *1. Caltech*
Contributing team(s): The Intermediate Palomar Transient Factory Collaboration

313.02 – Early rise of Type Ia supernovae in the iPTF sample

In the last three years, the intermediate Palomar Transient Factory undertook several nightly-cadence surveys. So far, iPTF has discovered and spectroscopically identified more than 40 Type Ia supernovae of different subtypes at phases earlier than two weeks before maxima. I will summarize the iPTF surveys and our discovery procedure of young supernovae. Then I will present the diverse early rise light curves of these young Type Ia supernovae and discuss how their early rise behaviors are related to their single or double degenerate progenitor systems. The iPTF surveys serve as a trailblazer for future large-scale time-domain surveys, such as ZTF and LSST.

Author(s): Yi Cao3, Shrinivas R. Kulkarni[1], Peter E. Nugent[2]
Institution(s): *1. Caltech, 2. Lawrence Berkeley National Lab, 3. University of Washington*
Contributing team(s): the intermediate Palomar Transient Factory collaboration

313.03 – Exploding massive stars in real time: highlights from iPTF studies of core-collapse supernovae

The ultimate explosions of massive stars as core-collapse supernovae (SNe) are an extremely diverse phenomenon, not well understood theoretically. iPTF has provided interesting contributions to this field in several aspects. I will highlight mainly two of these: studies of the early emission from SNe, including the rising part of the light curve and very early flash spectroscopy, which are quite unique to iPTF due to its high cadence; and studies of rare and unusual objects. These span a range of properties from rapidly evolving events to the most extended SNe we know of, events in the luminous and faint ends of the SN luminosity range, and events with complex temporal behavior, such as multiple light-curve bumps. Prospects for future studies with the upcoming ZTF will be briefly presented.

Author(s): Avishay Gal-Yam[1]
Institution(s): *1. Weizmann Institute of Science*

313.04 – Superluminous Supernovae and Other Transients from iPTF

Arguably one of the biggest science contributions from wide-field surveys like iPTF have been the discovery of new classes of transients across the luminosity-timescale phase space (“Zwicky Diagram”). One such class is “superluminous" supernovae (SLSNe), with peak luminosites 10-100 times those of ordinary core-collapse and Type Ia SNe. The physical origin of these enormous luminosities is still debated, requiring either a distinct explosion mechanism and/or an additional energy source compared to ordinary core-collapse supernovae. In this talk, I will review iPTF results on superluminous supernovae, including both studies of the sample as a whole, and of individual, exciting objects. I will also highlight results on other rare classes of transients across the Zwicky Diagram.

Author(s): Ragnhild Lunnan[1], Robert Quimby4, Lin Yan[1], Annalisa De Cia3, Avishay Gal-Yam5, Paul Vreeswijk5, Giorgos Leloudas5, Daniel A. Perley[2]
Institution(s): *1. California Institute of Technology , 2. Dark Cosmology Center, 3. ESO, 4. SDSU, 5. Weizmann Institute of Science*
Contributing team(s): Intermediate Palomar Transient Factory

313.05 – Leo Singer

313.06 – The iPTF variability data and the iPTF Galactic Plane survey

The Palomar Transient Factory (PTF and iPTF) has obtained a large synoptic data set with fifty or more exposures per field and over a thousand exposures for some fields with a baseline of 6 years. Since 2013 we have conducted a dedicated survey of the Northern Galactic Plane in R-band, with a median of about 50 epochs in the |b| < 20 degrees region. This unique dataset allows mapping variable stars throughout the Galaxy, including rare compact binaries, pulsators but also outbursting sources like cataclysmic variables. I will describe the performance of the survey and give an overview of some interesting results.

Author(s): Thomas Kupfer[1], Eric Christopher Bellm[1], Thomas A Prince[1], Shrinivas R. Kulkarni[1], Frank J. Masci[2], Russ Laher[2], David L. Shupe[2]
Institution(s): *1. Caltech, 2. IPAC/Caltech*
Contributing team(s): intermediate Palomar Transient Factory Collaboration

313.07 – Exploring Near to Home: Solar System Science with the Palomar Transient Factory

The Palomar Transient Factory (PTF) is best known for its contributions to the science of extragalactic transients. However, the same large-area observations of the sky that yield detections of extragalactic transients can also be used to characterize, and discover, solar system objects. In this talk I will review the work of the PTF collaboration in the area of solar system science, in particular observations of asteroids and comets. Specific topics that will be covered include: characterization of asteroid rotation periods through observation of their synoptic light curves, transient activity of comets, and detection of small (less than 20 meter!) near-earth asteroids. Several of the investigations undertaken using PTF are prototypes of those that will be possible using the Zwicky Transient Facility (ZTF) which will have 10-20 times more capability for observations of solar system objects. ZTF will become operational later in 2017.

Author(s): Thomas Allen Prince[1]
Institution(s): *1. Caltech/JPL*
Contributing team(s): Palomar Transient Factory, Intermediate Palomar Transient Factory

314 – Graduate, Majors, & Gen. Ed. Astronomy Education: Research, Practice, & Funding Opportunities!

314.01 – The AstroPAL Starter Pack: How to Create a Grad Mentoring Program That Fosters Equity and Inclusion in Your Department

The Astronomy Peer Advising Leaders program (AstroPAL) at Georgia State University is a grassroots effort initiated by one PhD student with no budget, yet has quickly become a successful program that especially impacts students of marginalized identities. AstroPAL provides guidance for incoming grad students and helps them adjust to the workload, stress, and other difficulties that can come with grad school. This talk will cover the AstroPAL goals and accomplishments, its logistical structure, and its longterm sustainability. We will discuss how the program has helped create a bridge between faculty and students as well as the positive effect it has had on our community. I will also provide tools that anyone can use to launch AstroPAL at their home institution.

Author(s): Nicole Cabrera[1]
Institution(s): *1. Georgia State University*

314.02 – ZTF Undergraduate Astronomy Institute at Caltech and Pomona College

From the new Zwicky Transient Facility (ZTF), an NSF funded project based at Caltech, comes a new initiative for undergraduate research known as the Summer Undergraduate Astronomy Institute. The Institute brings together 15-20 students from across the world for an immersive experience in astronomy techniques before they begin their summer research projects. The students are primarily based at Caltech in their SURF program but also includes a large cohort of students enrolled in research internships at Pomona College in nearby Claremont CA. The program is intended to introduce students to research techniques in astronomy, laboratory and computational technologies, and to observational astronomy. Since many of the students are previously computer science or physics majors with little astronomy experience, this immersive experience has been extremely helpful for enabling students to learn about the terminologies, techniques and technologies of astronomy. The field trips to the Mount Wilson and Palomar telescopes deepen their knowledge and excitement about astronomy. Lectures about astronomical research from Caltech staff scientists and graduate students also provide context for the student research. Perhaps more importantly, the creation of a cohort of like-minded students, and the chance to reflect about careers in astronomy and research, give these students opportunities to consider themselves as future research scientists and help them immensely as they move forward in their careers. We discuss some of the social and intercultural aspects of the experience as well, as our cohorts typically include international students from many countries and several students from under-represented groups in science.

Author(s): Bryan Edward Penprase[2], Eric Christopher Bellm[1]
Institution(s): *1. California Institute of Technology, 2. Yale-NUS College*

314.03 – Harvard Observing Project (HOP): Involving Undergraduates in Research Projects

The Harvard Observing Project (HOP) is designed to get students excited about observational astronomy while collecting data valuable to the scientific community. The primary goal is to give undergraduates a chance to try out observing with "no strings attached". Observations are led by experienced observers, mostly graduate students. This not only gives graduate students extra opportunities to interact and teach undergraduates, but also a chance for them to get more observing experience. Each semester, we choose an interesting target and monitor it each week over the course of the semester using Harvard University's 16-inch DFM Clay Telescope. These observing projects often produce large amounts of data. This provides an excellent dataset for a young undergraduate to analyze. Some successful semester-long observing projects have included variable stars, supernova and binary systems. Short-term projects have included exoplanet candidate followup, asteroid and comet followup and collaborating with the Pro-Am White Dwarf Monitoring (PAWM) project in attempts to detect a transiting Earth-sized planet orbiting a white dwarf. Each dataset is an opportunity for an undergraduate to be introduced to scientific research and present the results to the community.

Author(s): Allyson Bieryla[1]
Institution(s): *1. Harvard Univ.*

314.04 – A Bridge to the Stars: A Model High School-to-College Pipeline to Improve Diversity in STEM

Increasing participation by historically underrepresented Americans in the STEM workforce remains a national priority. Existing strategies have failed to increase diversity especially in the physical sciences despite federal mandates. To meet this urgent challenge, it is imperative to immediately identify and support the expansion of effective high school-to-college STEM pipelines. A Bridge to the Stars (ABttS) is a creative and tested pipeline designed to steadily increase the numbers of disadvantaged 15-21 year-olds pursuing and completing 4-year STEM degrees. This unique program offers extended engagement in astronomy, arguably the most accessible window to science, through a 3-tier STEM immersion program of innovative learning (in a freshman science course), authentic research training (in a freshman science lab), and supportive near-peer mentoring at U.Missouri-Kansas City, an urban research university. Each tier of the ABttS pipeline by itself has the potential to broaden student aspirations for careers as technological innovators or STEM educators. Students who elect to transition through multiple tiers will substantially reinforce their successes with STEM activities, and significantly bolster their self-esteem necessary to personally manifest STEM aspirations. We will summarize the impact of this program after 5 years, and share our latest improvements. The long-term mission of ABttS is to see urban educational institutions across the U.S. adopt similar pipelines in all STEM disciplines built on the ABttS model.

Author(s): Daniel H. McIntosh[1], Derrick H Jennings[1]
Institution(s): *1. University of Missouri-Kansas City*

314.05 – Unpacking Exoplanet Detection Using Pedagogical Discipline Representations (PDRs)

Successful educators know the importance of using multiple representations to teach the content of their disciplines. We have all seen the moments of epiphany that can be inspired when engaging with just the right representation of a difficult concept. The formal study of the cognitive impact of different representations on learners is now an active area of education research.

The *affordances* of a particular representation are defined as the elements of disciplinary knowledge that students are able to access and reason about using that representation. Instructors with expert pedagogical content knowledge teach each topic using representations with complementary affordances, maximizing their students' opportunity to develop fluency with all aspects of the topic.

The work presented here examines how we have applied the theory of affordances to the development of *pedagogical discipline representation* (PDR) in an effort to provide access to, and help non-science-majors engage in expert-like reasoning about, general relativity as applied to detection of exoplanets.

We define a *pedagogical discipline representation* (PDR) as a representation that has been uniquely tailored for the purpose of teaching a specific topic within a discipline. PDRs can be simplified versions of expert representations or can be highly contextualized with features that purposefully help unpack specific reasoning or concepts, and engage learners' pre-existing mental models while promoting and enabling critical discourse.

Examples of PDRs used for instruction and assessment will be provided along with preliminary results documenting the effectiveness of their use in the classroom.

Author(s): Edward E. Prather[2], Timothy G. Chambers3, Colin Scott Wallace[1], Gina Brissenden[2]
Institution(s): *1. UNC Chapel Hill, 2. University of Arizona, 3. University of Michigan*

314.06 – Mobile Learning of Astronomy Through Apple's iTunes U

Students are using mobile devices such as smartphones and tablets increasingly for their education needs. For the past year and a half, a pilot project has been underway at Harrisburg Area Community College to teach a small number of classes using Apple's iTunes U app. As one of the six colleges and universities selected to pilot the iTunes U app before it was released in January of 2012, Harrisburg Area Community College has been significantly involved in mobile learning for a number of years. The author was able to offer an astronomy course with the initial release which now has nearly 70,000 subscribers around the world. Over the past few semesters, the course has been converted to be used with online credit courses at the college. Students can now complete the vast majority of their assignments on their iPad or iPhone. This allows the online student to not feel tied to their laptop or desktop computer as they can access and work on assignments wherever they might be. More of the course has been able to be moved to the iTunes U app each semester as updates are made to the app with the eventual goal to be able to have the entire course completed through a private course on the app. The flexibility of mobile learning allows for more students to be able to take the course without feeling tied down. Student response has been good. Many students like having the flexibility to be able to access course content on their phones at their convenience.

Author(s): Robert M. Wagner[1]
Institution(s): *1. Harrisburg Area Community College*

314.07 – Analysis of the NSF IUSE Physics & Astronomy Education Portfolio

The National Science Foundation's IUSE:EHR (Improving Undergraduate STEM Education) Program is now over 3 years old. This presentation will describe the characteristics of the awards presently in the physics & astronomy portfolio. Awards will be described based upon a) general characteristics (duration, total funding, PI rank, type of institution, etc.), b) applicability (intended audience, level, and arena of implementation), c) nature of project (educational research, practical implementation, or both), and d) pedagogical focus (curriculum, STEM recruitment, STEM retention, information collection, and tools and/or skills development). General trends and exemplars will be identified as well as voids in the portfolio. Understanding what has been funded will help attendees design future proposals that will make innovative contributions to the portfolio.

Author(s): Kevin M. Lee[1]
Institution(s): *1. National Science Foundation*

315 – Newton Lacy Pierce Prize: The Chemistry of Planet Formation, Karin Öberg (Harvard-Smithsonian, CfA)

315.01 – The Chemistry of Planet Formation

Exo-planets are common, and they span a large range of compositions. The origins of the observed diversity of planetary compositions is largely unconstrained, but must be linked to the planet formation physics and chemistry. Among planets that are Earth-like, a second question is how often such planets form hospitable to life. A fraction of exo-planets are observed to be 'physically habitable', i.e. of the right temperature and bulk composition to sustain a water-based prebiotic chemistry, but this does not automatically imply that they are rich in the building blocks of life, in organic molecules of different sizes and kinds, i.e. that they are chemically habitable. In this talk I will argue that characterizing the chemistry of protoplanetary disks, the formation sites of planets, is key to address both the origins of planetary bulk compositions and the likelihood of finding organic matter on planets. The most direct path to constrain the chemistry in disks is to directly observe it. In the age of ALMA it is for the first time possible to image the chemistry of planet formation, to determine locations of disk snowlines, and to map the distributions of different organic molecules. Recent ALMA highlights include constraints on CO snowline locations, the discovery of spectacular chemical ring systems, and first detections of more complex organic molecules. Observations can only provide chemical snapshots, however, and even ALMA is blind to the majority of the chemistry that shapes planet formation. To interpret observations and address the full chemical complexity in disks requires models, both toy models and astrochemical simulations. These models in turn must be informed by laboratory experiments, some of which will be shown in this talk. It is thus only when we combine observational, theoretical and experimental constraints that we can hope to characterize the chemistry of disks, and further, the chemical compositions of nascent planets.

Author(s): Karin I. Oberg[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

318 – Extrasolar Planets: Characterization & Theory V

318.01D – Observational constraints on planet formation and migration timescales

Short-period planets have the power to unlock many of the mysteries of planet formation and, fortunately, they are abundant. There is growing evidence that high-eccentricity migration channels are not responsible for all short-period planets; this notion is supported by the recent discovery of K2-33 b, a short-period, Neptune-sized exoplanet transiting a 5-10 Myr old star in the Upper Scorpius association. While *in situ* formation of K2-33 b can not be conclusively ruled out, the planet is parked just interior to the corotation radius, where theory predicts inwardly migrating planets are halted; this may be interpreted as tantalizing evidence of disk-driven migration. Occurrence rate studies of all clusters observed by *K2* will allow for robust conclusions about the predominant modes of planet migration. Moreover, K2-33 b is likely still contracting, and should eventually join the populous class of close-in sub-Neptunes. In addition to K2-33 b, the *Kepler/K2* mission has enabled the discovery of planets in the intermediate age Hyades and Praesepe clusters. Many of these close-in planets exhibit radii that are large given their semi-major axes and host star characteristics. It is possible that, even at ages of several hundred Myr, these planets have not finished contracting or are undergoing atmospheric mass loss. If this is the case, we are directly constraining the evolutionary timescales of short-period planets. Finally, the characteristic timescales of protoplanetary disk evolution (and thus giant planet formation) and debris disk evolution can be refined with new fundamental calibrators for pre-main sequence evolutionary models and modern catalogs of homogeneous stellar ages, respectively.

Author(s): Trevor J. David[1]
Institution(s): *1. California Institute of Technology*

318.02 – Forming Gaps in Debris Disks with Migrating Planets

The observed wide gaps of at least several AU in debris disks from ~10 Myr to Gyr old are suggestive of multiple planets. While two planets are likely needed for maintaining the inner and outer edges of such gaps, large gaps may require more than two if planets fully occupy the gap in dynamically packed configurations at the present day. But direct imaging surveys are not discovering enough high mass planets in these systems for giant planets to be the culprit. As an alternative to currently packed planets occupying gaps in debris disks, we investigate whether planetesimal driven planet migration could produce wide gaps with lower mass, fewer planets on relevant timescales with physically realistic planetesimal disks to be consistent with the observed properties of debris disk systems. We also assess what observational signatures we may expect in gaps cleared via migration versus more packed planetary systems. We discuss implications for the disk properties in which these mechanisms could operate within the broader evolutionary context linking planets, debris disks, and the protoplanetary disks from which they originated.

Author(s): Sarah J. Morrison[1], Kaitlin M. Kratter[1]
Institution(s): *1. Univ. of Arizona*

318.03D – Messages from the Reversing Layer: Clues to Planet Formation in Spectral Abundances

The abundances of elements in the protoplanetary disk evolve over time, but stellar abundances will reflect the initial chemical composition of the disk and this can provide constraints on the range of possible outcomes for planet interiors. Rocky planet habitability depends not just on the availability of liquid water, but also on volcansim and plate tectonics that can stabilize the climate on long timescales. The slow evolution of abundances in stellar photospheres, particularly abundance ratios between elements, makes them ideal laboratories to study primordial disk compositions.

In my thesis work, I developed a new spectroscopic analysis procedure that derives gravities consistent with asteroseismology to within 0.05 dex as well as abundances for 15 elements. Using this procedure, we analyzed and published a catalog of accurate stellar parameters and precise abundances for more than 1600 stars and used those to investigate questions of planet formation. The C/O and Mg/Si ratios in the solar neighborhood could affect rocky planet habitability. For lucky cases where planet atmosphereic abundances can be measured, the stellar host C/O and [O/H] ratios carry information about the formation site and migration of hot Jupiters. I will present results on both rocky planet compositions and hot Jupiter migration and discuss how they can help us identify potentially habitable systems and discriminate between different planet formation models.

Author(s): John Michael Brewer[1], Debra Fischer[1], Sarbani Basu[1]
Institution(s): *1. Yale University*

318.04 – The Formation of Close-in Exoplanets

Approximately half of Sun-like stars harbor exoplanets packed within a radius of 0.3 AU (85 day orbital period), but the formation of these planets and why they form in only ~50% of known systems are still not well understood. In order to gain physical insight into the origin of these close-in exoplanets, I describe a one-dimensional steady state model incorporating Shakura & Sunyaev alpha values extracted from recent numerical simulations of protoplanetary disk accretion processes. Due to the dominance of the Hall effect at small radii in these disks, the magnitude of alpha, and thus the steady-state gas surface density, depends on the orientation of large scale magnetic fields with respect to the disk's rotation axis. Solving for the metallicity as a function of radius, I find that for fields anti-aligned with the rotation axis, the inner regions of the model disk often falls within a region of parameter space not suitable for planetesimal formation, whereas in the aligned case, the inner disk regions are likely to produce planetesimals through some combination of streaming instability and gravitational collapse, though the degree to which this is true depends on the assumed parameters of our model. More robustly, the aligned field case always produces higher concentrations of solids at small radii compared to the anti-aligned case. In the in situ formation model, this bimodal distribution in solid enhancement leads directly to the observed dichotomy in close-in exoplanets, and thus, magnetic field geometry may very well be the key to explaining the bimodal distribution of exoplanet configurations.

Author(s): Jacob B. Simon[1]
Institution(s): *1. University of Colorado*

318.05 – Is Collisional Fragmentation a Barrier to the Formation of Short-Period Planets?

One of the great exoplanet surprises of recent years is the discovery of very short period (~1 day or less) rocky planets. Theory has so far been unable to conclusively determine whether such planets were formed in situ or had to form further out and reach their present orbits via migration. We examine a possible barrier to the formation of such small-period planets, collisional fragmentation during the giant impacts stage of planet formation. Differences in velocities of adjacent orbits increase with decreasing semimajor axis and, at some very small semimajor axes, may be large enough for collisions between protoplanets to be erosive and fragmentary, thus preventing the in situ formation of a planetary system at small semimajor axes. We examine this possibility with both analytic arguments and N-body simulations. For an initial system of rocky protoplanets, in situ formation of planetary systems is possible all the way down to the Roche radius.

Author(s): Joshua Wallace3, Scott D. Tremaine[2], John E. Chambers[1]
Institution(s): *1. Carnegie Inst. of Washington, 2. Institute for Advanced Study, 3. Princeton University*

318.07 – The World is Spinning: Constraining the Origin of Supermassive Gas Giant Planets at Wide Separations Using Planetary Spin

Planetary spin can inform our understanding of planet accretion histories, which determine final masses and atmospheric compositions, as well as the formation of moons and rings. At present, the physics behind how gas giant planets spin up is still very poorly understood. We know that when giant planets form, they accrete material and angular momentum via a circumplanetary disk, causing the planet to spin up. In order to prevent planet spins from reaching break-up velocity, some mechanism must regulate these spins. However, there is currently no well-formulated picture for how planet spins evolve. This is in part due to the fact that there are very few measurements of giant planet spin rates currently available. Outside the solar system, to date there has only been one published spin measurement of a directly imaged planet, beta Pic b. We use Keck/NIRSPEC to measure spin rates for a sample of bound and free-floating directly imaged planetary mass objects, providing a first look at the distribution of spin rates for these objects.

Author(s): Marta Bryan[1], Heather Knutson[1], Konstantin Batygin[1], Björn Benneke[1], Brendan Bowler[2]
Institution(s): *1. Caltech, 2. UT Austin*

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319 – AGN, QSO, Blazars: Hosts & Interactions

319.01 – Improving Calibration of the M_{BH}-σ_* Relation for AGN with the BRAVE Program

The M_{BH} - σ_* relation for AGN, which relates the mass of the central supermassive black hole (M_{BH}) to the bulge stellar velocity dispersion (σ_*) of the host galaxy, is a powerful tool for studying the evolution of structure across cosmic time. Accurate calibration of this relation is essential, and much effort has been put into improving M_{BH} determinations with this in mind. However calibration remains difficult because many nearby AGN with secure M_{BH} determinations are hosted by late-type galaxies, with significant kinematic substructure such as bars, disks and rings. Kinematic substructure is known to contaminate and bias σ_* determinations from long-slit and single aperture spectroscopy, ultimately limiting the utility of the M_{BH} - σ_* relation, and hampering efforts to investigate morphological dependencies. Integral-field spectroscopy (IFS) can be used to map the two dimensional kinematics, providing a method for measuring σ_* absent some of the biases inherent in other methods, and giving a more complete picture of the spatial variations in the dynamics. We present the first set of results from the **BRAVE** program, the long-term goal of which is to use IFS to more accurately determine σ_* for the calibrating sample of reverberation-mapped AGN. We present IFS kinematic maps for the sample of galaxies we have so far observed, which show clearly how spatial variation can impact σ_* determinations from long-slit spectroscopy. We present a new fit to the M_{BH} - σ_* relation for the sample of 16 reverberation-mapped AGN for which we currently have σ_* determinations from IFS, as well as a new determination of the virial scaling factor, *f*, for use with reverberation-mapping.

Author(s): Merida Batiste[2], Misty C. Bentz[2], Emily Manne-Nicholas[2], Sandra I. Raimundo3, Christopher A. Onken[1], Marianne Vestergaard3, Matthew A. Bershady4
Institution(s): *1. Australian National University, 2. Georgia State University, 3. Niels Bohr Institute, 4. University of Wisconsin*

319.02D – AGN multi-wavelength identification and host galaxy properties

I present results on AGN identification, selection biases, and host galaxy properties at z~2.3 and results on the relation between AGN accretion and star formation activity at z~0.8. In the MOSDEF survey, with a sample of X-ray, IR, and optically selected AGN at z~2.3, using rest-frame optical spectra obtained with the Keck/MOSFIRE instrument, I find clear selection biases in identifying AGN at these wavelengths. There is a strong bias against identifying AGN at any wavelength in low mass galaxies, and an additional bias against identifying IR AGN in the most massive galaxies. While AGN hosts span a wide range of SFR, IR AGN are mainly in less dusty galaxies with relatively higher SFR and optical AGN are in dusty galaxies with relatively lower SFR in our sample. X-ray AGN selection does not display a bias with host SFR. I also consider the relation between the growth of galaxies and their SMBHs using a large sample of X-ray AGN in the PRIMUS survey. I do not find a significant correlation between SFR and AGN instantaneous luminosity. However, I find a weak but significant correlation between the average luminosity of AGN and SFR, which likely reflects that AGN luminosities vary on shorter timescales than host galaxies SFR. My results indicate that AGN are also often hosted by quiescent galaxies, and within both the star-forming and quiescent galaxy populations the probability of hosting an AGN is a power-law distribution as a function of specific accretion rate. However, at a given stellar mass, I find that a star-forming galaxy is ~2–3 times more likely than a quiescent galaxy to host an AGN of a given specific accretion rate. The probability of a galaxy hosting an AGN is constant across the main sequence of star formation, while in quiescent galaxies increases with SFR.

Author(s): Mojegan Azadi[1], Alison L. Coil[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): The MOSDEF team, The PRIMUS team

319.03D – Investigating the host galaxies of luminous AGN in the local universe with integral field spectroscopy

This thesis investigates how galaxies and their super massive black holes coevolve. We use integral field spectroscopy to search for evidence of AGN feedback and triggering. We demonstrate that outflows are ubiquitous among luminous local type 2 AGN using observations from the AAT's SPIRAL instrument. Using multiple component Gaussian emission line decomposition we are able to disentangle the kinematic and ionisation properties of these winds. This allows us to argue that the outflows from these AGN are directly impacting the surrounding ISM within the galaxies.

We search for evidence of AGN triggering using data from The Close AGN Reference Survey (CARS). CARS aims to provide a detailed multi-wavelength view of 40 nearby ($0.01 < z < 0.06$) unobscured AGN to study the link between AGN and their host galaxies. The primary CARS observations come from the MUSE integral field unit on the VLT, and complementary multi-wavelength observations have been approved from SOFIA, Chandra, VLA, HST, and others. We compare the stellar kinematics of active galaxies from CARS to similar inactive galaxies. We then use kinemetry to estimate the degree of dynamical disturbance, to determine whether active nuclei are preferentially hosted in dynamically disturbed or merging systems.

Finally, we highlight the discovery of an AGN that has changed spectral type not once, but twice. So called 'changing look' AGN are an uncommon phenomenon, but twice changed AGN are much rarer. This AGN first transitioned from a narrow line AGN (type 2) to a broad line AGN (type 1) in the 1980s. It was recently observed as part of CARS. Examination of the MUSE data for this particular source showed that it no longer had the spectral features typical of a type 1 AGN. The continuum emission from the accretion disk was no longer visible and the broad lines were dramatically diminished. In this talk we describe the possible reasons for this change, supported by analysis of multi-epoch optical photometry and spectroscopy, alongside data obtained through director's discretionary time from Chandra, HST, and the VLA. We then conclude by discussing the implications of this discovery on our understanding of AGN timescales and the physics behind AGN spectral types.

Author(s): Rebecca McElroy[2], Scott Croom[2], Bernd Husemann[1]
Institution(s): *1. Max Planck Institute for Astronomy, 2. University of Sydney*
Contributing team(s): The Close AGN Reference Survey, The SAMI Galaxy Survey

319.04D – Characterizing the population of active galactic nuclei in dwarf galaxies

Clues to super-massive black hole (BH) formation and growth reside in the population and properties of BHs in local dwarf galaxies. The masses of BHs in these systems are our best observational constraint on the masses of the first BH "seeds" at high redshift. Moreover, present-day dwarf galaxies are unlikely to have undergone major mergers, making them a relatively pristine testbed for studying triggers of BH accretion. However, in order to find BHs in dwarf galaxies outside the Local Group, it is necessary to search for signatures of accretion, i.e., active galactic nuclei (AGN). Until recently, only a handful of dwarf galaxies were known to contain AGN. However, large surveys such as the SDSS have led to the production of samples of over a hundred dwarf galaxies with AGN signatures (see e.g., Reines et al. 2013). My dissertation work has involved in-depth, multi-wavelength follow-up of nearby ($z<0.055$) dwarf galaxies with optical spectroscopic AGN signatures in SDSS.

I analyzed high resolution spectra of dwarf galaxies with narrow-line AGN, which led to the discovery of a 50,000 M_{Sun} BH in the nucleus of RGG 118 - the smallest BH yet reported in a galaxy nucleus (Baldassare et al. 2015). I also used multi-epoch optical spectroscopy to study the nature of broad H-alpha emission in dwarf galaxies. A characteristic signature of dense gas orbiting around a BH, broad emission can also be produced by transient stellar processes. I showed that broad H-alpha in star-forming dwarf galaxies fades over a baseline of 5-10 years, and is likely produced by e.g., a Type II SN as opposed to an AGN. However, broad emission in dwarf galaxies with AGN/composite narrow lines is persistent and consistent across observations, suggesting an AGN origin (Baldassare et al. 2016). Finally, I analyzed X-ray and UV observations of dwarf galaxies with broad and narrow-line AGN signatures. All targets had nuclear X-ray detections at levels significantly higher than expected from X-ray binaries. With BH masses of ~10^5-10^6 M_{Sun}, inferred Eddington ratios range from 0.1-50%, akin to massive broad-line AGN at higher redshift (Baldassare et al. submitted). My dissertation work provides strong confirmation that these systems are *bona fide* AGN.

Author(s): Vivienne F Baldassare3, Amy E. Reines[1], Elena Gallo3, Jenny E. Greene[2]
Institution(s): *1. NOAO, 2. Princeton University, 3. University of Michigan*

319.05 – Galaxy Interactions and AGN-triggering to z~1: an unprecedented new view from the Hyper Suprime-Cam Survey

Collisions and interactions between galaxies are thought to be pivotal stages in their formation and evolution, causing the rapid production of new stars, and may also serve as a mechanism for fueling supermassive black holes (BH). Harnessing the exquisite spatial resolution (0.3—0.7 arcsec) afforded by the new 1400 deg^2 Hyper Suprime-Cam (HSC) Survey, we present our new constraints on the importance of major and minor mergers in growing BHs throughout the last ~7 Gyrs. Utilizing the first ~170 deg^2 of the HSC Survey, and mid-infrared observations in the WISE All-Sky survey, we have robustly selected active galactic nuclei (AGN), starburst, and mass-matched control galaxy samples, totaling ~120,000 spectroscopically confirmed systems at i<22 mag. We identify galaxy interactions using a novel machine-learning technique, and use these data to map the growth of BHs as a function of interaction-stage, redshift and AGN luminosity, ultimately providing the necessary large-number statistics required to investigate merger—AGN triggering in the context of galaxy evolution out to z~1.

Author(s): Andy D. Goulding[1], Jenny E. Greene[1], Rachel Bezanson[1], Johnny Greco[1], Sean Johnson[1], Elinor Medezinski[1], Michael A. Strauss[1]
Institution(s): *1. Princeton University*
Contributing team(s): The HSC Collaboration

319.06 – Serendipitous Discovery of a Radio Transient in the Luminous Radio Galaxy Cygnus A

Recent Jansky Very Large Array observations of the luminous radio galaxy Cygnus A have revealed the presence of a 3 mJy, flat-spectrum, unresolved radio source located 0.4" (450 pc) from the nucleus. This source was not present in observations made 25 years ago. The luminosity and SED of the transient are comparable to the most luminous supernovae in the universe, and to GRB afterglows, although the most likely interpretation is that the transient represents a luminous flare from the nucleus of a minor galaxy merging with the host of Cygnus A -- possibly in the form of a tidal disruption event. We present our observations and interpretation of this event using recent JVLA and VLBA observations, and discuss its implications for the Cygnus A system and for dusty, merging galaxies generally.

Author(s): Richard A. Perley[2], Daniel A. Perley[1], Chris Luke Carilli[2], Vivek Dhawan[2]
Institution(s): *1. Dark Cosmology Centre, 2. NRAO*

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320 – Extrasolar Planets Detection: Radial Velocity I

320.01 – Upgrades to MINERVA control software

The MINiature Exoplanet Radial Velocity Array (MINERVA) is an array of four robotic telescopes located on Mt. Hopkins in Arizona that will find and characterize rocky planets around our nearest stars. We discuss the latest upgrades to the MINERVA robotic control software. Previously, our robotic control software was only capable of taking radial velocities or photometry for the entire night, but not both. We have recently increased the speed and ease of transitioning between photometry and radial velocity (RV) observations. We can now arbitrarily assign a subset of the telescopes to either photometric or spectroscopic observations. This capability enables us to monitor stellar activity while measuring the star's RV, gather photometry on one star while continuing our RV survey of other targets and provide education and public outreach opportunities where others can observe with one or more telescopes while we continue using the remaining telescopes for research.
This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. 1144152.

Author(s): Maurice Wilson[1], Jason D Eastman[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

320.02 – Spectroscopic commissioning results from MINERVA

MINERVA is a robotic observatory with four 0.7 meter telescopes at Mt. Hopkins, Arizona, dedicated to precise photometry and radial velocity observations of bright, nearby stars for the discovery and characterization of small exoplanets. Here we present the first radial velocity results from MINERVA during commissioning at the Fred Lawrence Whipple Observatory in Arizona, demonstrating m/s precision over month-long timescales. These results show that MINERVA is capable of achieving its primary science goal of finding super-Earths around the nearest, brightest stars.

Author(s): Jason D Eastman[2], Samson Johnson5, Sharon Wang[1], David Sliski[8], Maurice Wilson[2], John A. Johnson[2], Nate McCrady[6], Robert A. Wittenmyer7, Jason Wright4, Peter Plavchan3, Cullen Blake[8], Thomas G. Beatty4
Institution(s): *1. Department of Terrestrial Magnetism Carnegie Institution of Washington, 2. Harvard-Smithsonian Center for Astrophysics, 3. Missouri State University, 4. Pennsylvania State University, 5. The Ohio State University, 6. University of Montana, 7. University of New South Wales, 8. University of Pennsylvania*

320.03D – The Promise of Many Worlds: Detection and Characterization of Exoplanets with Extreme Precision Spectroscopy

Two decades ago, technological advancement aligned with some of mankind's oldest and most compelling questions to give birth to exoplanet science. Since then, the study of exoplanets, more than any other field of astrophysics, has grown in direct consonance with new instrumentation. In this dissertation talk I will discuss the development of three precision spectrographs that are pushing the limits on current radial velocity (RV) precision: (a) PARAS, a workhorse optical instrument achieving ~1m/s over several months, (b) the Habitable Zone Planet Finder, an upcoming NIR instrument for the 10m Hobby Eberly Telescope, and (c) NEID, an extreme precision instrument that will be the centerpiece of the NASA-NSF Exoplanet Observational Research (NN-EXPLORE) partnership. The path to the extreme precisions required to detect Earth analogs (~10cm/s), requires severe technical artistry and demands unprecedented performance from both hardware and software. I will summarize the most challenging sources of measurement error and the hardware solutions we have innovated, including my work on the invention of an efficient ball lens double scrambler (patent pending) that essentially retires issues of illumination instability. As software architect of these instruments, I will also describe the pathways to extreme precision data analysis pipelines, rooted firmly in the heritage of current instruments in the field. Fortunately, the scientific return from these meticulously produced spectra will be manifold, extending beyond precision RVs. I will briefly discuss my work leveraging the stability and resolution of similar instruments for stellar activity diagnosis and the determination of insidious false positives, as well as for the direct detection of reflected light from exoplanets. These efforts together underline both the formidable demands and rich rewards of extreme precision spectroscopy, which remains our fundamental tool for the discovery of potentially habitable non-transiting worlds, and may be the best method for identifying targets for future flagship direct imaging missions like HabEx and LUVOIR.

Author(s): Arpita Roy[1]
Institution(s): *1. The Pennsylvania State University*

320.04 – Discovery of Two Jovian Planet Candidates Around AU Mic

We present a pair of candidate Jovian exoplanets discovered with the radial velocity (RV) technique in the near-infrared (NIR) orbiting the young M dwarf star AU Mic (a ~ 0.3 and 3.5 AU; M_p ~ 1.5 and 6 M_J). Data were obtained at 2.3 microns from 2010-2016 with the R=46,000 CSHELL spectrograph at the NASA Infrared Telescope Facility, and from 2005-2007 with the R=25,000 NIRSPEC spectrograph at the Keck Observatory. AU Mic possesses long-lived BY Draconis type polar starspots with a known rotation period of 4.865 days. No signal in the NIR RVs is identified that is consistent with the rotation period of the star, but stellar activity remains a possible explanation for the observed NIR RV variability. The outer Jovian planet candidate offers a plausible dynamical explanation for the observed debris disk dynamics of moving "clumps" on several year time-scales. It may be possible to directly image the outer planet candidate with the current generation of high contrast imaging instruments. If confirmed, this discovery would demonstrate the utility of RV precursor observations for informing direct imaging surveys and the utility of NIR RV searches for planets around young and/or active stars. These results also point to the promise of future NIR precise RVs, including iSHELL, SPIRou, HPF and CARMENES, which will operate at higher precision and with larger spectral grasp than

CSHELL.

Author(s): Peter Plavchan9, Peter Gao10, Jonathan Gagne1, Angelle M. Tanner8, Elise Furlan5, Carolyn Brinkworth12, Kaspar von Braun7, David R. Ciardi5, Stephen R. Kane11, Russel White3, John A. Johnson4, Ryan Hall9, Frank Giddens9, Perri Zilberman6, Joe Huber9, America Nishimoto9, Andrew Cancino9, Denise Weigand2, Christopher Klenke9
Institution(s): *1. Carnegie DTM, 2. Central Methodist U, 3. Georgia State University, 4. Harvard, 5. IPAC, Caltech, 6. JFK High School, 7. Lowell Observatory, 8. Mississippi State University, 9. Missouri State University, 10. NASA Ames, 11. San Francisco State University, 12. UCAR*

320.05 – Update from the ongoing precision radial velocity campaign to characterize the HD 3167 system

HD 3167 is a bright (V=8.9, K=7.0), nearby (46pc) K0-type star in K2 campaign 8, which was recently announced to host two transiting planets - a 1.7 REarth super-Earth on a 0.95-day orbit, and a 3.0 REarth mini-Neptune on a 29.8-day orbit. The super-Earth planet is very close to the putative divide between rocky and volatile-rich planets, and joins a relatively small number of super-Earth planets with accurate masses obtainable with current precision radial velocity measurements. Both targets are particularly compelling for HST and JWST characterization, given the brightness of the host star, however accurate masses will be needed in order to interpret the observations. Here we present the latest results from our multi-instrument (Keck/HIRES, TNG/HARPS-N, and Lick/APF) precision radial velocity campaign to measure the masses of the planets in the HD 3167 system.

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Contributing team(s): team members from the CHAI collaboration, Harvard-Smithsonian Center for Astrophysics, Carnegie Institute of Washington, and University of California Santa Cruz

320.06D – Hide and Seek: Radial-velocity searches for planets around active stars

The ultimate obstacle to determining the masses of small, rocky exoplanets through radial-velocity (RV) monitoring is the intrinsic variability of the host stars themselves. For my PhD, I developed an intuitive and robust data analysis framework in which the activity-induced variations are modelled with a Gaussian process that has the frequency structure of the stellar magnetic activity. This allowed me to determine precise and accurate masses of the planets in the CoRoT-7, Kepler-78 and Kepler-10 systems.
In parallel, I explored the physical origin of activity-induced RV variations of our best-known star: the Sun. I conducted the first systematic RV campaign of the Sun seen as an exoplanet host star using the 3.6m/HARPS spectrograph, by observing sunlight reflected off the bright asteroid 4/Vesta. I used images from the Solar Dynamics Observatory to reconstruct the RV signals incurred by individual surface features such as sunspots, faculae and granulation. I found that the activity-induced RV variations are driven by the suppression of convective blueshift arising dominantly from the presence of faculae. I also identified the full-disc magnetic flux as an excellent proxy for activity-induced RV variations.
I am now pursuing my solar investigations using Sun-as-a-star RV observations acquired with the new solar telescope feed at HARPS-N. In particular, I am investigating the impact of magnetic surface features on the shapes of the spectral line profiles, rather than on the RVs themselves (which are a single moment of these lines). This work is key to developing physically-driven, better-tailored models for activity-induced RV variations, in preparation for the potentially habitable, Earth-like planets to be discovered and characterised in the coming years with TESS and GMT/G-CLEF.
This work was funded by the Science and Technology Facilities Council in the United Kingdom and the John Templeton Foundation.

Author(s): Raphaelle Haywood1
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320.07 – The Anglo-Australian Planet Search Legacy

Radial velocity searches for exoplanets have undergone a revolution in recent years: now precisions of 1 m/s or better are being demonstrated by many instruments, and new purpose-built spectrographs hold the promise of bringing Earth-mass planets into the realm of secure detectability. In the "race to the bottom," it is critical not to overlook the impact of long-running planet search programs that continue to hold the advantage of time. We highlight the continuing impact of the 18-year Anglo-Australian Planet Search: the characterisation of long-period giant planets, and the insights into the occurrence rate of Jupiter and Saturn analogs. To fully understand the origins of planetary systems and the fundamental question of how common (or rare) the architecture of the Solar system is in the Galaxy, we must continue these "legacy" surveys to probe ever-larger orbital separations.

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321 – Galaxy Formation & Evolution

321.01 – Quantifying the Effects of Gas-Rich Flyby Encounters on Galaxy Evolution

Recent work has shown that flyby encounters may be a common event in a galaxy's lifetime. Galaxy flybys are a one-time encounter when two halos interpenetrate, but unlike a galaxy merger, the two halos later detach. Relatively little work has been done to assess how flybys affect galaxy evolution. We present preliminary results of a suite of high-resolution hydrodynamical + N-body simulations of gas-rich flyby encounters, concentrating on Milky Way-like primaries. We track the bulk changes in structure, star formation history, kinematics, and morphology over a broad span of flyby encounters.

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321.02D – Evolving Galaxies in a Hierachical Universe

Observations of galaxies using large surveys (SDSS, COSMOS, PRIMUS, etc.) have firmly established a global view of galaxy properties out to z~1. Galaxies are broadly divided into two classes: blue, typically disk-like star forming galaxies and red, typically elliptical quiescent ones with little star formation. The star formation rates (SFR) and stellar masses of star forming galaxies form an empirical relationship referred to as the "star formation main sequence". Over cosmic time, this sequence undergoes significant decline in SFR and causes the overall cosmic star formation decline. Simultaneously, physical processes cause significant fractions of star forming galaxies to "quench" their star formation. Hierarchical structure formation and cosmological models provide precise predictions of the evolution of the underying dark matter, which serve as the foundation for these detailed trends and their evolution. Whatever trends we observe in galaxy properties can be interpreted within the narrative of the underlying dark matter and halo occupation framework. More importantly, through careful statistical treatment and precise measurements, this connection can be utilized to better constrain and understand key elements of galaxy evolution. In this spirit, for my dissertation I connect observations of evolving galaxy properties to the framework of the hierarchical Universe and use it to better understand physical processes responsible for the cessation of star formation in galaxies. For instance, through this approach, I constrain the quenching timescale of central galaxies and find that they are significantly longer than the quenching timescale of satellite galaxies.

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321.03 – The Spatial Distribution and Kinematics of the Circumgalactic Medium

We have examined the spatial distribution and kinematics of the circumgalactic medium (CGM) within 200 kpc of galaxies in the redshift range 0.1 to 1.0. The galaxies are resolved in HST images and are selected to have background quasars with sightlines that probe their CGM. We measured the cool/warm CGM in MgII absorption and the warm/hot CGM in OVI absorption using Keck/HIRES, VLT/UVES, and HST/COS. We have found that the CGM gas is highly organized such that: (1) gas is concentrated along the galaxy polar axes with high velocity dispersion, and (2) gas is concentrated along the galaxy major axes with smaller velocity dispersion. We constrain the geometry of the gas to reside between 20-40 degrees of the projected major axis and within 60 degrees of the projected minor axis, with little-to-no gas found in between. Furthermore, strongest absorption and largest velocity spreads are found for highly inclined (face on) galaxies with the bluest colors, suggesting outflows along the minor axes of star-forming galaxies. The major axis of bluer galaxies have similar velocity spreads to those of the gas surrouncding redder galaxies, which show little spatial preference in the distribution of the gas dynamics. Our results are consistent with the current view of the CGM originating from major axis (co-planer) inflows/recycled gas and from minor axis wind-driven outflows. We address how our results place strong contraints on the baryon cycle.

Author(s): Christopher W. Churchill[1], Nikole M. Nielsen3, Glenn Kacprzak3, Jane C. Charlton[2], Sowgat Muzahid[2]
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321.04D – First Detection of a Cluster-scale Gradient in the ISM metallicity of the Star-forming Galaxies

Understanding the effect of cluster environment on galaxy formation and evolution is a central topic in extragalactic astronomy. The interstellar medium (ISM) metallicity provides a powerful constraint on the complex interplay of star formation and the galactic inflow/outflow. Disentangling the effect of internal (stellar mass) and external (environment) processes on galaxy evolution is difficult because high mass galaxies tend to exist in dense environments. For the past decade, the difference between mass-metallicity relations in the cluster and field environment have been used to disentangle the effect of internal/external processes. Current observations of the mass-metallicity relation show minimal dependence on the large-scale environment. In this talk, I will present the radial distribution of ISM metallicity in galaxy clusters as an alternative method to study the impact of environment on galaxy evolution. I will present the first observation of cluster-scale negative abundance gradients in two CLASH clusters at z~0.35: MACS1115+0129 and RXJ1532+3021. Our observation presents the highest metallicity enhancement observed in a galaxy cluster on the mass-metallicity relation to date. Most strikingly, we discover that neither the radial metallicity gradient nor the offset on the mass-metallicity relation show any obvious dependence on the stellar mass of cluster members. I will discuss the different physical processes in the cluster environment such as disk truncation due to ram-pressure stripping and self-enrichment due to strangulation that can lead to the observed cluster-scale negative abundance gradient in ISM metallicity.

In our follow-up work, we have performed simulations of the disk-truncation in cluster environment using a sample of CALIFA galaxies. Our analytical model of disk-truncation is based on the ram-pressure stripping of the cold gas component of the infalling galaxy in the cluster environment. I will present the simulated radial metallicity gradient in the cluster, purely due to the truncation of the outer-galactic disk as the galaxy moves closer to the cluster center.

Author(s): Anshu Gupta[1], Tiantian Yuan[1], Kim-Vy Tran[2], davide martizzi3, Philip Taylor[1], Lisa J. Kewley[1]
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321.05D – Observations and Models of Galaxy Assembly Bias

The assembly history of dark matter haloes imparts various correlations between a halo's physical properties and its large scale environment, i.e. assembly bias. It is common for models of the galaxy-halo connection to assume that galaxy properties are only a function of halo mass, implicitly ignoring how assembly bias may affect galaxies. Recently, programs to model and constrain the degree to which galaxy properties are influenced by assembly bias have been undertaken; however, the extent and character of galaxy assembly bias remains a mystery. Nevertheless, characterizing and modeling galaxy assembly bias is an important step in understanding galaxy evolution and limiting any systematic effects assembly bias may pose in cosmological measurements using galaxy surveys.

I will present work on modeling and constraining the effect of assembly bias in two galaxy properties: stellar mass and star-formation rate. Conditional abundance matching allows for these galaxy properties to be tied to halo formation history to a variable degree, making studies of the relative strength of assembly bias possible. Galaxy-galaxy clustering and galactic conformity, the degree to which galaxy color is correlated between neighbors, are sensitive observational measures of galaxy assembly bias. I will show how these measurements can be used to constrain galaxy assembly bias and the peril of ignoring it.

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322 – Beyond the Academy: Panel Discussion on Entering Non-Academic Careers

More of our astronomy colleagues are choosing meaningful careers in industry, and yet very little information trickles back into academia about what those careers are like, what skills transferred from astronomy training, or even how to make the career transition. The lack of solid information and mentoring can make any career path beyond the academy seem daunting. We propose to fill this information gap in a continuation of the Employment Committee's professional development workshops and seminars at the annual winter meeting of the American Astronomical Society (AAS). In partnership with the American Institute of Physics (AIP), the 2017 meeting will feature a panel discussion on careers beyond academia. Invited speakers from the professional, entrepreneurial, and government sectors will be joined by recruiters and other astronomers from a wide spectrum of fields for an engaging panel discussion on how to start a career outside academia. Topics will cover advice on: marketing your existing skills for a position outside academia, what highly-sought skills will increase your competitiveness, how the job-hunting process works, what to expect in the interview process, and what the initial transition is really like. We will have the panel introduce themselves for 30 minutes, followed by questions from the audience for 30 minutes. The final 30 minutes will allow the audience to network with individual panelists in small groups.

323 – Cosmic Microwave Background

323.01 – The Atacama Cosmology Telescope: Two-season spectrum and parameters

We present the temperature and polarization angular power spectra measured by the Atacama Cosmology Telescope polarimeter (ACTPol) over 548 deg^2 of sky on the celestial Equator, from nighttime data collected during 2013–14 using two kilo-detector arrays at 146 GHz. We use these spectra, and the spectra measured with the MBAC camera on ACT from 2008–10, in combination with Planck and WMAP satellite data to estimate cosmological parameters from the temperature, polarization, and temperature-polarization cross-correlations. We find the new ACTPol data to be consistent with the ΛCDM model. The ACTPol temperature-polarization cross-spectrum now provides stronger constraints on multiple parameters than the ACTPol temperature power spectrum, including the baryon density and the acoustic peak position angle, and the derived Hubble constant. Adding the new data to Planck temperature data tightens the limits on damping tail parameters, which we present here.

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Contributing team(s): Atacama Cosmology Telescope

323.02D – Multifrequency Beam Characterization and Systematics for the Keck Array, BICEP3, and Future CMB Polarization Experiments

The BICEP/Keck Array cosmic microwave background (CMB) polarization experiments located at the South Pole are a series of small-aperture refracting telescopes focused on the degree-scale B-mode signature of inflationary gravitational waves. These highly-targeted experiments have produced the world's deepest maps of CMB polarization, leading to the most stringent constraints on the tensor-to-scalar ratio to date: sigma(r) = 0.024 and r < 0.09 from B-modes alone, and r < 0.07 in combination with other datasets. These constraints will rapidly improve with upcoming measurements at the multiple frequencies needed to separate Galactic foregrounds from the CMB, and in combination with higher-resolution experiments to remove B-modes induced by gravitational lensing. The primary instrumental systematic for pair differencing CMB experiments is temperature-to-polarization leakage from mismatched co-located orthogonally polarized beams. We present extensive far field beam measurements taken in situ at the South Pole, and demonstrate how the resulting high-fidelity beam maps for each detector are used in dedicated simulations to predict the expected leakage in the final CMB maps, focusing on the 95, 150, and 220 GHz beams present in the BK15 dataset. We discuss prospects for dealing with temperature-to-polarization leakage in next-generation CMB experiments with hundreds of thousands of detectors, and how the beams systematics levels we achieve with current instrument and analysis technology will scale with detector count.

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Contributing team(s): BICEP/Keck Array Collaboration

323.03D – The Cosmology Large Angular Scale Surveyor

The Cosmology Large Angular Scale Surveryor (CLASS) is a ground based telescope array designed to measure the large-angular scale polarization signal of the Cosmic Microwave Background (CMB). The large-angular scale CMB polarization measurement is essential for a precise determination of the optical depth to reionization (from the E-mode polarization) and a characterization of inflation from the predicted polarization pattern imprinted on the CMB by gravitational waves in the early universe (from the B-mode polarization). CLASS will characterize the primordial tensor-to-scalar ratio, r, to 0.01 (95% CL).

CLASS is uniquely designed to be sensitive to the primordial B-mode signal across the entire range of angular scales where it could possibly dominate over the lensing signal that converts E-modes to B-modes while also making multi-frequency observations both high and low of the frequency where the CMB-to-foreground signal ratio is at its maximum. The design enables CLASS to make a definitive cosmic-variance-limited measurement of the optical depth to scattering from reionization.

CLASS is an array of 4 telescopes operating at approximately 40, 90, 150, and 220 GHz. CLASS is located high in the Andes mountains in the Atacama Desert of northern Chile. The location of the CLASS site at high altitude near the equator minimizes atmospheric emission while allowing for daily mapping of ~70% of the sky.

A rapid front end Variable-delay Polarization Modulator (VPM) and low noise Transition Edge Sensor (TES) detectors allow for a high sensitivity and low systematic error mapping of the CMB polarization at large angular scales. The VPM, detectors and their coupling structures were all uniquely designed and built for CLASS.

We present here an overview of the CLASS scientific strategy, instrument design, and current progress. Particular attention is given to the development and status of the Q-band receiver currently surveying the sky from the Atacama Desert and the development of 90 GHz focal planes and associated detector technologies.

Author(s): Aamir Ali[2], John W Appel[2], Charles L. Bennett[2], Fletcher Boone[8], Michael Brewer[2], Manwei Chan[2], David T. Chuss[9], Felipe Colazo[3], Sumit Dahal[2], Kevin Denis[3], Rolando Dünner[5], Joseph Eimer[2], Thomas Essinger-Hileman[2], Pedro Fluxa[5], Mark Halpern[7], Gene Hilton[4], Gary F. Hinshaw[7], Johannes Hubmayr[4], Jeffrey Iuliano[2], John Karakla[2], Tobias Marriage[2], Jeff McMahon[8], Nathan Miller[3], Samuel H Moseley[3], Gonzalo Palma[6], Lucas Parker[2], Matthew Petroff[2], Bastián Pradenas[6], Karwan Rostem[3], Marco Sagliocca[9], Deniz Valle[2], Duncan Watts[2], Edward Wollack[3], Zhilei Xu[2], Lingzhen Zeng[1]
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323.04 – Testing the ultra-light axion hypothesis with CMB-SIV

Measurements of cosmic microwave background (CMB) anisotropies provide strong evidence for the existence of dark matter and dark energy. They can also test its composition, probing the energy density and particle mass of different dark-matter and dark-energy components. CMB data have already shown that ultra-light axions (ULAs) with mass in the range 10−32 eV→10−26 eV compose a fraction <0.01 of the cosmological critical density. Here, the sensitivity of a proposed CMB-Stage IV (CMB-S4) experiment (assuming a 1 arcmin beam and <1 μK−arcmin noise levels over a sky fraction of 0.4) to the density of ULAs and other dark-sector components is assessed. CMB-S4 data should be ~10 times more sensitive to the ULA energy-density than Planck data alone, across a wide range of ULA masses 10−32<ma<10−23 eV, and will probe axion decay constants of fa≈1016 GeV, at the grand unified scale. CMB-S4 could improve the CMB lower bound on the ULA mass from ~10−25 eV to 10−23 eV, nearing the mass range probed by dwarf galaxy abundances and dark-matter halo density profiles. These improvements will allow for a multi-σ detection of percent-level departures from CDM over a wide range of masses. Much of this improvement is driven by the effects of weak gravitational lensing on the CMB, which breaks degeneracies between ULAs and neutrinos. We also find that the addition of ULA parameters does not significantly degrade the sensitivity of the CMB to neutrino masses. These results were obtained using the axionCAMB code (a modification to the CAMB Boltzmann code), presented here for public use.

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323.05 – Cosmic Microwave Background Small-Scale Structure: I. Observations of the Foreground Emission

The derivation of the small-scale structure in the cosmic microwave background (CMB) relies on an accurate subtraction of foreground signals from the Milky Way Galaxy. Known sources include thermal emission from interstellar cirrus, galactic synchrotron emission resulting from interactions between cosmic ray electrons and magnetic fields, and electron-ion free-free emission from interstellar H II regions. Additional sources include spinning and spinning-wobbling dust grains, and emission from rotational transitions of carbon monoxide. Verschuur (2015 and references therein) showed many examples of connections, associations, and overlaps of galactic HI and CMB structure. Clark et al. (2014) showed that the long, thin filamentary features seen in the high sensitivity, high dynamic range Galactic Arecibo L-Band Feed Array (GALFA) HI survey appear to be aligned along magnetic field directions, which are inferred from the optical polarization of star light. Clark et al. (2015) took this important discovery a step further, relating those magnetic field orientations to the polarized PLANCK 353 GHz dust emission. These results imply that the neutral hydrogen in the interstellar medium is tightly coupled to the galactic magnetic field, which requires a population of electrons. Taken together, these HI results suggest a candidate for a previously unidentified foreground component that may need to be understood in order to improve our ability to measure and interpret the CMB small-scale structure. This work is supported by NASA and NSF.

Author(s): Joan T. Schmelz[1], Gerrit L. Verschuur[1]
Institution(s): *1. Arecibo Observatory*

323.06 – Cosmic Microwave Background Small-Scale Structure: II. Model of the Foreground Emission

We have investigated the possibility that a population of galactic electrons may contribute to the small-scale structure in the cosmic microwave background (CMB) found by WMAP and PLANCK. Model calculations of free-free emission from these electrons which include beam dilution produce a nearly flat spectrum. Data at nine frequencies from 22 to 100 GHz were fit with the model, which resulted in excellent values of reduced chi squared. The model involves three unknowns: electron excitation temperature, angular extent of the sources of emission, and emission measure. The resulting temperatures agree with the observed temperatures of related HI features. The derived angular extent of the continuum sources corresponds well with the observed angular extent of HI filamentary structures in the areas under consideration. The derived emission measures can be used to determine the fractional ionization along the path lengths through the emitting volumes of space. Understanding the role that free-free emission plays in the small-scale features observed by PLANCK and WMAP should allow us to create better masks of the galactic foreground. Pursuing such discoveries may yet transform our understanding of the origins of the universe.

Author(s): Gerrit L. Verschuur[1], Joan T. Schmelz[1]
Institution(s): *1. Arecibo Observatory*

324 – Surveys & Data - Radio and High Energy

324.01 – MALATANG: MApping the dense moLecular gAs in the sTrongest stAr-formiNg Galaxies

The MALATANG Large Program is a 390 hr campaign, using the heterodyne array HARP on the JCMT to map the HCN and HCO+ J = 4 – 3 line emission in 23 of the nearest IR-brightest galaxies beyond the Local Group. The observations will reach a sensitivity of 0.3 K km/s (~ 4.5 x 10^6 Msun) at linear resolutions of 0.2–2.8kpc. It is the first survey to systematically map the distribution of dense molecular gas out to large galactocentric distances in a statistically significant sample of nearby galaxies. MALATANG will bridge the gap, in terms of physical scale and luminosity, between extragalactic (i.e., galaxy-integrated) and Galactic (i.e., single molecular clouds) observations. A primary goal of the survey is to delineate for the first time the distributed dense gas star-formation relations, as traced by the HCN and HCO+ J = 4–3, on scales of ~1kpc across our targets. Exploring the behaviour of these star-formation relations in low surface density regions found in the disks as well as in the nuclear regions where surface densities are high, will shed new light on whether such environments are host to fundamentally different star-formation modes. The MALATANG data products of resolved HCN and HCO+ J = 4–3 maps of 23 IR-bright local galaxies, will be of great value to the extragalactic community and, in and of themselves, carry significant legacy value. At the moment, about 50% (~195hrs) of the 390hrs of time allocated to MALATANG has been observed. We here show some very preliminary results as well after introducing our project.

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Contributing team(s): Zhiyu Zhang, Thomas Greve, and MALATANG team

324.02 – First imaging results from Apertif, a phased-array feed for WSRT

Apertif is a phased-array feed for the Westerbork Synthesis Radio Telescope (WSRT), increasing the field of view of the telescope by a factor of twenty-five. In 2017, three legacy surveys will commence: a shallow imaging survey, a medium-deep imaging survey, and a pulsars and fast transients survey. The medium-deep imaging survey will include coverage of the northern Herschel Atlas field, the CVn region, HetDex, and the Perseus-Pisces supercluster. The shallow imaging survey increases overlap with HetDex, has expanded coverage of the Perseus-Pisces supercluster, and includes part of the Zone of Avoidance. Both imaging surveys are coordinating with MaNGA and will have WEAVE follow-up. The imaging surveys will be done in full polarization over the frequency range 1130-1430 MHz, which corresponds to redshifts of z=0-0.256 for neutral hydrogen (HI). The spectral resolution is 12.2 kHz, or an HI velocity resolution of 2.6 km/s at z=0 and 3.2 km/s at z=0.256. The full resolution images will have a beam size of 15"x15"/sin(declination), and tapered data products (i.e., 30" resolution images) will also be available. The shallow survey will cover ~3500 square degrees with a four-sigma HI imaging sensitivity of 2.5x10^20 atoms cm^-2 (20 km/s linewidth) at the highest resolution and a continuum sensitivity of 15 uJy/beam (11 uJy/beam for polarization data). The current plan calls for the medium deep survey to cover 450 square degrees and provide an HI imaging sensitivity of 1.0x10^20 atoms cm^-2 at the highest resolution and a continuum sensitivity of 6 uJy/beam, close to the confusion limit (4 uJy/beam for polarization data, not confusion limited). Up-to-date information on Apertif and the planned surveys can be found at: http://www.apertif.nl.

Commissioning of the Apertif instrument is currently underway. Here we present first results from the image commissioning, including the detection of HI absorption plus continuum and HI imaging. These results highlight the data quality that will be achieved for the surveys.

Author(s): Elizabeth A. Adams[1], Björn Adebahr[1], Willem J.G. de Blok[1], Kelley M Hess3, Boudewijn Hut[1], Danielle M. Lucero3, Filippo Maccagni3, Raffaella Morganti[1], Tom Oosterloo[1], Lister Staveley-Smith[2], Thijs van der Hulst3, Marc Verheijen3, Joris Verstappen3
Institution(s): *1. ASTRON, 2. ICRAR, 3. Kapteyn Astronomical Institute*

324.03 – The VLA Sky Survey - science goals and some early results from the pilot survey

In this talk I shall outline the science possible with the VLA Sky Survey (VLASS). The VLASS will survey the entire sky north of declination -40 deg in three epochs at 3GHz with full polarization information at 3-arcsec resolution, reaching a depth of 70muJy when the three epochs are combined. Key science for this survey includes the detection of radio transients and polarimetric observations across the 2-4GHz band covered by the observations. A pilot survey was conducted during the summer of 2016 to test the data acquisition and reduction strategy. The pilot survey fields were selected to be in regions of the sky well studied at other wavelengths, and I will present some early science results from the pilot, including the results of matching the pilot survey catalogs to overlapping infrared/optical surveys.

Author(s): Mark Lacy[1], Claire J. Chandler[1], Amy E. Kimball[1], Steven T. Myers[1], Frank Schinzel[1]
Institution(s): *1. NRAO*
Contributing team(s): VLASS Survey Science Group

324.04 – The VLA Sky Survey (VLASS): Technical Implementation and Pilot Survey Results

The VLA Sky Survey (VLASS) is a 5520 hour project to survey the 33885 square degrees of the sky above Declination -40 degrees from 2-4 GHz at 2.5" angular resolution using the upgraded Karl G. Jansky Very Large Array (VLA). Over the survey duration of 7 years, each area of the sky will be covered in 3 epochs spaced 32 months apart, to a depth of 0.12mJy/beam rms noise per epoch and 0.07mJy/beam for 3 epochs combined. Pilot observations were taken in mid-2016, with the full survey to start in September 2017. The raw data will be available in the NRAO archive immediately with no proprietary period and science data products will be provided to the community in a timely manner.

Basic Data Products (BDP) that will be produced by the survey team include: raw and calibrated visibility data, quick-look continuum images, single-epoch images and spectral image cubes, single-epoch basic object catalogs, and cumulative "static sky" images and image cubes and basic object catalogs to the full survey depth. Single-epoch and cumulative images are in intensity and linear polarization (Stokes IQU). In addition to the BDP provided by NRAO and served through the NRAO archive, there are opportunities for Enhanced Data Products and Services that are provided by the community in partnership with the VLASS team.

In this presentation we describe the survey design and the Technical Implementation Plan (TIP) for the VLASS, and report on results from the VLASS Pilot observations. The pilot survey covered 2480 unique square degrees, with 2160 square degrees within the SDSS/FIRST footprint. The pilot also covered key deep fields including COSMOS, GOODS-N, CDFS, Elais-N1, and the SDSS Stripe-82. Preliminary imaging and comparisons have been carried out for selected pilot fields as part of early science verification. We also discuss the technical issues and challenges remaining to be addressed before commencing the survey and our plans moving forward. There are also opportunities for community involvement in VLASS technical areas, including the involvement of undergraduate and graduate students in science verification and commissioning activities.

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Contributing team(s): for the VLA Sky Survey Team, and the Survey Science Group

324.05 – An Enhanced Multiwavelength Photometric Catalog for the Spitzer Extragalactic Representative Volume Survey

Although our knowledge of the physics of galaxy evolution has made great strides over the past few decades, we still lack a complete understanding of the formation and growth of galaxies at high redshift. The Spitzer Extragalactic Representative Volume Survey (SERVS) aims to address this issue through deep Spitzer observations at [3.6] and [4.5] microns of 4 million sources distributed over five well-studied "deep fields" with abundant ancillary data from ground-based near-infrared surveys. The large SERVS footprint covers 18 square degrees and will provide a census of the multiwavelength properties of massive galaxies in the redshift range z = 1-6. A critical aspect of the scientific success and legacy value of SERVS is the construction of a robust source catalog. While multiwavelength source catalogs of the SERVS fields have been generated using traditional techniques, the photometric accuracy of these catalogs is limited by their inability to correctly measure fluxes of individual sources that are blended and/or inherently faint in the IRAC bands. To improve upon this shortfall and maximize the scientific impact of SERVS, we are using The Tractor image modeling code to produce a more accurate and complete multiwavelength source catalog. The Tractor optimizes a likelihood for the source properties given an image cut-out, light profile model, and the PSF information. Thus, The Tractor uses the source properties at the fiducial, highest-resolution band as a prior to more accurately measure the source properties in the lower-resolution images at longer wavelengths. We provide an overview of our parallelized implementation of The Tractor, discuss the subsequent improvements to the SERVS photometry, and suggest future applications.

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Institution(s): *1. NRAO*

324.06 – The SAGE-Spec Spitzer Legacy program: Identification of Spitzer-IRS staring mode targets in the Large Magellanic Cloud

The Infrared Spectrograph (IRS) on the Spitzer Space Telescope observed over 1000 point sources in the Large Magellanic Cloud (LMC). As a follow up to the SAGE-Spec legacy program (Kemper et al. 2010), we have now extended the initial classification of 197 sources in the LMC (Woods et al. 2011) to all 1000 Spitzer-IRS staring mode targets in the SAGE footprint. We classify these point sources into evolutionary and chemical types according to their infrared spectral features, continuum and spectral energy distribution shape, bolometric luminosity, cluster membership, and variability information. This spectral classification will allow us improve our understanding of the stellar populations in the LMC, study the composition, and characteristics of dust species in a variety of LMC objects, and to verify the photometric classification methods used by mid-IR surveys. Finally we discuss the application of mid-IR spectral and photometric classifications to data that will be obtained from the MIRI instrument on JWST.

Author(s): Olivia Jones[1]
Institution(s): *1. STScI*
Contributing team(s): Sage-Spec team

325 – The Sun

325.01 – Why Theory Fails to Reproduce the Observed Variation of Acoustic Cutoff in the Solar Atmosphere?

Recent observational results by Wisniewska et al. (2016) suggest that the acoustic cutoff frequency varies with height within the solar atmosphere, and that the existing theoretical formulas for the cutoff cannot account for the observed variations. Specifically, five formulas for acoustic cutoffs commonly used in helioseismology and asteroseismology failed to reproduce the observations. We present results of both numerical and analytical studies, and discuss improvements that may be applied to the theory in order to fully reproduce the observational results. In addition, we use observational and theoretical results to seismically probe the physical parameters of the background solar atmosphere.

Author(s): Zdzislaw E. Musielak[2], Krzysztof Murawski[1]
Institution(s): *1. Uni. Maria Curie-Sklodowska, 2. Univ. of Texas, Arlington*

325.02 – The solar corona through the sunspot cycle: preparing for the August 21, 2017, total solar eclipse

We discuss the evolution of the solar corona as seen at eclipses through the solar-activity cycle. In particular, we discuss the variations of the overall shape of the corona through the relative proportions of coronal streamers at equatorial and other latitudes vs. polar plumes. We analyze the two coronal mass ejections that we observed from Gabon at the 2013 total solar eclipse and how they apparently arose from polar crown filaments, one at each pole. We describe the change in the Ludendorff flattening index from

solar maximum in one hemisphere as of the 2013 eclipse through the 2015 totality's corona we observed from Svalbard and, with diminishing sunspot and other magnetic activity in each hemisphere, through the 2016 corona we observed from Ternate, Indonesia.
We discuss our observational plans for the August 21, 2017, total solar eclipse from our main site in Salem, Oregon, and subsidiary sites in Madras, OR; Carbondale, IL; and elsewhere, our main site chosen largely by its favorable rating in cloudiness statistics. We discuss the overlapping role of simultaneous spacecraft observations, including those expected not only from NASA's SDO, ESA's SWAP on PROBA2, and NRL/NASA/ESA's LASCO on SOHO but also from the new SUVI (Solar Ultraviolet Imager) aboard NOAA's GOES-R satellite, scheduled as of this writing to have been launched by the time of this January 2017 meeting.
Our research on the 2013 and 2015 total solar eclipses was supported by grants from the Committee for Research and Exploration of the National Geographic Society (NG-CRE). Our research on the 2017 total solar eclipse is supported by both NG-CRE and the Solar Terrestrial Program of the Atmospheric and Geospace Sciences Division of the National Science Foundation.

Author(s): Jay M. Pasachoff3, Daniel Seaton[2], Vojtech Rusin[1]
Institution(s): *1. Astronomical Inst., Slovak Academy of Sciences, 2. CIRES, U. Colorado, 3. Williams College*

325.03 – A Hierarchical Relationship between CME Properties and the Fluence Spectral Index of Large Solar Energetic Particle Events

We report on a hierarchical relationship found between properties of white-light coronal mass ejections (CMEs) and the fluence spectral indices of the associated Large Solar Energetic Particle (SEP) Events. We consider 74 large SEP events from the western hemisphere in solar cycles 23 and 24 by multiple spacecraft (SAMPEX, GOES, and STEREO). The associated CMEs are observed by SOHO. We find that CMEs with high initial acceleration are associated with SEP events with the hardest fluence spectra, while those with lowest initial acceleration have SEP events with the softest fluence spectra; CMEs with intermediate initial acceleration result in SEP events with moderately hard fluence spectra. Impulsive acceleration leading to high CME speeds close to the Sun results in shock formation close to the Sun, where the ambient magnetic field and density are high and the particles are energized more efficiently. Slowly accelerating CMEs drive shocks at large distances from the Sun, where the magnetic field and density have fallen off significantly, reducing the efficiency of shock acceleration. These opposite extremes are represented by ground level enhancement (GLE) events that have high speeds early on (high initial acceleration) and the SEP events associated with CMEs from quiescent filament region that have low early speeds (low initial acceleration). This finding strongly supports the idea that CME-driven shocks accelerate SEPs and the heliocentric distance where the acceleration takes place decides the hardness of the SEP fluence spectrum.

Author(s): N. Gopalswamy[1], Seiji Yashiro[2], Neeharika Thakur[2], Pertti Makela[2], Hong Xie[2], Sachiko Akiyama[2]
Institution(s): *1. NASA GSFC, 2. The Catholic University of America*

325.04D – White-Light and Radioastronomical Remote-Sensing of Coronal Mass Ejections

Coronal mass ejections (CMEs) are large-scale eruptions of plasma from the Sun that play an important role in space weather. Faraday rotation (FR) is the rotation of the plane of polarization that results when a linearly polarized signal passes through a magnetized plasma (such as a CME) and is proportional to the path integral through the plasma of the electron density and the line-of-sight component of the magnetic field. FR observations of a source near the Sun can provide information on the plasma structure of a CME shortly after launch; however, separating the contribution of the plasma density from the line-of-sight magnetic field is challenging.

We report on simultaneous white-light and radio observations made of three CMEs in August 2012. We made radio observations using the Very Large Array (VLA) at 1 - 2 GHz frequencies of a "constellation" of radio sources through the solar corona at heliocentric distances that ranged from 6 - 15 solar radii: two sources (0842+1835 and 0900+1832) were occulted by a single CME and one source (0843+1547) was occulted by two CMEs. In addition to our radioastronomical observations, which represent one of the first active hunts for CME Faraday rotation since Bird et al. (1985) and the first active hunt using the VLA, we obtained white-light coronagraph images from the LASCO/C3 instrument to determine the Thomson scattering brightness (BT), providing a means to independently estimate the plasma density and determine its contribution to the observed Faraday rotation.

A constant density force-free flux rope embedded in the background corona was used to model the effects of the CMEs on BT and FR and infer the plasma densities (6 - 22 x 10^3 cm^{-3}) and axial magnetic field strengths (2 - 12 mG) for the three CMEs. A single flux rope model successfully reproduces the observed BT and FR profiles for 0842+1835 and 0900+1832; however 0843+1547 was occulted by two CMEs. Using the multiple viewpoints provided by LASCO/C3 and STEREO-A/COR2, we model observations of 0843+1547 using two flux ropes embedded in the background corona and demonstrate the model's ability to successfully reproduce both BT and FR profiles.

Author(s): Jason E. Kooi[1], Steven R. Spangler[2]
Institution(s): *1. U.S. Naval Research Laboratory, 2. University of Iowa*

326 – Binary & X-ray Stellar Systems

326.01 – Flow Patterns in Simulated Contact Binaries

We present long-term dynamical evolutions of symmetric contact binaries through approximately 90 orbits. Our simulations are conducted with a fully three-dimensional Eulerian code for self-gravitating fluids. While the initial data for the simulations describe two symmetric stars that just reach up to the inner Lagrange point, a steady flow and exchange of material between the two stars is quickly established. We examine this flow and the role that similar features may play in real contact binary systems.

Author(s): Patrick M. Motl[1], Kundan Kadam[2], Juhan Frank[2], Geoffrey C. Clayton[2]
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326.02D – A *Chandra* X-ray census of the interacting binaries in old open clusters - NGC 188

We present a new X-ray study of NGC 188, one of the oldest open clusters known in the Milky Way (7 Gyr). Our X-ray observation using the *Chandra* X-ray Observatory is aimed at uncovering the population of close interacting binaries in the cluster. We detect 84 X-ray sources with a limiting X-ray luminosity, $L_X \sim 4\times10^{29}$ erg s^{-1} (0.3-7 keV), of which 28 are within the half-mass radius. Of these, 13 are proper-motion or radial-velocity cluster members, wherein we identify a mix of active binaries (ABs) and blue straggler stars (BSSs). We also identify one tentative cataclysmic variable (CV) candidate which is a known short-period photometric variable, but whose membership to NGC 188 is unknown. We have compared the X-ray luminosity per unit of cluster mass (i.e. the X-ray emissivity) of NGC 188 with those of other old Galactic open clusters and dense globular clusters (47 Tuc, NGC 6397). Our findings confirm the earlier result that old open clusters have higher X-ray emissivities than the globular clusters ($L_X \geq 1\times10^{30}$ erg s^{-1}). This may be explained by dynamical encounters in globulars, which could have a net effect of destroying binaries, or the typically higher metallicities of open clusters. We find one intriguing X-ray source in NGC 188 that is a BSS and cluster member, whose X-ray luminosity cannot be explained by its currently understood binary configuration. Its X-ray detection invokes the need for a third companion in the system.

Author(s): Smriti Vats[1], Maureen Van Den Berg[1]
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326.03 – Low-mass X-ray binaries in the outer halo of NGC 4472: a consequence of natal kicks?

We present new Chandra observations of the outer halo of the giant elliptical galaxy NGC 4472 (M49) in the Virgo Cluster. The data extend to 130 kpc (28'), and have a total exposure time of 150 ks. After eliminating background active galactic nuclei and globular cluster (GC) sources, and correcting for completeness, we find that the number of field low-mass X-ray binaries (LMXBs) per unit stellar light increases significantly with galactocentric radius. The excess of field LMXBs at large galactocentric radii may be a consequence of natal kicks on neutron stars and black holes in binary systems in the inner part of the galaxy. These systems, some of which will become LMXBs, will generally move into wider galactic orbits. Since the metallicity in the halo of NGC 4472 strongly decreases towards larger galactocentric radii, the number of field LMXBs is anti-correlated with metallicity, in contrast to GCs. An alternative to natal kicks to explain the spatial distribution of field LMXBs is therefore a reversed metallicity effect.

Author(s): Lennart M Van Haaften[4], Thomas J. Maccarone[4], Paul Sell[5], Chris Mihos[1], David J. Sand[4], Arunav Kundu[2], Stephen Zepf[3]
Institution(s): *1. Case Western Reserve University, 2. Eureka Scientific, 3. Michigan State University, 4. Texas Tech University, 5. University of Crete*

326.04 – Tracing X-ray Binary Population Evolution By Galaxy Dissection: First Results from M51

Recently, we have found, in the Chandra Deep Field-South, that the emission from X-ray binary (XRB) populations in galaxies evolves significantly with cosmic time, most likely due to changes in the physical properties of galaxies like star-formation rate, stellar mass, stellar age, and metallicity. However, it has been challenging to directly show that these same physical properties are connected to XRB populations using data from nearby galaxies. We present a new technique for empirically calibrating how X-ray binary (XRB) populations evolve following their formation in a variety of environments. We first utilize detailed stellar population synthesis modeling of far-UV to far-IR broadband data of nearby (< 10 Mpc) face-on spiral galaxies to construct maps of the star-formation histories on subgalactic scales. Using Chandra data, we then identify the locations of the XRBs within these galaxies and correlate their formation frequencies with local galaxy properties. In this talk, I will show promising first results for the Whirlpool galaxy (M51), and will discuss how expanding our sample to an archival sample of 20 face-on spirals will lead to a detailed empirical timeline for how XRBs form and evolve in various environments.

Author(s): Bret Lehmer[6], Rafael T. Eufrasio[6], Larissa Markwardt[6], Andreas Zezas[1], Antara Basu-Zych[4], Tassos Fragos[2], Ann E. Hornschemeier[4], Vassiliki Kalogera[5], Andrew Ptak[4], Panayiotis Tzanavaris[4], Mihoko Yukita[3]
Institution(s): *1. Crete, 2. Geneva Observatory, 3. Johns Hopkins University, 4. NASA GSFC, 5. Northwestern, 6. Univ of Arkansas*

326.05 – The evolution of triple-star systems

While the principles of stellar and binary evolution theory have been accepted for a long time, our understanding of triple-star evolution is lagging behind. It is important to understand these systems, as triples are common in the field. About 15% of low-mass stellar systems are triples, but for high-mass stars the fraction increases to over 50%. At the same time, triple evolution is often invoked to explain exotic systems which cannot be explained easily by binary evolution. Examples are low-mass X-ray binaries, supernova type Ia progenitors and blue stragglers.

Modeling triple evolution, however, is challenging as it is a combination of three-body dynamics and stellar evolution. In the past, most studies of three-body systems have focused on purely dynamical aspects without taking stellar evolution into account. However, in recent years, the first interdisciplinary studies have taken place which demonstrate the richness of the interacting regime. Here, I will show the first results of our new code TRES for simulating the evolution of stellar triples, which combines stellar evolution and interactions with three-body dynamics. In this talk, I will give an overview of the evolution of realistic (stellar) triples and I will discuss how triple evolution differs from binary evolution. What are the common evolutionary pathways that triple systems evolve through? Are there any evolutionary pathways open to triples, which are not open to isolated binaries? These are some of the important questions we want to answer.

Author(s): Silvia Toonen[1], Adrian Hamers[2], Simon Portegies Zwart[3]
Institution(s): *1. Anton Pannekoek Institute, 2. Institute for Advanced Study, 3. Leiden University*

326.06 – Close encounters of Proxima and alpha Centauri as a consequence of the galactic environment

The recent discovery of a terrestrial mass planet orbiting Proxima Centauri has generated renewed interest in the stellar system alpha Centauri, to which Proxima may be gravitationally bound. Because of the observed high abundance of heavy elements of these stars, we argue that this triple system almost certainly formed within about 4.5 kpc of the galactic center, and hence has undergone significant radial migration. We have developed a secular model for the dynamics of the system, including the effects of galactic tides, stellar encounters, and three body interactions between Proxima and alpha Cen A and B. This secular model allows us to explore many possible initial parameters for the system including different galacto-centric formation distances and radial migration times. Galactic tides and stellar encounters make close approaches between Proxima and alpha Cen possible, particularly when the system spends much of its life in a denser environment than the present solar neighborhood. Precession of Proxima's orbit due to three body interactions mitigates this to some extent by widening the distances of closest approach. However, whether or not Proxima is indeed bound to alpha Cen at the present day, there remains a significant possibility that it has had close encounters with alpha Cen in the past. Such close encounters have implications for the type of planetary system that may orbit Proxima today. An extended planetary system with planets or small bodies at large semi-major axes is likely to be disrupted. Proxima b may be the remnant of a more extended planetary system that destabilized during a prior close passage.

Author(s): Russell Deitrick[2], Thomas R. Quinn[2], Rory Barnes[2], Nathan A. Kaib[1]
Institution(s): *1. University of Oklahoma, 2. University of Washington*

326.07 – N-body Simulation of Binary Star Mass Transfer

Over 70% of the stars in our galaxy are multiple star systems, many of which are two stars that orbit around a common center of mass. The masses of the individual stars can be found using Newton's and Kepler's Laws. This allows astronomers to use these systems as astrophysical laboratories to study properties and processes of stars and galaxies. Among the many types observed, the dynamics of contact systems are the most interesting because they exhibit mass transfer, which changes the composition and function of both stars. The process by which this mass exchange takes place is not well understood. The lack of extensive mass transfer analysis, inadequate theoretical models, and the large time scale of this process are reasons for our limited understanding. In this work, a model was made to give astronomers a method for gaining a deeper knowledge and visual intuition of how the mass transfer between binary stars takes place. We have built the foundations for a simulation of arbitrary systems, which we plan to elaborate on in the future to include thermodynamics and nuclear processes.

Author(s): Taylor Hutyra[1], William Sumpter[1]
Institution(s): *1. Tarleton State University*

326.08 – Hunting the Huntsmen: Compact Pulsar Binaries with Giant Companions

Our group has been pursuing follow-up observations of unassociated Fermi-LAT γ-ray sources in an effort to identify new Milky Way compact binaries. Some of our recent observations include the preliminary discovery of a long-period (~8.1d), γ-ray bright binary with a heavy (~1.9 M) neutron star (NS) primary and giant secondary (~0.5 M) that shows some unusual variability characteristics in multiple wavelengths. Evolutionary models of compact binaries indicate that this system is likely in the late phases of *typical* millisecond pulsar (MSP) binary formation in the Galactic field, phases which up until now have been unobserved. This system also appears remarkably similar to the recently discovered NS binary 1FGL J1417.7–4407 (Strader et al. 2015), which showed optical, X-ray, and γ-ray signatures consistent with transitional MSPs in their disk state. Despite this evidence, 1FGL J1417.7–4407 was simultaneously found to host a radio MSP, implying accreting material is not reaching the pulsar surface and further bringing into question how and when these systems switch on or off as radio MSPs. The confirmation of a second long-period γ-ray bright binary system with a massive NS primary and giant secondary would show that the rich phenomenology that can be observed when an accretion disk is present remains unclear, and facilitates a discussion on whether such systems constitute a distinct class of compact binaries.

Author(s): Samuel Swihart[2], Jay Strader[2], Laura Chomiuk[2], David J. Sand[4], Chi C. Cheung[3], Tyrel J. Johnson[1]
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327 – ALMA Observations of Circumstellar Disks

327.01 – The End of Protoplanetary Disk Evolution: An ALMA Survey of Upper Scorpius

The evolution of the mass of solids in circumstellar disks is a key factor in determining how planets form. Infrared observations have established that the dust in primordial disks vanishes around the majority of stars by an age of 5-10 Myr. However, how this disappearance proceeds is poorly constrained. Only with longer wavelength observations, where the dust emission is optically thin, is it possible to measure disk dust mass and how it varies as a function of age. To this end, we have obtained ALMA 0.88 mm observations of over 100 sources with suspected circumstellar disks in the Upper Scorpius OB Association (Upper Sco). The 5-11 Myr age of Upper Sco suggests that any such disks will be quite evolved, making this association an ideal target to compare to systems of younger disks in order to study evolution. With ALMA, we achieve an order of magnitude improvement in sensitivity over previous (sub)millimeter surveys of Upper Sco and detect 58 disks in the continuum. We calculate the total dust masses of these disks and compare their masses to those of younger disks in Taurus, Lupus, and Chamaeleon. We find strong evidence for a decline in disk dust mass between these 1-3 Myr old systems and the 5-11 Myr old Upper Sco. Our results represent the first definitive measurement of a decline in disk dust mass with age.

Author(s): Scott A. Barenfeld[1], John M. Carpenter[3], Anneila I. Sargent[1], Luca Ricci[2], Andrea Isella[4]
Institution(s): *1. California Institute of Technology, 2. Harvard-Smithsonian Center for Astrophysics, 3. Joint ALMA Observatory, 4. Rice University*

327.02 – A Steeper than Linear Disk Mass-Stellar Mass Scaling Relation

The disk mass is among the most important input parameter of planet formation models as it determines the number and masses of the planets that can form. I will present an ALMA 887 micron survey of the disk population around objects from 2 to 0.03Msun in the nearby 2 Myr-old Chamaeleon I star-forming region. Assuming isothermal and optically thin emission, we convert the 887 micron flux densities into dust disk masses (Mdust) and show that the Mdust-Mstar scaling relation is steeper than linear. By re-analyzing all millimeter data available for nearby regions in a self-consistent way, we find that the 1-3 Myr-old regions of Taurus, Lupus, and Chamaeleon I share the same Mdust-Mstar relation, while the 10 Myr-old Upper Sco association has an even steeper relation. Theoretical models of grain growth, drift, and fragmentation reproduce this trend and suggest that disks are in the fragmentation-limited regime. In this regime millimeter grains will be located closer in around lower-mass stars, a prediction that can be tested with deeper and higher spatial resolution ALMA observations.

Author(s): Ilaria Pascucci[1]
Institution(s): *1. LPL/University of Arizona*
Contributing team(s): SLICK, EOS

327.03D – Millimeter Studies of Nearby Debris Disks

At least 20% of nearby main sequence stars are known to be surrounded by disks of dusty material resulting from the collisional erosion of planetesimals, larger bodies similar to asteroids and comets in our own Solar System. Since the dust-producing planetesimals are expected to persist in stable regions like belts and resonances, the locations, morphologies, and physical properties of dust in these 'debris disks' provide probes of planet formation and subsequent dynamical evolution. Observations at millimeter wavelengths are especially critical to our understanding of these systems, since the large grains that dominate emission at these long wavelengths do not travel far from their origin and therefore reliably trace the underlying planetesimal distribution. The newly upgraded capabilities of millimeter interferometers like ALMA are providing us with the opportunity to image these disks with unprecedented sensitivity and resolution. In this dissertation talk, I will present my ongoing work, which uses observations of the angularly resolved brightness distribution and the spectral dependence of the flux density to constrain both the structure and grain size distribution of a sample of nearby debris disks. I will present constraints on the position, width, surface density gradient, and any asymmetric structure of several debris disks (including Epsilon Eridani, Tau Ceti, and Fomalhaut) determined from ALMA and SMA observations. In addition, I will present the results of a survey using the VLA and ATCA to measure the long wavelength spectral index and thus the grain size distribution of fifteen debris disks. Together these results provide a foundation to investigate the dynamical evolution of planetary systems through multi-wavelength observations of debris disks.

Author(s): Meredith A. MacGregor[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

327.04 – ALMA 1.3 mm Observation of the Fomalhaut Debris Disk

We present ALMA Band 6 (1.3 mm) observations of Fomalhaut and its debris disk. Since the system is relatively close at 7.7 pc, it has been the target of numerous studies at multiple wavelengths, and can serve as a testbed for debris disk evolution models and planet-disk interactions. Outstanding issues that need to be resolved to properly characterize the debris include tightening constraints on the spectral index in the submm/mm regime and determining whether there is indeed excess over the stellar emission, indicating the presence of an inner debris disk or ring.

These ALMA 1.3 mm observations provide the highest resolution observations to date of the mm grains the outer ring. Tight constraints are placed on the geometry of the disk and on the mm-wavelength spectral index. We explore fitting the debris disk model in the image plane in addition to the standard method of fitting the visibilities. The results are compared and potential advantages/disadvantages of each approach are discussed.

The central emission detected is indistinguishable from a point source, with 0.90 mJy being the best fit flux of the host star for Fomalhaut itself. This implies that any inner debris component must contribute little to the total central emission. Moreover, the stellar flux is less than 70% of that predicted by extrapolating a blackbody from the constrained photosphere temperature and just over 70% of the flux if extrapolating from the far infrared. This behavior is similar to that seen in the Sun for submm/mm wavelengths, but even more pronounced. Currently, insufficient data exists to properly constrain the degree to which stellar atmospheres affect the observed flux in the submm/mm regime. This result is part of an ongoing larger project focused on measuring the emission from stellar atmospheres at submm/mm wavelengths, which directly impacts inferred excesses for debris disk studies.

Author(s): Jacob White4, Aaron C. Boley4, Eric B. Ford3, Matthew J. Payne[2], William Dent[1], Stuartt Corder[1]
Institution(s): *1. ALMA, 2. Harvard CfA, 3. Pennsylvania State University, 4. University of British Columbia*

327.05D – Searching for the Youngest Protostellar Disks and Earliest Signs of Planet Formation

Circumstellar disks are fundamental for accretion and angular momentum distribution during the early phases of star formation. Class 0 objects are the youngest protostars and most embedded in their natal envelopes, and circumstellar disks can form even at this earliest stage of star formation. Less-embedded Class I protostars have cleared part of their surrounding envelope, yet the envelopes enshrouding Class 0 and Class I protostars have made detection of young protostellar disks difficult. Before this work, only 4 Class 0 and 10 Class I Keplerian disks were known. Through observational work with the VLA and ALMA on disks around some of the youngest protostars, my dissertation addresses two key questions regarding circumstellar disks and initial conditions for planet formation.

1) How common are large Class 0 and I protostellar disks and what are their properties?
We analyze dust continuum emission data toward all (~90) Class 0 and I sources in the Perseus molecular cloud from the 8 mm VLA Nascent Disk and Multiplicity (VANDAM) survey with 12 AU resolution. Because we lack kinematic data on small scales to confirm any resolved, elongated structures as rotationally supported, we fit the deprojected, averaged, and binned data in the u,v-plane to a disk-shaped profile to determine which sources are disk candidates.

2) How early can disk substructures, and hence signs of early planet formation, be found in young disks?
We study the ALMA 1.3 mm continuum observations of the disk of Class I source IRS 63 with 8 AU resolution to search for gaps in a young protostellar disk. Previous studies of disk substructure have revealed gaps in the disks of more evolved Class II sources, such as the famous HL Tau. If rings and gaps are observed in IRS 63, then planet formation and the associated disk sculpting must have started early in the Class I phase or before. If gaps are absent, then planets must have begun to form during the (late) Class I phase, rather than during the deeply embedded Class 0 phase.

Author(s): Dominique Segura-Cox[1]
Institution(s): *1. University of Illinois*

327.06 – ALMA Measurements of Circumstellar Material in the GQ Lup System

We present ALMA observations of the GQ Lup system, a young Sun-like star with a substellar mass companion in a wide-separation orbit. These observations of 870 micron continuum and CO J=3-2 line emission with beam 0.3 arcsec (45 AU) resolve the disk of dust and gas surrounding the primary star, GQ Lup A, and provide deep limits on any circumplanetary disk surrounding the companion, GQ Lup b. The 3 sigma upper limit on the 870 micron flux density of < 0.15 mJy implies an upper limit on the GQ Lup b disk mass of about 0.04 solar masses for standard assumptions about optically thin dust emission. Given the non-detection of a circumplanetary disk around GQ Lup b, and other similar systems observed by ALMA, we discuss implications for formation mechanisms of wide-separation substellar companions.

Author(s): David J. Wilner3, Meredith A. MacGregor3, Ian Czekala3, Sean M. Andrews3, Yu Sophia Dai[1], Gregory Herczeg4, Kaitlin M. Kratter5, Adam L. Kraus[6], Luca Ricci3, Leonardo Testi[2]
Institution(s): *1. Caltech, 2. ESO, 3. Harvard-Smithsonian, CfA, 4. KIAA, 5. University of Arizona, 6. University of Texas*

327.07 – A Three-Dimensional View of Turbulence Amid Complex Structure in the HD 163296 Protoplanetary Disk

Gas kinematics are an important part of planet formation, influencing processes ranging from the growth of sub-micron sized grains to the migration of gas giant planets. Dynamical behavior can be traced with both synoptic observations of the mid-infrared excess, sensitive to the inner disk, and spatially resolved radio observations of gas emission, sensitive to the outer disk. I report new constraints on the vertical structure of turbulence in the disk around HD 163296, based on ALMA observations of DCO+ and CO isotoplogues that are sensitive to different layers of the disk. These data place upper limits on the turbulence (<0.05cs) that fall approximately an order of magnitude below that predicted in the upper disk layers by models of full-blown magneto-rotational instability. In measuring the turbulence we also find evidence for three distinct rings of DCO+ emission, indicating a complex chemical structure within this system. I also discuss the potential for further ALMA constraints on turbulence amid differing ionization environments.

Author(s): Kevin M. Flaherty5, A. Meredith Hughes5, Sanaea Rose4, Sean M. Andrews[1], David J. Wilner[1], Eugene Chiang3, Jacob B. Simon[2]
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328 – CubeSats in Astronomy & Astrophysics

CubeSats, small satellites built in increments of 10 cm cubes (1 cube is called 1U or "unit," two 10 cm cubes together are known as 2U, and so on) are being used more and more to carry out science observations and collect data while providing low-cost access to space, platforms for technology development, and training ground for students and other early-career researchers. While most CubeSats launched to date are studying the earth and other objects within the solar system, interest in using CubeSats in astronomy and astrophysics is growing. An ad hoc committee of the The National Academy has recently concluded a study reviewing the current state of the scientific potential and technological promise of CubeSats. This study, chaired by Thomas Zurbuchen (Univ. Michigan), focused on the potential of using CubeSats as platforms for obtaining high priority science, such as that recommended in recent Decadal Surveys and the 2014 NASA Science Plan. Their report, to be released this month (May 2016) includes an overview of science goals that can be accomplished with current CubeSat technological capabilities and those anticipated in the near future. This Special Session will provide a broad look at CubeSats in astronomy and astrophysics, including an overview of their scientific potential, as well as the current state and future promise of CubeSat technology. Application of CubeSats to study decadal priorities will be highlighted, and experiences with carrying out CubeSat development in university settings will be shared.

328.01 – Achieving Science with CubeSats: Thinking Inside the Box

We present the results of a study conducted by the National Academies of Sciences, Engineering, and Medicine. The study focused on the scientific potential and technological promise of CubeSats. We will first review the growth of the CubeSat platform from an education-focused technology toward a platform of importance for technology development, science, and commercial

use, both in the United States and internationally. The use has especially exploded in recent years. For example, of the over 400 CubeSats launched since 2000, more than 80% of all science-focused ones have been launched just in the past four years. Similarly, more than 80% of peer-reviewed papers describing new science based on CubeSat data have been published in the past five years.
We will then assess the technological and science promise of CubeSats across space science disciplines, and discuss a subset of priority science goals that can be achieved given the current state of CubeSat capabilities. Many of these goals address targeted science, often in coordination with other spacecraft, or by using sacrificial or high-risk orbits that lead to the demise of the satellite after critical data have been collected. Other goals relate to the use of CubeSats as constellations or swarms, deploying tens to hundreds of CubeSats that function as one distributed array of measurements. Finally, we will summarize our conclusions and recommendations from this study; especially those focused on nearterm investment that could improve the capabilities of CubeSats toward increased science and technological return and enable the science communities' use of CubeSats.

Author(s): Thomas H. Zurbuchen[2], **Bhavya Lal[1]**
Institution(s): *1. IDA Science and Technology Policy Institute, 2. Univ. of Michigan*

328.02 – How CubeSats contribute to Science and Technology in Astronomy and Astrophysics

CubeSats are nanosatellites, spacecraft typically the size of a shoebox or backpack. CubeSats are made up of one or more 10 cm x 10 cm x 10 cm units weighing 1.33 kg (each cube is called a "U"). CubeSats benefit from relatively easy and inexpensive access to space because they are designed to slide into fully enclosed spring-loaded deployer pods before being attached as an auxiliary payload to a larger vehicle, without adding risk to the vehicle or its primary payload(s). Even though CubeSats have inherent resource and aperture limitations due to their small size, over the past fifteen years, researchers and engineers have miniaturized components and subsystems, greatly increasing the capabilities of CubeSats. We discuss how state of the art CubeSats can address both science objectives and technology objectives in Astronomy and Astrophysics. CubeSats can contribute toward science objectives such as cosmic dawn, galactic evolution, stellar evolution, extrasolar planets and interstellar exploration.
CubeSats can contribute to understanding how key technologies for larger missions, like detectors, microelectromechanical systems, and integrated optical elements, can not only survive launch and operational environments (which can often be simulated on the ground), but also meet performance specifications over long periods of time in environments that are harder to simulate properly, such as ionizing radiation, the plasma environment, spacecraft charging, and microgravity. CubeSats can also contribute to both science and technology advancements as multi-element space-based platforms that coordinate distributed measurements and use formation flying and large separation baselines to counter their restricted individual apertures.

Author(s): Kerri Lynn Cahoy[1], Ewan Douglas[1], Ashley Carlton[1], James Clark[1], Christian Haughwout[1]
Institution(s): *1. MIT*

328.04 – CUTIE: Cubesat Ultraviolet Transient Imaging Experiment

We describe a mission concept for the Cubesat Ultraviolet Transient Imaging Experiment (CUTIE). CUTIE will image an area on the sky of ~ 1700 square degrees every ~ 95 min at near-UV wavelengths (260-320 nm) to a depth of 19.0 mag (AB). These capabilities represent orders of magnitude improvement over past UV imagers, allowing CUTIE to conduct the first true synoptic survey of the transient and variable sky in the UV bandpass. CUTIE will uniquely address key Decadal Survey science questions such as how massive stars end their lives, how super-massive black holes accrete material and influence their surroundings, and how suitable habitable-zone planets around low-mass stars are for hosting life. By partnering with upcoming ground-based time-domain surveys, CUTIE will further leverage its low-Earth orbit to provide a multi-wavelength view of the dynamic universe that can only be achieved from space. The remarkable sensitivity for such a small payload is achieved via the use of large format delta-doped CCDs; space qualifying this technology will serve as a key milestone towards the development of future large missions (Explorers and Surveyors). Finally, our innovative design in a 6U cubesat form factor will enable significant cost savings, accelerating the timeline from conception to on-sky operation (5 years; well matched for graduate student participation).

Author(s): Stephen B. Cenko[4], Eric Christopher Bellm[1], Avishay Gal-Yam[6], Suvi Gezari[5], Varoujan Gorjian[3], April Jewell[3], Jeffrey W. Kruk[4], Shrinivas R. Kulkarni[1], Richard Mushotzky[5], Shouleh Nikzad[3], Anthony Piro[2], Eli Waxman[6], Eran Oded Ofek[6]
Institution(s): *1. Caltech, 2. Carnegie Observatories, 3. JPL, 4. NASA Goddard Space Flight Center, 5. University of Maryland, 6. Weizmann Institute of Science*

328.03 – HaloSat – A CubeSat to Study the Hot Galactic Halo

Observations of the nearby universe fail to locate about half of the baryons observed in the early universe. The missing baryons may be in hot galactic halos. HaloSat is a CubeSat designed to map oxygen line emission (O VII and O VIII) around the Milky Way in order to constrain the mass and spatial distribution of hot gas in the halo. HaloSat has a grasp competitive with current X-ray observatories. Its observing program will be optimized to minimize contributions from solar wind charge exchange (SWCX) emission that limit the accuracy of current measurements. We will describe the HaloSat mission concept, progress towards its implementation, and plans for archiving and distribution of the data.

Author(s): Philip Kaaret[1]
Institution(s): *1. Univ. of Iowa*

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329 – Results from the New Half-Degree Imager on the WIYN-0.9m Telescope

We will discuss early results from the new HDI imager in operation on the WIYN-0.9m telescope at Kitt Peak National Observatory. While part of the session will deal with the technical aspects of the imager and early science results: we will also discuss opportunities for the community to become involved and use of the telescope in education and outreach activities. The partner institutions of the WIYN-0.9m consortium represent a range of universities from small to large; undergraduate-only to Tier-1 research schools; and public and private educational institutions. The associated poster session will present early science results developed using HDI, including many student-led projects.

329.01 – Technical Summary of the Half-Degree Imager (HDI)

The Half-Degree Imager (HDI) was first attached to the WIYN 0.9-m Telescope in October, 2013. In the three years since then, it has served a large community of astronomers throughout the WIYN 0.9-m consortium. The large field of view and relatively short readout time, combined with a large selection of broad-band and narrow-band filters, make HDI a powerful tool for large-area surveys. I will provide a summary of the technical features of this CCD camera and its operations, and present statistics on its use -- showing the fraction of time lost due to bad weather and technical problems. I will reserve time to answer questions from the audience, including those who may be interested in using HDI for their own projects.

Author(s): Michael W. Richmond[1]
Institution(s): *1. Rochester Inst. of Tech.*

329.02 – Undergraduate Education with the WIYN 0.9-m Telescope

Several models have been explored at Indiana University

Bloomington for undergraduate student engagement in astronomy using the WIYN 0.9-m telescope at Kitt Peak. These models include individual student research projects using the telescope, student observations as part of an observational techniques course for majors, and enrichment activities for non-science majors in general education courses. Where possible, we arrange for students to travel to the telescope. More often, we are able to use simple online tools such as Skype and VNC viewers to give students an authentic observing experience. Experiences with the telescope motivate students to learn basic content in astronomy, including the celestial sphere, the electromagnetic spectrum, telescopes and detectors, the variety of astronomical objects, date reduction processes, image analysis, and color image creation and appreciation. The WIYN 0.9-m telescope is an essential tool for our program at all levels of undergraduate education

Author(s): Catherine A. Pilachowski[1]
Institution(s): *1. Indiana University*

329.03 – Using the HDI camera with Tohono O'odham Tribal Community College Students

Tohono O'odham Community College is a small two-year tribal college, located at the foot of I'oligam Du'ag, also known as Kitt Peak. In recognition and appreciation of Kitt Peak National Observatory's location on the Tohono O'odham reservation, NOAO has worked with the college to offer an introduction astronomy class when requested. The class has been taught by NOAO scientific staff and post docs, and the lab component of this 4-credit class has been carried out at Kitt Peak. With support from the WIYN0.9-m Consortium, students have been able to observe on the 0.9m telescope. Most recently they have used the HDI camera for an evening, which has been a highlight of the class that students always note in their final evaluation. I will describe challenges and rewards in developing and maintaining this class, including identifying post docs and graduate students who are able to teach it. However, we feel the challenges are worth it: this may be the only formal astronomy class offered at a tribal college.

Author(s): Catharine D. Garmany[1]
Institution(s): *1. NOAO*

329.04 – Making and Using Aesthetically Pleasing Images With HDI

The Half-Degree Imager (HDI) was installed as the primary imager on the 0.9-m WIYN telescope in October 2013. In the three plus years since then it has proven to be highly effective as a scientific instrument for the 0.9-m WIYN consortium. One thing that has been missing from the mix are aesthetically pleasing images for use in publicity and public outreach. The lack of "pretty pictures" is understandable since the HDI is designed for scientific use and observers are given limited telescope time. However, images which appeal to the general public can be an effective tool for public outreach, publicity and recruitment of students into astronomy programs. As a counter to the loss of limited telescope time an observer has, "pretty picture" images can be taken under less than desirable conditions when photometric studies would have limited usefulness. Astroimaging has become a popular pastime among both amateur and professional astronomers. At Austin Peay State University astrophotography is a popular course with non-science majors that wish to complete an astronomy minor as well as physics majors pursuing the astrophysics track. Images of a number of Messier objects have been taken with the HDI camera and are used to teach the basics of image calibration and processing for aesthetic value to students in the astrophotography class. Using HDI images with most image processing software commercially available to the public does present some problems, though. The extended FITS format of the images is not readable by most amateur image processing software and such software can also have problems recognizing the filter configurations of the HDI. Overcoming these issues and how the images are used in APSU courses, publicity and public outreach as well as finished pictures will be discussed in this presentation. A poster describing the processing techniques used will be displayed during the concurrent HDI poster session along with several poster-sized prints of images.

Author(s): Spencer L. Buckner[1]
Institution(s): *1. Austin Peay State Univ.*

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330 – Neutron Stars (Pulsars, Magnetars, Pulsar Wind Nebulae) II

330.01 – Localizing the Fast Radio Burst 121102

The precise localization of a fast radio burst and the identification of its host counterpart would allow constraints on their distances and energetics, and enable us to discriminate between various origin scenarios, from the local and mundane to the cosmological and exotic. Here we report on the results of an ongoing localization campaign on the repeating fast radio burst source, FRB 121102, with the VLA, Arecibo, and other telescopes.

Author(s): Shami Chatterjee[3], Robert Wharton[3], Casey J. Law[10], Jason Hessels[2], Sarah Burke-Spolaor[11], Geoffrey C. Bower[1], Matthew W Abruzzo[5], Cees Bassa[2], Bryan J. Butler[9], James M. Cordes[3], Demorest Paul[9], Victoria M. Kaspi[7], Maura McLaughlin[11], Scott M. Ransom[9], Paul Scholz[4], Andrew Seymour[8], Laura Spitler[6], Shriharsh P. Tendulkar[7]
Institution(s): *1. ASIAA, 2. ASTRON, 3. Cornell University, 4. DRAO, 5. Haverford College, 6. Max-Planck-Institut für Radioastronomie, 7. McGill University, 8. NAIC, 9. NRAO, 10. University of California, 11. West Virginia University*
Contributing team(s): PALFA Survey Team, VLA+AO FRB121102 Simultaneous Campaign Team, EVN FRB121102 Campaign Team

330.02 – Finding and Localizing FRBs in Realtime with *realfast*

Fast Radio Bursts (FRBs) are mysterious millisecond radio transients that seem to originate from outside of the Milky Way. Despite having discovered roughly 20 FRBs, single-dish radio telescopes have not localized an FRB well enough to associate them confidently with multiwavelength counterparts (e.g., a host galaxy). Thus, fundamental questions about their distance, energetics, and origin remain open. Radio interferometers expand on science capabilities of single-dish radio telescopes by their ability to instantaneously localize sources. However, using interferometers at millisecond timescales ("fast imaging") generates a Terabyte of data per hour, enough to choke typical data analysis pipelines and too large to move via the internet.
To open access to this novel capability of interferometers, we are building *realfast*, a GPU cluster at the Very Large Array (VLA) that will be dedicated to real-time, fast transient searches. Real-time processing will be used to trigger data recording for those brief moments when millisecond transients occur. *Realfast* will be integrated with the VLA correlator to search a fast copy of all observations, a fundamentally new capability that will be open to all VLA users. By controlling the output data rate, *realfast* will observe thousands of hours per year, enough to find and localize dozens of FRBs. I will present early development progress and discoveries from *realfast* observations.

Author(s): Casey J. Law[5], Geoffrey C. Bower[1], Sarah Burke-Spolaor[4], Bryan J. Butler[4], Demorest Paul[4], Joseph Lazio[3], Michael P. Rupen[2]
Institution(s): *1. ASIAA, 2. DRAO, 3. JPL/NASA, 4. National Radio Astronomy Observatory, 5. UC Berkeley*

330.03 – Properties of Radio Sources in the FRB 121102 Field

Fast radio bursts are millisecond duration radio pulses of unknown origin. With dispersion measures substantially in excess of expected Galactic contributions, FRBs are inferred to originate extragalactically, implying very high luminosities. Models include a wide range of high energy systems such as magnetars, merging neutron star binaries, black holes, and strong stellar magnetic fields driving coherent radio emission. Central to the mystery of FRB origins are the absence of confirmed host objects at any wavelength. This is primarily the result of the poor localization from single dish detection of FRBs. Of the approximately 20 known examples, only one, FRB 121102, has been observed to repeat. This repetition presents an opportunity for detailed follow-up if interferometric localization to arcsecond accuracy can be obtained. The Very Large Array has previously been used to localize individual pulses from pulsars and rotating radio transients to arcsecond localizaiton. We present here the results of radio observations of the field of FRB 121102 that permit us to constrain models of possible progenitors of this bursting source. These observations can characterize active galactic nuclei, stars, and other progenitor objects.

Author(s): Geoffrey C. Bower[1], Shami Chatterjee3, Robert Wharton3, Casey J. Law9, Jason Hessels[2], Sarah Spolaor[8], Matthew W. Abruzzo4, Cees Bassa[2], Bryan J. Butler[8], James M. Cordes3, Paul Demorest[8], Victoria M. Kaspi5, Maura McLaughlin[10], Scott M. Ransom[8], Paul Scholz5, Andrew Seymour7, Laura Spitler[6], Shriharsh P. Tendulkar5
Institution(s): *1. ASIAA, 2. ASTRON, 3. Cornell University, 4. Haverford College, 5. McGill, 6. MPIfR, 7. NAIC, 8. NRAO, 9. UC Berkeley, 10. WVU*
Contributing team(s): PALFA Survey, VLA+AO FRB121102 Simultaneous Campaign Team, EVN FRB121102 Campaign Team, realfast team

330.05 – A polarised fast radio burst at low Galactic latitude

Fast radio bursts (FRBs) are a growing population of transients detected with radio telescopes which are thought to originate outside the Milky Way. Fewer than 20 sources exist in the literature and the majority of bursts have been found away from the plane of the Galaxy or where the Galactic contribution to the total electron column density is low. Here we report on the discovery of a new burst, FRB 150215, discovered with the Parkes radio telescope in real-time in February 2015. The burst was found to be 43±5% linearly polarised with an imprecisely determined rotation measure (RM) consistent with zero. The burst was followed-up with 9 telescopes to search for radio, optical, X-ray, γ-ray and neutrino emission from the location of the burst. No transient or variable emission was found to be associated with the burst and no repeat pulses have been observed in nine hours of Parkes observations. Radio images of the field were obtained following the FRB but would not have been sensitive enough to pick up a signal like the one emanating from WISE J071634.59−190039.2 following FRB150418 if it had been present. The sightline to the burst is close to the Galactic plane and the Galactic RM foreground may approach a null along this sightline, corresponding to a decreased total electron column density from the Milky Way. This might explain why this burst was detectable at low latitude whereas previous searches have been relatively unsuccessful.

Author(s): Emily Petroff[1]
Institution(s): *1. ASTRON*
Contributing team(s): SUPERB collaboration, HESS collaboration, ANTARES collaboration

330.06D – Algorithms for searching Fast radio bursts and pulsars in tight binary systems.

Fast radio bursts (FRB's) are an exciting, recently discovered, astrophysical transients which their origins are unknown.
Currently, these bursts are believed to be coming from cosmological distances, allowing us to probe the electron content on cosmological length scales. Even though their precise localization is crucial for the determination of their origin, radio interferometers were not extensively employed in searching for them due to computational limitations.
I will briefly present the Fast Dispersion Measure Transform (FDMT) algorithm,
that allows to reduce the operation count in blind incoherent dedispersion by 2-3 orders of magnitude.
In addition, FDMT enables to probe the unexplored domain of sub-microsecond astrophysical pulses.
Pulsars in tight binary systems are among the most important astrophysical objects as they provide us our best tests of general relativity in the strong field regime.
I will provide a preview to a novel algorithm that enables the detection of pulsars in short binary systems using observation times longer than an orbital period.
Current pulsar search programs limit their searches for integration times shorter than a few percents of the orbital period.
Until now, searching for pulsars in binary systems using observation times longer than an orbital period was considered impossible as one has to blindly enumerate all options for the Keplerian parameters, the pulsar rotation period, and the unknown DM.
Using the current state of the art pulsar search techniques and all computers on the earth, such an enumeration would take longer than a Hubble time. I will demonstrate that using the new algorithm, it is possible to conduct such an enumeration on a laptop using real data of the double pulsar PSR J0737-3039.
Among the other applications of this algorithm are:
1) Searching for all pulsars on all sky positions in gamma ray observations of the Fermi LAT satellite.
2) Blind searching for continuous gravitational wave sources emitted by pulsars with non-axis-symmetric matter distribution.
Previous attempts to conduct all of the above searches contained substantial sensitivity compromises.

Author(s): Barak Zackay[1]
Institution(s): *1. Weizmnann Institute of Science*

330.07 – Interstellar Medium Effects on Radio Pulsars PSR B1937+21 and PSR B2224+65, and Implications for Gravitational Wave Detection

Noise in pulsar timing residuals due to the ionized interstellar medium (IISM) is a critical limiting factor for pulsar timing arrays (PTAs) as gravitational wave detectors. PSR B1937+21 is the brightest millisecond pulsar in the northern sky and serves as a laboratory for studying uncertainties and systematic changes in pulse times-of-arrival. Its high flux, its high degree of scattering along the line-of-sight, and its giant pulses interact in a dynamic way to affect individual times-of-arrival on different timescales. Noise budget results on this pulsar are relevant to understanding the timing of other millisecond pulsars. We present data from an Arecibo Observatory campaign on PSR B1937+21 at 1.4GHz, the standard radio frequency at which the times-of-arrival of PSR B1937+21 and other PTA pulsars are routinely measured for the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). The campaign was strategized to probe the pulsar's noise budget, particularly with respect to the IISM from high S/N dynamic spectra that show flux distributed irregularly across the bandwidth from interstellar scintillation. Similarly, PSR B2224+65, while not a NANOGrav pulsar, is associated with the Guitar Nebula, a region with significant ISM density fluctuations. We also present data from a Green Bank Telescope monitoring campaign on PSR B2224+65 at 342MHz and 1.4GHz, which uses dispersion measure (DM) variations to constrain the influence of the IISM on the pulsar's times-of-arrival. By utilizing the dynamic spectra, single pulse, and DM data from these campaigns, we analyze the noise budgets of these pulsars on very short and very long timescales due to the changing intervening IISM.

Author(s): Timothy Dolch3, Shami Chatterjee[2], James M. Cordes[2], Demorest Paul4, Daniel Halmrast3, Cody Jessup3, Glenn Jones[1], Michael T. Lam[8], Andrew Lyne[6], Maura McLaughlin[8], Joshua Ramette3, Dan Stinebring5, Benjamin Stappers[6], Kevin Stovall7
Institution(s): *1. Columbia University, 2. Cornell University, 3. Hillsdale College, 4. NRAO, 5. Oberlin College, 6. University of Manchester, 7. University of New Mexico, 8. West Virgina University*

330.08 – An Update on the Timing of the Millisecond Pulsar in a Triple System

The millisecond pulsar J0337+1715, in a hierarchical triple system with two white dwarfs, is providing continued high-precision timing and a unique new test of general relativity. Our relativistic timing model of the system, based on accurate three-body gravitational integrations, has provided high-precision orbital inclinations and masses of all three stars, and we have begun to measure secular changes in the inner orbit. Limits on predicted systematic variations of the shape of the inner orbit based on our fantastic timing data, primarily now from Arecibo and the GBT, are providing the best-ever test of the Strong Equivalence Principle (SEP). This test will have important implications for basic physics since general relativity is the only known workable theory of gravity where the SEP must hold.

Author(s): Scott M. Ransom[1], Anne Archibald[2], Ingrid H. Stairs[3], Jason Hessels[2], Duncan Lorimer[4], Ryan S Lynch[1]
Institution(s): *1. NRAO, 2. University of Amsterdam, 3. University of British Columbia, 4. West Virginia University*

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331 – Helen B. Warner Prize: Feedback: Now with Physics, Philip Hopkins (Caltech)

331.01 – Feedback: Now with Physics

The most fundamental unsolved problems in galaxy formation revolve around "feedback" from massive stars and black holes. In the last few years, a new generation of theoretical models have emerged which combine new numerical methods and physics in an attempt to realistically model the diverse physics of the interstellar medium, star formation, and feedback from super-massive black holes and massive stars (winds, jets, SNe, and radiation). These mechanisms lead to 'self-regulated' galaxy and star formation, in which global correlations such as the Schmidt-Kennicutt law, the inefficiency of star formation, and the stellar mass function -- emerge naturally. Within galaxies, feedback regulates the structure of the interstellar medium, and many observed properties of the ISM, star formation, and galaxies can be understood as a fundamental consequence of super-sonic turbulence in a rapidly cooling, self-gravitating medium. But feedback also produces galactic super-winds that can dramatically alter the cosmological evolution of galaxies, change the nature of dark matter cores and 'cusps', and re-structure the circum-galactic and inter-galactic medium. These winds depend non-linearly on multiple feedback mechanisms in a way that explains why they have been so difficult to model in previous "sub-grid" approaches. This resolves long-standing problems in understanding even apparently "simple" galaxy properties like the mass-metallicity relation. Finally, I'll discuss where feedback fails, and where either additional, exotic physics, or new, previously-dismissed feedback mechanisms, may be needed to explain observations.

Author(s): Philip F. Hopkins[3], Eliot Quataert[3], Claude-Andre Faucher-Giguere[2], Dusan Keres[5], Andrew R. Wetzel[4], Norman W. Murray[1]
Institution(s): *1. Canadian Institute for Theoretical Astrophysics, 2. Northwestern University, 3. UC Berkeley, 4. UC Davis, 5. UC San Diego*

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332 – Plenary Talk: Astronomy from the Upper Stratosphere: Key Discoveries and New Opportunities from High Altitude Scientific Balloons, Laura Fissel (Northwestern University)

332.01 – Astronomy from the Upper Stratosphere: Key Discoveries and New Opportunities from High Altitude Scientific Balloons

Stratospheric balloons offer a near-space astronomy platform for a small fraction of the cost of an equivalent satellite. These balloons can lift scientific payloads of up to 6,000 lbs as high as 40 km above the Earth's surface (above >99.5% of the atmosphere). In this presentation I will discuss the contribution that scientific balloon experiments have made to astronomy, from the early days when astronomers had to accompany their telescopes to the stratosphere, to the present era where automated payloads are in some cases able to achieve a pointing precision of better than an arcsecond. In particular, I will discuss the important contributions that balloon telescopes have made to our current understanding of the Universe through detailed measurements of the Cosmic Microwave Background. I will also show how recent observations from sub-millimeter balloon telescopes such as BLAST and BLASTPol have been used to study both star formation and magnetic fields of nearby giant molecular clouds in unprecedented detail, and also to constrain models of interstellar dust composition. With improving ballooning technology, such as NASA's new Super-Pressure Balloon program, we will soon have the capability for science flights of several months (rather than weeks) duration, thus beginning an exciting new era in balloon astronomy.

Author(s): Laura M. Fissel[1]
Institution(s): *1. National Radio Astronomy Observatory*

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333 – Astronomy Majors & Graduate Students: Curriculum & the GRE Poster Session

333.01 – Effectiveness of Online Module for Graduate Astronomy Course

We noticed that teaching an important galaxy formation model in a graduate-level course (Structure and Dynamics of Galaxies) with lecture-style instruction did not promote active learning on the part of the student and that the level and quality of in-class discussion varied wildly from semester to semester. Hoping to improve the learning experience for the students, we designed and incorporated an online module to deliver course content, activities, and assessments. We investigate the effectiveness of this online module as a teaching tool by monitoring students' learning gains and present our preliminary results.

Author(s): Lauren E. P. Campbell[1], Kelly Holley-Bockelmann[1], Cynthia Brame[1]
Institution(s): *1. Vanderbilt University*

333.02 –
Physics GRE Scores of Prize Postdoctoral Fellows in Astronomy

The Physics GRE has long been a required element of the graduate admissions process in many U.S. astronomy programs; however, its predictive power and utility as a means of selection "successful" applicants had not been quantitatively examined until recently. In the fall of 2015 we circulated a short questionnaire to 271 people who have held U.S. prize postdoctoral fellowships in astrophysics between 2010-2015, asking them to report their Physics GRE scores. The response rate was 64%, and the responding sample was unbiased with respect to the overall gender distribution of prize fellows. The responses revealed that the Physics GRE scores of prize fellows do not adhere to any minimum percentile score and show no statistically significant correlation with the number of first author papers published. As an example, a Physics GRE percentile cutoff of 60% would have eliminated 44% of 2010-2015 U.S. prize postdoctoral fellows, including 60% of the female fellows. From these data, we found no evidence that the Physics GRE could be used as an effective predictor of "success" either in or beyond graduate school. Following this work and last year's official recommendation from the AAS, several astronomy departments have recently decided to eliminate the Physics GRE as a requirement for graduate applicants.

Author(s): Emily M. Levesque[2], Rachel Bezanson[1], Grant Tremblay[3]
Institution(s): *1. Princeton, 2. University of Washington, 3. Yale*

333.03 – The Benefits of Adding SETI to the

University Curriculum and What We Have Learned from a SETI Course Recently Offered at UCLA
We advocate for the inclusion of a full-term course entirely devoted to SETI in the university curriculum. SETI usually warrants only a few lectures in a traditional astronomy or astrobiology course. SETI's rich interdisciplinary character serves astronomy students by introducing them to scientific and technological concepts that will aid them in their dissertation research or later in their careers. SETI is also an exciting topic that draws students from other disciplines and teaches them astronomical concepts that they might otherwise never encounter in their university studies. We have composed syllabi that illustrate the breadth and depth that SETI courses provide for advanced undergraduate or graduate students. The syllabi can also be used as a guide for an effective SETI course taught at a descriptive level.

After a pilot course in 2015, UCLA formally offered a course titled "EPSS C179/279 - Search for Extraterrestrial Intelligence: Theory and Applications" in Spring 2016. The course was designed for advanced undergraduate students and graduate students in the science, technical, engineering, and mathematical fields. In 2016, 9 undergraduate students and 5 graduate students took the course. Students designed an observing sequence for the Arecibo and Green Bank telescopes, observed known planetary systems remotely, wrote a sophisticated and modular data processing pipeline, analyzed the data, and presented the results. In the process, they learned radio astronomy fundamentals, software development, signal processing, and statistics. The instructor believes that the students were eager to learn because of the engrossing nature of SETI. The students rated the course highly, in part because of the observing experience and the teamwork approach. The next offering will be in Spring 2017.

See lxltech.com and seti.ucla.edu

Author(s): Larry Lesyna[6], Jean-Luc Margot[2], Adam Greenberg[5], Akshay Shinde[1], Yashaswi Alladi[1], Srinivas Prasad MN[3], Oliver Bowman[2], Callum Fisher[5], Szilard Gyalay[5], William McKibbin[5], Brittany E. Miles[5], Donald Nguyen[5], Conor Power[3], Namrata Ramani[4], Rashmi Raviprasad[5], Jesse Santana[5]
Institution(s): *1. Department of Computer Science, University of California, Los Angeles, 2. Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, 3. Department of Electrical Engineering, University of California, Los Angeles, 4. Department of Materials Science and Engineering, University of California, Los Angeles, 5. Department of Physics and Astronomy, University of California, Los Angeles, 6. LXL Technology*

333.04 – "Pretty Pictures" with the HDI
The Half-Degree Imager (HDI) has been in use on the 0.9-m WIYN telescope since October 2013. The instrument has well served the consortium as evidenced by the posters in this session and presentations at the concurrent special session held at this meeting. One thing that has been missing from the mix are aesthetically pleasing images for use in publicity and public outreach. Making "pretty pictures" with a scientific instrument such as HDI presents a number of challenges and opportunities. The chief challenge is finding the time to do the basic imaging given the limited telescope time available to users. Most users are understandably reluctant to take time away from imaging for their scientific research to take images whose primary purpose is to make a pretty picture. Fortunately, imaging of some objects to make pretty pictures can be done under sky conditions that are less than ideal when photometric studies would have limited usefulness. Another challenge is the raw HDI images must be converted from an extended FITS format into a normal FITS and a filter line added to the header to make the images usable by most commercially available image processing software. On the plus side, pretty picture images can serve to inspire prospective students into astronomy. Austin Peay State University has a popular astrophotography class that makes use of images taken with the HDI camera to introduce students to basic image processing techniques. The course is taken by both physics majors on the astrophysics track and non-science majors completing the astronomy minor. Pretty pictures can also be used as a recruitment tool to bring students into astronomy. APSU houses physics, biology, chemistry, agriculture and medical technology in the same building and displaying astronomical pictures at strategic locations around the building serves to recruit non-science majors to take more astronomy courses. Finally, the images can be used in publicity and outreach efforts by the university. This poster presents some of the techniques used in processing the images tor aesthetic value and how those images are used in recruitment, publicity and outreach. Several of the finished images in poster-sized prints will be available for viewing.

Author(s): Spencer L. Buckner[1]
Institution(s): *1. Austin Peay State Univ.*

333.05 – Demonstrating Supernova Remnant Evolution
We have created a software tool to calculate at display supernova remnant evolution which includes all stages from early ejecta dominated phase to late-time merging with the interstellar medium. The software was created using Python, and can be distributed as Python code, or as an executable file. The purpose of the software is to demonstrate the different phases and transitions that a supernova remnant undergoes, and will be used in upper level undergraduate astrophysics courses as a teaching tool. The usage of the software and its graphical user interface will be demonstrated.

Author(s): Denis A. Leahy[1], Jacqueline Williams[1]
Institution(s): *1. Univ. of Calgary*

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334 – K12 & Citizen Science Research Collaborations: Involving Scientists, Teachers, & Students Poster Session

334.01 – Effective Models for Scientists Engaging in Meaningful Education and Outreach
We present a central paradigm, extending the model of "Teacher-Scientist" partnerships towards a new philosophy of "Scientist-Instructor-Learner-Communicator" Partnerships. In this paradigm modes of, and expertise in, communication, and the learners themselves, are held is as high status as the experts and teachers in the learning setting.

We present three distinctive models that rest on this paradigm in different educational settings. First a model in which scientists and teachers work together with a communications-related specialist to design and develop new science exploration tools for the classroom, and gather feedback from learners. Secondly, we present a model which involves an ongoing joint professional development program helping scientists and teachers to be co-communicators of knowledge exploration to their specific audience of learners. And thirdly a model in which scientists remotely support classroom research based on online data, while the teachers and their students learn to become effective communicators of their genuine scientific results.

This work was funded in part by the American Association for the Advancement of Science, and by NASA awards NNX16AC68A and NNX16AJ21G. All opinions are those of the authors.

Author(s): Jacob Noel-Storr[1], Isaiah Gurule[1]
Institution(s): *1. InsightSTEM*
Contributing team(s): InsightSTEM Teacher-Scientist-Communicator-Learner Team

334.02 – The NASA/IPAC Teacher Archive Research Program (NITARP): Lessons Learned
NITARP, the NASA/IPAC Teacher Archive Research Program, gets teachers involved in authentic astronomical research. We partner small groups of educators with a professional astronomer mentor

for a year-long original research project. The teams echo the entire research process, from writing a proposal, to doing the research, to presenting the results at an American Astronomical Society (AAS) meeting. The program runs from January through January. Applications are available annually in May and are due in September. The educators' experiences color their teaching for years to come, influencing hundreds of students per teacher. In support of other teams planning programs similar to NITARP, in this poster we present our top lessons learned from running NITARP for more than 10 years. Support is provided for NITARP by the NASA ADP program.

Author(s): Luisa M. Rebull[1], Varoujan Gorjian [1], Gordon K. Squires[1]
Institution(s): *1. Caltech*

334.03 – NITARP: Changing Perceptions of Science Among Secondary Students and Teachers

The NASA/IPAC Teacher Archival Research Program (NITARP) provides secondary teachers and their students with an authentic, high-level research experience. NITARP participants work alongside one another as colleagues, allowing both teachers and students to experience the challenges of actual research. Teachers and students learn that science doesn't always follow the prescriptive methodology taught in most high schools. Current NITARP students and teachers were interviewed on how their perceptions of the methods by which science is really conducted changed over the course of the program. Following participation in the NITARP program, both teacher and student perceptions of how science operates were found to have changed in many ways.

Author(s): Russell Kohrs3, Kelly Kilts[2], Vincent Urbanowski5, Thomas Rutherford4, Varoujan Gorjian[1]
Institution(s): *1. JPL, 2. Lexington High School, 3. Massanutten Regional Governor's School for Environmental Science and Technology, 4. Sullivan South High School, 5. The Academy of Information Technology and Engineering*

334.04 – STEM Education is Missing This.......

STEM education gets a lot of attention in schools, media, politics, and funding. But while the acronym grows from STEM to STEAM to STREAM, we still see a lack of student participation in real science, using big data and building partnerships with professionals in the field, and real student growth in science achievement. After the NITARP experience, we believe that NITARP is a rich, demanding, and authentic experience for dedicated teachers and students that provides a caliber of learning that is hard, if not impossible, to achieve in the traditional classroom. This poster looks at what STEM still needs to be and become for it to be the driving force behind greater student involvement, interest, and increased academic performance in the sciences. We focus on our own experiences and that of our students; our different teaching backgrounds and school environments; and the effects we see on our students using traditional and new STEM education and participation in the NITARP program. We come from backgrounds and situations that range from urban to rural, middle to high school, wide socioeconomic variety, gender differences, as well as different exposures to STEM opportunities.
We propose that traditional and current standards for STEM education are falling short of what is needed for students to truly experience, understand, and gain the skills to accurately apply and advance in science. Incoming and current science teachers at all levels are not provided with quality, realistic, or applicable preparation. NITARP is truly a STEM experience because it actually integrates the 4 fields and provides opportunities for students to experience the overlap of the 4 fields in an authentic way. The deep, long term exposure to authentic research and technology as well as opportunity to talk with working scientists in a variety of fields have a huge impact on the students and teachers alike. Exposure to programs and experiences like NITARP are needed to help drive and support STEM education to meet its goals and intentions. Support provided for this work by the NASA/IPAC Teacher Archive Research Program (NITARP), which receives funding from the NASA ADP program.

Author(s): Laura Orr4, Milton Johnson[1], Alexandra Miller3, Luisa M. Rebull[2]
Institution(s): *1. Bioscience High School, 2. Caltech, 3. Milken Community Schools, 4. Ukiah High School*

334.05 – Hawaii Student / Teacher Astronomy Research program (HI STAR): 10 years of high school students exploring the universe

For the past decade, the Hawaii Student / Teacher Astronomy Research program (HI STAR) at UH Manoa's Institute for Astronomy has trained astronomy-enthusiastic high school students in research, data analysis and science presentation skills. Every summer, a selected group of 8th-to-12th-grade students attend a week-long residential astronomy "camp" in Honolulu, Hawaii. The students experience the profession of astronomy by learning scientific skills such as imaging and spectroscopy, data-reduction, and data analysis. The week culminates with presention of a research project guided by professional astronomer mentors. During the following six months, each student continues to work with a mentor to complete a research project for submission to their local science fair. From 2012 - 2015, ~80% of students completed their long-term projects. Many have performed well; in each of 2015 and 2016, 5 alumni progressed to the International Science and Engineering Fair. Here we present the current structure of HI STAR and plans for the future.

Author(s): Geoffrey Mathews[2], James Armstrong[1], Michael A. Nassir[2], Carolyn Kaichi[1]
Institution(s): *1. Institute for Astronomy, 2. University of Hawaii at Manoa*

334.06 – Are We Alone? GAVRT Search for Extra Terrestrial Intelligence (SETI) Project

The Goldstone Apple Valley Radio Telescope Program (GAVRT) is a partnership between NASA's Jet Propulsion Laboratory and the Lewis Center for Educational Research. The program is an authentic science investigation program for students in grades K through 12 and offers them the ability to learn how to be a part of a science team while they are making a real contribution to scientific knowledge.

Using the internet from their classroom, students take control of a 34-meter decommissioned NASA radio telescope located at the Goldstone Deep Space Network complex in California. Students collect data on strong radio sources and work in collaboration with professional radio astronomers to analyze the data.

Throughout history man has wondered if we were alone in the Universe. SETI - or the Search for Extra Terrestrial Intelligence - is one of the programs offered through GAVRT that is designed to help answer that question. By participating in SETI, students learn about science by doing real science and maybe, if they get very lucky, they might make the most important discovery of our lifetime: Intelligent life beyond Earth!

At St. Mary's School, students in grades 6-12 have participated in the project since its inception. The St. Mary's Middle School Astronomy Club is leading the way in their relentless search for ET and radio telescope studies. Students use the radio telescope to select a very small portion of the Milky Way Galaxy - or galactic plane - and scan across it over and over in the hopes of finding a signal that is not coming from humans or radio interference. The possibility of being the first to discover an alien signal has kept some students searching for the past three years. For them to discover something of this magnitude is like winning the lottery: small chance of winning - big payoff. To that end, the club is focusing on several portions of the Milky Way where they have detected a strong candidate in the past. The hope is to pick it up a second and third time. If that happens, the club will be one step closer to proving intelligent life does exist.

Author(s): Holly Bensel[1], Ian Cool[1]
Institution(s): *1. St. Mary's School*
Contributing team(s): St. Mary's High School Astronomy Club , St. Mary's Middle School Astronomy Club

334.07 – Highschool astronomy research workshop in Thailand and how it transforms Thai astronomy education

The National Astronomical Research Institute of Thailand (NARIT) have launched the program "Advance Teacher Training Workshop" that aims to introduce both the students and astronomy teacher alike to the nature of critical thinking in science via hands on experience in astronomy projects. Students and accompanying teachers are participated in 5 days workshop in which each of them must select an individual astronomy research project. The project is then carried out on their own for the next 6 months, after which their works are presented in a conference. Progress is monitored and extra aid is delivered as needed via the use of social media. Over a hundred projects have been completed under this program. Follow up study have suggests that this workshop has shown to be quite successful at improving critical thinking skills in participants. As the program became more popular, other schools began to follow. To support the growing interest, we have also launched the "Thai Astronomical Society: student session", a highschool astronomy conference for anyone who participated or interested in astronomy related projects. Via these stages we are able to secure a permanent foothold in Thai astronomy education and inspire new generations to participate in astronomy projects.

Author(s): Matipon Tangmatitham[1]
Institution(s): *1. Michigan Technical University*

334.08 – Confirming and Improving Ross Variable Star RV Del

RV Del is an intrinsic pulsating variable star in the constellation Delphinus, discovered by Ross (1926). The AAVSO list RV Del as a RRAB type of variable star. RV Del has been found to have a magnitude that varies from 12.9 - 14.2 and a period of 11.9553 hours.

The purpose of our research of RV Del is to confirm and improve previous results as well as explore different methods to engage middle school students in the scientific method and astronomy. The SKYNET network of telescopes allows students to request images from a group of international research class telescopes. The telescope request process allows students first-hand experience in astronomy while the data analysis allows students to understand advance software systems to produce publishable results. Data is being gathered using the SKYNET network and Stone Edge Observatory to gather photometry of RV Del and create a new light curve. Findings will be presented the January 2017 AAS.

Author(s): Tyler R. Linder[1], Rick Sanchez[2], Sage Palser[2], Kendra Schultze[2], Jessica Kenney[2], Briana Thompson[3], Richard DeCoster[3], Frank Mills[3], Wayne Osborn[3], Vivian L. Hoette[3]
Institution(s): *1. Astronomical Research Institute, 2. Johnson County School District, 3. Yerkes Observatory*
Contributing team(s): Skynet Junior Scholars , Stone Edge Observatory

334.09 – Visual Double Stars - St. Mary's High School Astronomy Club

The St. Mary’s School Astronomy Club is working towards measuring positions and angles of relatively unstudied visual binary stars. We are starting with confirming prior results we obtained at the Pine Mountain Observatory Summer Science Research Workshop in 2009 - 2012 on ARY 52 (Frey et al. 2009, JDSO), Iota Bootis (Bensel et al. 2009, JDSO), and Mizar (Bensel et al. 2009, JDSO). We are also comparing our results with those published in the Washington Double Star Catalog (Mason 2009). We are using Pine Mountain Observatory’s remote imaging 14-inch Meade Schmidt-Cassegrain telescope equipped with a CCD camera operated by Scott Fisher at the University of Oregon and local astronomer Sean Curry’s 12.5" PlaneWave CDK telescope. We are practicing using tools such as astrometry.net and DS9 software to measure positions and angles on known double stars with well established values before attempting new measurements. Our next project will be to study “neglected visual double stars,” lesser studied double stars with fainter magnitudes. (A neglected double star is one that has not been observed extensively or recently.)

Double star analysis is relatively straight forward and can be performed with equipment available to most high schools. Educational outcomes include instrument setup, orientation, instruction, observations, analysis, presentation of data, and writing up findings for publication. Accurate recording of data is a useful and important life skill for all students to learn. Another important life skill is learning to work together to accomplish a specific goal. This project allows novice and experienced observers to work hand-in-hand to accomplish a specific goal, such as the publishing of a research paper in the Journal of Double Star Observations.

Author(s): Holly Bensel[1], Thanh Tran[1], Sean Hicks[1], Yifan He[1], Mitchell Moczygemba[1], Yuqi Shi[1], Leah Sternenberg[1], Kaycia Watson[1], kieran rooney[1], Paige Birmingham[1], Ruiyang You[1]
Institution(s): *1. St. Mary's School*

334.10 – South African Student Constructed Indlebe Radio Telescope

The Indlebe Radio Telescope (IRT) is a small transit telescope with a 5 m diameter parabolic reflector working at 21 cm. It was completely constructed by South African (SA) students from the Durban University of Technology (DUT), where it is located. First light occurred on 28 July 2008, when the galactic center, Sagittarius A, was detected. As a contribution to the International Year of Astronomy in 2009, staff members in the Department of Electronic Engineering at DUT in 2006 decided to have their students create a fully functional radio telescope by 2009. The specific project aims are to provide a visible project that could generate interest in science and technology in high school students and to provide a real world system for research in radio astronomy in general and an optimization of low noise radio frequency receiver systems in particular. These aims must be understood in terms of the SA’s government interests in radio astronomy. SA is a partner in the Square Kilometer Array (SKA) project, has constructed the Karoo Array Telescope (KAT) and MeerKat, which is the largest and most sensitive radio telescope in the southern hemisphere. SA and its partners in Africa are investing in the construction of the African Very Long Baseline Interferometry Network (AVN), an array of radio telescopes throughout Africa as an extension of the existing global Very Long Baseline Interferometry Network (VLBI). These projects will allow SA to make significant contributions to astronomy and enable astronomy to contribute to the scientific education and development goals of the country. The IRT sees on a daily basis the transit of Sag A. The transit time is influenced by precession, nutation, polar motion, aberration, celestial pole offset, proper motion, length of the terrestrial day and variable ionospheric refraction. Of these eight factors six are either predictable or measureable. To date neither celestial pole offset nor variable ionospheric refraction are predicable. Currently, we are comparing the observed transit times of Sag A with the calculable predications in order to obtain information over these two factors, with a view to better understanding them.

Author(s): Charles H. McGruder[2], Stuart MacPherson[1], Gary Peter Janse Van Vuuren[1]
Institution(s): *1. Durban University of Technology, 2. Western Kentucky Univ.*

334.11 – Results of Needs Assessments Related to Citizen Science Projects

The CosmoQuest Virtual Research Facility invites the public and classrooms to participate in NASA Science Mission Directorate related research that leads to publishable results and data catalogues. One of the main goals of the project is to support professional scientists in doing science and the general public--including parents, children, teachers, and students--in learning and doing science. Through the effort, the CosmoQuest team is developing a variety of supports and opportunities to support the doing and teaching of science. To inform our efforts, we have implemented a set of needs surveys to assess the needs of our different audiences. These surveys are being used to understand the interests, motivations, resources, challenges and demographics of our growing CosmoQuest community and others interested in engaging in citizen science projects. The surveys include those for teachers, parents, adult learners, planetarium professionals, subject matter experts (SMEs), and the general public. We will share the results of these surveys and discuss the implications of the results for broader education and outreach programs.

Author(s): Sanlyn Buxner[1], Georgia Bracey[2], Anna Glushko[2], Maya Bakerman[1], Pamela L. Gay[2]
Institution(s): *1. Planetary Science Institute, 2. Southern Illinois University Edwardsville*
Contributing team(s): CosmoQuest Team

334.12 – Recording A Sunrise: A Citizen Science Project to Enhance Sunrise/set Prediction Times

Smartphones, with their ever increasing capabilities, are becoming quite instrumental for data acquisition in a number of fields. Understanding refraction and how it affects what we see on the horizon is no exception. Current algorithms that predict sunrise and sunset times have an error of one to four minutes at mid-latitudes (0° - 55° N/S) due to limitations in the atmospheric models they incorporate. At higher latitudes, slight changes in refraction can cause significant discrepancies, even including difficulties determining when the Sun appears to rise or set. A thorough investigation of the problem requires a substantial data set of observed rise/set times and corresponding meteorological data from around the world, which is currently lacking. We have developed a mobile application so that this data can be taken using smartphones as part of a citizen science project. The app allows the viewer to submit a video of sunrise/set and attaches geographic location along with meteorological data taken from a local weather station. The project will help increase scientific awareness in the public by allowing members of the community to participate in the data-taking process, and give them a greater awareness of the scientific significance of phenomenon they witness every day. The data from the observations will lead to more complete rise/set models that will provide more accurate times to the benefit of astronomers, navigators, and outdoorsmen. The app will be available on the Google Play Store.

Author(s): Teresa Wilson[1], Malynda Chizek Frouard[2], Jennifer L. Bartlett[2]
Institution(s): *1. Michigan Technological University, 2. United States Naval Observatory*

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335 – Education Resources & Projects Spanning Broad Audiences Poster Session

335.01 – Multimedia Astronomy Communication: Effectively Communicate Astronomy to the Desired Audience

A fundamental aspect of our jobs as scientists is communicating our work to others. In this, the field of astronomy holds the double-edged sword of ubiquitous fascination: the topic has been of interest to nearly the entire global population at some point in their lives, yet the learning curve is steep within any subfield and rife with difficult-to-synthesize details. Compounding this issue is the ever-expanding array of methods to reach people in today's Communications Era. Each communication medium has its own strengths and weaknesses, is appropriate in different situations, and requires its own specific skillset in order to maximize its functionality. Despite this, little attention is given to training astronomers in effective communication techniques, often relying on newcomers to simply pick up the ability by mimicking others and assuming that a firm grasp on the subject matter will make up for deficiencies in communication theory. This can restrict astronomers to a narrow set of communication methods, harming both the communicators and the audience who may struggle to access the information through those media.

Whether writing a research paper to academic peers or giving an astronomy talk to a pubic audience, successfully communicating a scientific message requires more than just an expert grasp on the topic. A communicator must understand the makeup and prior knowledge of the desired audience, be able to break down the salient points of the topic into pieces that audience can digest, select and maximize upon a medium to deliver the message, and frame the message in a way that hooks the audience and compels further interest. In this work we synthesize the requirements of effective astronomy communication into a few key questions that every communicator needs to answer. We then discuss some of the most common media currently used to communicate astronomy, give both effective and poor examples of utilizing these media to communicate astronomy, and provide key strategies to consider when communicating via each medium. Be it to peers through journals and conferences, a funding source review board, students in a classroom, or the general public, the value of our community's work is enhanced by our abilities to disseminate that information to others.

Author(s): Kimberly Michelle Star Cartier[1], Jason Wright[1]
Institution(s): *1. Pennsylvania State University*

335.02 – Astrobites: Engaging Undergraduate Science Majors with Current Astrophysical Research

Astrobites is a graduate-student organization that publishes an online astrophysical literature blog (astrobites.com). The purpose of the site is to make current astrophysical research accessible to and exciting for undergraduate physical science majors and astronomy enthusiasts, and the site now hosts an archive of over 1300 posts summarizing recent astrophysical research. In addition, Astrobites presents posts on career guidance, practical 'how-to' articles, conference summaries, and astronomy news. Astrobites has an average of more than 1000 pageviews per day and reaches not only its target audience of undergraduates, but also graduate students and professionals within astronomy, astronomy enthusiasts, and educators. As we enter our seventh year of successful blogging, we share here the most up-to-date summary of our organization, readership, and growth.

Author(s): Michael Zevin[1]
Institution(s): *1. Northwestern*
Contributing team(s): Astrobites

335.03 – APOD Data Release of Social Network Footprint for 2015

APOD data for 2015 are being made freely available for download and analysis. The data includes page view statistics for the main NASA APOD website at https://apod.nasa.gov, as well as for APOD's social media sites on Facebook, Instagram, Google Plus, and Twitter. General APOD-specific demographic information for each site is included. Popularity statistics that have been archived including Page Views, Likes, Shares, Hearts, and Retweets. The downloadable Excel-type spreadsheet also includes the APOD title and (unlinked) explanation. This data is released not to highlight APOD's popularity but to encourage analyses, with potential examples involving which astronomy topics trend the best and whether popularity is social group dependent.

Author(s): Robert J. Nemiroff3, David Russell3, Alice Allen[2], Paul Connelly[1], Stuart R. Lowe[1], Sydney Petz[1], Ralf Haring[1], Jerry T. Bonnell[1]
Institution(s): *1. APOD, 2. Astrophysics Source Code Library, 3. Michigan Technological Univ.*
Contributing team(s): APOD Team

335.04 – Active Galactic Videos: A YouTube Channel for Astronomy Education and Outreach

Active Galactic Videos is an astronomy-focused YouTube channel run by a team at the University of Arizona. The channel has two main purposes: to produce educational content for public audiences, and to learn about astronomy and to open a window into the world of professional astronomy by showcasing the work done at Steward Observatory and in Southern Arizona. Our team consists of faculty, staff, and students from a variety of backgrounds including: astronomy, education, film, music, english, and writing. In addition to providing educational content for public audiences, this project provides opportunities for undergraduate students to learn about astronomy content, educational practice, and science communication while developing the practical skills needed to write, film, score, direct, and edit videos that effectively engage and teach viewers about topics in astronomy. The team has produced various styles of video: presentational, interviews, musical/poetic, and documentaries. In addition to YouTube, the Active Galactic Videos team maintains a social media presence on Facebook, Twitter, and Instagram. These help to widely distribute the content as well as to publicize the main Youtube channel. In addition to providing an overview of our educational work, this poster will present a year's worth of online analytics that we are using to better understand our audience, to examine what videos have been popular and successful and how people are accessing our content. We will present our experience in order to help others learn about improving astronomy education online, and astronomy communication and outreach in general.

Author(s): Carmen Austin[1], Jenny Calahan[1], Alexandria Resi Baucco[1], Christopher William Bullivant[1], Ross Eckley[1], W. Haydon Ekstrom[1], M. Ryleigh Fitzpatrick[1], Taylor Fay Genovese[1], Chris David Impey[1], Kaitlin Libby[1], Galen McCaw[1], Alexander N Olmedo[1], Joshua Ritter[1], Matthew Wenger[1], Stephanie Williams[1]
Institution(s): *1. University of Arizona*

335.05 – When Will It Be ...?: U.S. Naval Observatory Religious Calendar Computers Expanded

Reflecting increasing sensitivity to differing religious practices, the U.S. Naval Observatory (USNO) has expanded its on-line calendar resources to compute additional religious dates for specific years via an Application Programming Interface (API). This flexible method now identifies Christian, Islamic, and Jewish events in JavaScript Object Notation (JSON) that anyone can use.
Selected Christian Observances (http://aa.usno.navy.mil /data/docs/easter.php) returns dates of eight events for years after 1582 C.E. (A.D. 1582): Ash Wednesday, Palm Sunday, Good Friday, Easter, Ascension, Whit Sunday, Trinity Sunday, and the first Sunday of Advent. The determination of Easter, a moveable feast, uses the method of western Christian churches.
Selected Islamic Observances (http://aa.usno.navy.mil/data/docs /islamic.php) returns approximate Gregorian dates of three events for years after 1582 C.E. (A.H. 990) and Julian dates for 622–1582 C.E. (A.H. 1–990) along with the corresponding Islamic year (*anno Hegirae*). Ramadân, Shawwál, and the Islamic year begin at sunset on the preceding Gregorian or Julian date. For planning purposes, the determination of these dates uses a tabular calendar; in practice, observation of the appropriate waxing crescent Moon determines the actual date, which may vary.
Selected Jewish Observances (http://aa.usno.navy.mil/data/docs /passover.php) returns Gregorian dates of six events for years after 1582 C.E. (A.M. 5342) and Julian dates for the years 360–1582 C.E. (A.M. 4120–5342) along with the corresponding Jewish year (*anno Mundi*). Passover, Shavuot, Rosh Hashanah, Yom Kippur, and Hanukkah begin at sunset on the preceding Gregorian or Julian date.
On-line documentation for using the API-enabled calendar computers, including sample calls, is available (http://aa.usno.navy.mil/data/docs/api.php). The webpage also describes how to use the API with the Complete Sun and Moon Data for One Day, Phases of the Moon, Solar Eclipse Computer, Day and Night Across the Earth, Apparent Disk of a Solar System Object, Julian Date Conversion, and Sidereal Time services.
Introduction to Calendars (http://aa.usno.navy.mil/faq/docs /calendars.php) provides an overview of the topic and links to additional resources.

Author(s): Jennifer L. Bartlett[2], Malynda Chizek Frouard[2], Cross Ziegler[1], Michael V. Lesniak[2]
Institution(s): *1. Science and Engineering Apprenticeship Program, 2. US Naval Observatory*

335.06 – Planning for the Future: Revealing Underrepresented Stories in the History of Physics and Astronomy

Women and minorities are, and have historically been, underrepresented in the physical sciences. This summer we wrote and revised over 40 teaching guides that highlight the often forgotten contributions of women and minorities to the physical sciences. Of these guides, 18 focus on astronomy/astrophysics specifically. We have ensured that these teaching guides meet national educational standards, fit well into social and natural science curricula, and are available for free online. They include lesson plans, worksheets, PowerPoints and readings. We intend for these resources to be easily integrated into classrooms from the first grade through the college level, and that they provide students with a diverse set of role models while also calling attention to ongoing diversity issues in STEM.

Author(s): Victoria DiTomasso[2], Samantha Spytek[4], Stephen Neal[3], Lance Burch[1], Gregory Good[1]
Institution(s): *1. American Institute of Physics, 2. CUNY Macaulay Honors College at Hunter College, 3. University of Wisconsin-Madison, 4. Virginia Polytechnic Institute and State University*

335.07 – Astronomers Who Write Science Fiction: Using SF as a Form of Astronomy Outreach

In a recent survey, I have identified 21 living professional astronomers who write science fiction, plus a yet uncounted number of physicists. Many of the science fiction stories by this group involve, as you might imagine, reasonable extrapolation from current scientific ideas and discoveries. These stories, some of which are available free on the Web or are collected in inexpensive anthologies, represented a method of astronomy outreach to which relatively little attention has been paid. I will list the authors identified in the survey and provide a representative list of their stories or novels, organized by astronomical topic. I will also discuss how written SF (and SF films based on ideas by scientists, such as Kip Thorne's "Interstellar") can be used in general education classes and public programs. Scientists do not need to cede the field to wizards, dragons, and zombies! (Note: The author is included in the list of 21, having published two short stories in two different anthologies recently.)

Author(s): Andrew Fraknoi[1]
Institution(s): *1. Foothill College*

335.08 – Conceptualizing Astronomical Distances for Urban Populations

Students living in urban environments may have a washed-out night sky, but their enthusiasm for astronomy can still shine bright. As an educator, it can sometimes be a challenge to see the opportunities afforded by city living to the teaching of astronomy; however, several benefits can be identified. For example, the intrinsic understanding children have of the distances and scales involved in their everyday life is enhanced when they live in a regimented urban structure. This existing understanding of scale is critical to building a foundation for later conceptualizing of the universe.
Leveraging the assets of New York City and the resources found in the American Museum of Natural History, The Science and Nature Program offers students (PreK through 8th grade) robust science learning experiences. To address concepts important for studying astronomy, we present a novel twist on the classic lesson “Earth as a Peppercorn,” by scaling the solar system to the size of New York City. Using local landmarks and their distance in relation to the Museum to represent the planets, students can use their prior knowledge of their surroundings to appreciate the impressive scale of our neighborhood in space in the context of their own neighborhoods. We correlate the activity with NGSS standards,

present preliminary feedback on it's success, and discuss the opportunities to apply a similar model lesson to other astronomical systems.

Author(s): Mark Popinchalk[1], Kristen Olson[1], Jenny Ingber[1], Mariel O'Brien[1]
Institution(s): *1. American Museum of Natural History*

335.09 – Dark Skies, Bright Kids Year 8

We present activities from the eighth year of Dark Skies Bright Kids (DSBK), an entirely volunteer-run outreach organization based out of the Department of Astronomy at the University of Virginia. Our core mission is to enhance elementary science education and literacy in Central Virginia through fun, hands-on activities that introduce basic Astronomy concepts. Over the past seven years, our primary focus has been hosting an 8-10 week after-school astronomy club at underserved elementary and middle schools, and over the past several years, we have partnered with local businesses to host our Annual Central Virginia Star Party, a free event open to the community featuring star-gazing and planetarium shows. This past summer we expanded our reach through a new initiative to bring week-long summer day camps to south and southwest Virginia, home to some of the most underserved communities in the commonwealth.

Author(s): Lauren E. Bittle[2], Trey Wenger[2], Kelsey E. Johnson[2], Dylan Angell[2], Andrew Burkhardt[2], Blair Davis[1], Ariel Firebaugh[2], Danielle Hancock[2], Whitney Richardson[2], Christian Rochford Hayes[2], Sean Linden[2], Sandra Liss[2], Allison Matthews[2], Shunlante McNair[2], Brian Prager[2], Matthew Pryal[2], Nicholas William Troup[2]
Institution(s): *1. Albemarle County Virginia Public Schools, 2. University of Virginia*

335.10 – If You Planet, They Will Come: Reviving the CCNY Planetarium

The planetarium at CUNY-City College of New York (CCNY), located in the Harlem neighborhood of NYC, has reopened its doors. Originally installed in 1973, the CCNY Planetarium had previously hosted bi-weekly shows for its own student body and for neighboring public schools throughout the 1970s, 80s and 90s. In the early 2000s, planetarium programming declined to a few shows every several years, closing its doors in late 2013. Since its revival in Spring 2016, students have run planetarium shows on the local night sky, dark energy, cosmic inflation and habitable exoplanets along with rooftop astronomy events, allowing many CCNY students to view Saturn, Jupiter and the surface of the moon through a telescope for the first time. Each of these events has been attended to capacity (75+ attendees per event), resulting in higher astronomy interest and engagement on campus. Over 80% of CCNY's student body is composed of underrepresented populations in STEM, and the CCNY Planetarium provides an access point for current undergraduate students along with visiting elementary/high school students to gain an interest in STEM and learn about career paths in astronomy and physics. We share statistics on current engagement along with plans to incorporate cross-discipline collaborations with local public schools.

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Institution(s): *1. CUNY - Hunter College, 2. CUNY - The City College of New York*

335.11 – The Expanding Universe of Astronomy on Tap

Astronomy on Tap (AoT) is a constellation of free public outreach presentations held in bars. AoT events aim to engage audiences who might not choose to attend public lectures in a university setting by creating an informal atmosphere and combining scientific talks with music, games, and prizes. The events have a flexible format, typically consisting of between one and three astronomy-related presentations, sometimes with additional games and trivia, and some locations also produce merchandise. The flexible structure means that the format can be adapted to the resources available in the location and the time commitment the local organizers are willing to make. Some events are broadcast online through live streaming, with some others being posted to YouTube. In conjunction with an active social media presence, this ensures engagement beyond those able to attend events in person. Astronomy on Tap events have now been held in 20 cities around the world and are typically organised by postdocs and graduate students, with some involvement from faculty and outreach or education staff. Holding these events under the global AoT constellation facilitates knowledge transfer, sharing of resources, and networking opportunities for scientists interested in outreach/communication. The events have been highly successful, with some locations regularly attracting more than 200 people per month. In this poster we describe the goals and characteristics of AoT events, the different adaptations by various locations, the resources we have developed, and provide information for those interested in starting a new event in their location.

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336 – Promoting Research, Mentorship, & Diversity for Astronomy Majors Poster Session

336.01 – CAMPARE and Cal-Bridge: Two Institutional Networks Increasing Diversity in Astronomy

We describe two programs, CAMPARE and Cal-Bridge, with the common mission of increasing participation of groups traditionally underrepresented in astronomy, through summer research opportunities, in the case of CAMPARE, scholarships in the case of Cal-Bridge, and significant mentoring in both programs, creating a national impact on their numbers successfully pursuing a PhD in the field.

In 7 years, the CAMPARE program has sent 80 students, >80% from underrepresented groups, to conduct summer research at one of 14 major research institutions throughout the country. The graduation rate among CAMPARE scholars is 98%, and of the CAMPARE scholars who have graduated with a Bachelor's degree, more than 60% have completed or are pursuing graduate education in astronomy or a related field, at institutions including UCLA, UC Riverside, UC Irvine, UC Santa Barbara, USC, Stanford, Univ. of Arizona, Univ. of Washington, and the Fisk-Vanderbilt Master's-to-PhD program.

Now entering its third year, the Cal-Bridge program is a CSU-UC Bridge program comprised of over 75 physics and astronomy faculty from 5 University of California (UC), 9 California State University (CSU), and 14 California Community College (CCC) campuses in Southern California. In the first three years, 22 Cal-Bridge Scholars have been selected, including 11 Hispanic, 3 African-American and 8 female students, 5 of whom are from URM groups. Nineteen (19) of the 22 Cal-Bridge Scholars are first-generation college students. The entire first cohort of 4 Cal-Bridge scholars was accepted to one or more PhD programs in astronomy or physics, including UC Irvine, UC Santa Cruz, UC Davis, Michigan State, and Georgia State Universities. The second cohort of 8 Cal-Bridge scholars is applying to graduate schools this fall.

Cal-Bridge provides much deeper mentoring and professional development experiences over the last two years of undergraduate and first year of graduate school to students from this diverse network of higher education institutions. Cal-Bridge Scholars benefit from substantial financial support, intensive, joint mentoring by CSU and UC faculty, professional development workshops, and exposure to research opportunities at the participating UC campuses.

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336.02 – AstroCom NYC: Equity, Inclusion, and the Next Generation of Astrophysicists

AstroCom NYC is an undergraduate mentoring program designed to improve urban minority student access to opportunities in astrophysical research by greatly enhancing partnerships between research astronomers in New York City (City University of New York – an MSI, American Museum of Natural History, and Columbia). AstroCom NYC provides centralized, personalized mentoring as well as financial and academic support, to CUNY undergraduates throughout their studies, plus the resources and opportunities to further CUNY faculty research with students. The goal is that students' residency at AMNH helps them build a sense of belonging in the field, and readies and inspires them for graduate study. AstroCom NYC provides a rigorous Methods of Scientific Research course developed specifically to this purpose, a laptop, research and career mentors, outreach activities, scholarships and stipends, Metrocards, and regular assessment for maximum effectiveness. The goal of this support is to remove barriers to access and success. AMNH serves as the central hub for our faculty and students, who are otherwise dispersed among all five boroughs of the City. We welcomed our fourth cohort last year, along with 25 additional students through a NASA community college initiative. Our advanced AstroCom NYC students earned external summer internships at REU sites, and we had our first graduate school acceptance. We review plans for Year 5, when we have a number of graduate school applicants, and our deepening participation and leadership within partner activities.

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336.03 – The National Astronomy Consortium (NAC)

The National Astronomy Consortium (NAC) program is designed to increase the number of underrepresented minority students into STEM and STEM careers by providing unique summer research experiences followed by long-term mentoring and cohort support. Hallmarks of the NAC program include: research or internship opportunities at one of the NAC partner sites, a framework to continue research over the academic year, peer and faculty mentoring, monthly virtual hangouts, and much more. NAC students also participate in two professional travel opportunities each year: the annual NAC conference at Howard University and poster presentation at the annual AAS winter meeting following their summer internship.

The National Astronomy Consortium (NAC) is a program led by the National Radio Astronomy Consortium (NRAO) and Associated Universities, Inc. (AUI), in partnership with the National Society of Black Physicist (NSBP), along with a number of minority and majority universities.

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336.04 – Results from a Pilot REU Program: Exploring the Cosmos Using Sloan Digital Sky Survey Data

In the Summer of 2016 we conducted a 10-week pilot Research Experience for Undergraduates (REU) program aimed at increasing the participation of underrepresented minority undergraduate students in research using data from the Sloan Digital Sky Survey (SDSS). This program utilized a distributed REU model, whereby students worked with SDSS scientists on exciting research projects while serving as members of a geographically distributed research community. The format of this REU is similar to that of the SDSS collaboration itself, and since this collaboration structure has become a model for the next generation of large scale astronomical surveys, the students participating in the SDSS REU received early exposure and familiarity with this approach to collaborative scientific research. The SDSS REU also provided the participants with a low-risk opportunity to audition for graduate schools and to explore opportunities afforded by a career as a research scientist.

The six student participants were placed at SDSS REU host sites at the Center for Astrophysics at Harvard University, University of Wisconsin–Madison, Vanderbilt University, and the University of Portsmouth. Their research projects covered a broad range of topics related to stars, galaxies, and quasars, all making use of SDSS data. At the start of the summer the REU students participated in a week-long Boot Camp at NMSU, which served as a program orientation, an introduction to skills relevant to their research projects, and an opportunity for team-building and cohort-forming. To foster a sense of community among our distributed students throughout the summer, we conducted a weekly online meeting for all students in the program via virtual meeting tools. These virtual group meetings served two purposes: as a weekly check-in to find out how their projects were progressing, and to conduct professional development seminars on topics of interest and relevance to the REU participants. We discuss the outcomes of this pilot REU program and future plans for involving underrepresented minority undergraduate students in SDSS-related research.

This work was supported by a grant from Sloan Foundation to the Astrophysical Research Consortium.

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336.05 – The FAST Initiative: Fostering a More Inclusive SDSS Collaboration

The success of the Sloan Digital Sky Survey (SDSS) hinges on tapping into a diverse talent base. From our experience, however, it is clear that simply allowing access to SDSS data is not enough to increase the participation of underrepresented minorities in the collaboration. For this reason, the SDSS collaboration instituted the Faculty and Student Team (FAST) Program, which pairs teams of faculty and students from underrepresented groups with SDSS partners to build serious, long-term research collaborations. Our intent is to build capacity at the faculty level to propagate SDSS research to students in the long-term. We present the FAST initiative in detail and outline results from the first 1.5 years of the program.

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336.06 – The NRAO Observing for University Classes Program

The NRAO "Observing for University Classes" program is a tremendous resource for instructors of courses in observational astronomy. As a service to the astronomical and educational communities, the NRAO offers small amounts of observing time on the Very Large Array (VLA) and the Very Long Baseline Array to such instructors. The data can be used by students and faculty to demonstrate radio astronomy theory with modern data products. Further, the results may lead to publication; this is a unique opportunity for faculty members to integrate research into the classroom. Previous experience with NRAO facilities is required for instructors; individuals without radio astronomy experience can take advantage of other NRAO educational opportunities (e.g., the Synthesis Imaging Workshop) prior to using the program. No previous experience with radio astronomy data is required for students; this is the primary target audience of the program. To demonstrate concept, this poster describes three different VLA observing programs that have been completed using the "Observing for University Classes" resource at Macalester College; undergraduate students have published the results of all three of these programs. Other recent "Observing for University Classes" programs are also described.

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336.07 – Introducing Research Methods to Undergraduate Majors Through an On-Campus Observatory with The University of Toledo's Ritter Observatory

With a 1-m telescope on the University of Toledo (OH) main campus, we have initiated a grad student-undergraduate partnership to help teach the undergraduates observational methods and introduce them to research through peer mentorship. For the last 3 years, we have trained up to 21 undergraduates (primarily physics/astronomy majors) in a given academic semester, ranging from freshman to seniors. Various projects are currently being conducted by undergraduate students with guidance from graduate student mentors, including constructing three-color images, observations of transiting exoplanets, and determination of binary star orbits from echelle spectra. This academic year we initiated a large group research project to help students learn about the databases, journal repositories, and online observing tools astronomers use for day-to-day research. We discuss early inclusion in observational astronomy and research of these students and the impact it has on departmental retention, undergraduate involvement, and academic success.

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Contributing team(s): Ritter Observing Team

336.08 – Spectroscopic Instrumentation in Undergraduate Astronomy Laboratories

We have designed and built two spectrographs for use in undergraduate astronomy laboratories at the University of Iowa. The first, a low cost (appx. $500) low resolution (R ~ 150 - 300) grating-prism (grism) spectrometer consists of five optical elements and is easily modified to other telescope optics. The grism spectrometer is designed to be used in a modified filter wheel. This type of spectrometer allows students to undertake projects requiring sensitive spectral measurements, such as determining the redshifts of quasars. The second instrument is a high resolution (R ~ 8000), moderate cost (appx. $5000) fiber fed echelle spectrometer. The echelle spectrometer will allow students to conduct Doppler measurements such as those used to study spectroscopic binaries. Both systems are designed to be used with robotic telescope systems. The availability of 3D printing enables both of these spectrographs to be constructed in hands-on instrumentation courses where students build and commission their own instruments. Additionally, these instruments enable introductory majors and non-majors laboratory students to gain experience conducting their own spectroscopic observations.

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336.09 – Variable Stars as an Introduction to Computational Research

As a part of larger effort to enhance the research activity at SC State and involve more undergraduates in research activities, we present our efforts to develop an introductory research experience where the goal is a balance of astrophysical understanding, general research skills, and programming skills which the students can carry into a wide variety of future research activities. We have found that variable stars are a very good topic for this sort of introductory experience due to a combination of factors including: accessibility of data, easily understandable physical processes, and a relatively straight forward data analysis process. We will present an outline of our research experiences to guide a student from the very initial stages of learning to final presentation of the student's work.

“This work was supported in part by NSF PAARE award AST-1358913 and NSF HBCU-UP award HRD-1332449 to SCSU.”

Author(s): Jennifer Cash[1], Donald K. Walter[1]
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337 – Gen. Ed. Astronomy (Astro 101): Courses, Classroom, Design, & Student Research Poster Session

337.01 – A General Education Course in Cultural Astronomy: Exploring the Universe Through Human Eyes

Astronomy courses for non-science majors (often referred to as Astro 101) are the bread and butter of the general education service obligation of astronomy faculty and programs across the US. Their content has traditionally been a general survey of the solar system, stars and galaxies, or even the entire universe. However, because the audience is students who will not be continuing on in astronomy, there is actually no need to cover a broad range of specific topics. Rather, it is more important to concentrate on the scientific *process*, and hopefully leave the student with an understanding of the relevance of science in everyday life, regardless of his or her major. As a result, some faculty prefer a more interdisciplinary focus for their Astro 101 classes, for example courses on the search for extraterrestrial life. Another option for general education astronomy courses is what has become known as *cultural astronomy*. Cultural astronomy focuses on the ways in which astronomical knowledge and belief influences human behavior and social structures. Under this umbrella fall two important areas of study, *archaeoastronomy* (concentrating on ancient cultures) and *enthoastronomy* (focusing on extant cultures). Such interdisciplinary courses draw heavily upon archaeology, history, anthropology, art, and other fields more traditionally aligned with the humanities and social sciences than the natural sciences, and therefore can be attractive to students in these non-science majors. In such courses, students experience the “humanity” of science: the important connections between science and the human experience, and how experts in myriad fields contribute in meaningful ways to our understanding of how astronomical knowledge has been constructed and disseminated across time and space. This poster describes the content and pedagogy of a general education course in cultural astronomy for non-science majors that stresses hands-on and experiential learning, including the use of planispheres, sundials, simple sextants, astrolabes and the planetarium, as well as the integration of mathematics, myth, and creative writing.

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Institution(s): *1. Central Connecticut State University*

337.02 – The Art of Astronomy: A New General Education Course for Non-Science Majors

The Art of Astronomy is a new general education course developed at Indiana University. The topic appeals to a broad range of undergraduates and the course gives students the tools to understand and appreciate astronomical images in a new way. The course explores the science of imaging the universe and the technology that makes the images possible. Topics include the night sky, telescopes and cameras, light and color, and the science behind the images. *Coloring the Universe: An Insider's Look at Making Spectacular Images of Space*" by T. A. Rector, K. Arcand, and M. Watzke serves as the basic text for the course, supplemented by readings from the web. Through the course, students participate in exploration activities designed to help them first to understand astronomy images, and then to create them. Learning goals include an understanding of scientific inquiry, an understanding of the basics of imaging science as applied in astronomy, a knowledge of the electromagnetic spectrum and how observations at different wavelengths inform us about different environments in the universe, and an ability to interpret astronomical images to learn about the universe and to model and understand the physical world.

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Institution(s): *1. Indiana University*

337.03 – Teaching Astronomy Classes and Labs in a Smart Classroom

Saint Anselm College is a small liberal arts college in New Hampshire with an enrollment of approximately 1900 students. All students are required to take one science course with a laboratory component. Introduction to Astronomy is now being offered in regular rotation in the Department of Physics, taking advantage of the new "smart" classrooms with the technology and set up to encourage active learning. These classrooms seat 25 students and feature 5 "pods," each with their own screen that can be hooked up to a student computer or one of the iPads available to the professor. I will present how these classrooms are used for Introduction to Astronomy and related courses under development for active learning. Since the class requires a laboratory component and New Hampshire weather is notably unpredictable, the smart classroom offers an alternative using freely available computer simulations to allow for an alternative indoor laboratory experience.

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337.04 – Update on the NSF PAARE Program at SC State

We report on results from our NSF PAARE program during Year 2 of the project. Our partnership under this PAARE award includes South Carolina State University (a Historically Black College/University), Clemson University (a Ph.D. granting institution) as well as individual investigators at NASA Ames and Carnegie Mellon University. Our recent work on variable and peculiar stars, work with the Kepler Observatory and our educational products in cosmology for non-STEM majors will be presented.

We have successfully piloted sharing our teaching resources by offering an upper-level astrophysics course taught at Clemson via video conferencing , allowing a graduating senior from SC State to take a course not available through his home institution. Additionally, we are working on a memorandum of agreement between the two institutions that will allow for the seamless transfer of an undergraduate from SC State to Clemson's graduate program in physics and astronomy. Our curriculum work includes new web-based cosmology activities and laboratory experiments.

SC State undergraduates are reporting at this conference on their work with the light curves of semiregular variables using Kepler data. Additionally, we are heavily involved in the *Citizen CATE Experiment*. A PAARE scholarship student from SC State and the PAARE PI traveled to Indonesia for the March 2016 solar eclipse. Their results are also being presented elsewhere at this conference (see Myles McKay's poster).

Support for this work includes our NSF PAARE award AST-1358913 as well as resources and support provided by Clemson University and the National Optical Astronomy Observatory. Additional support has been provided by the South Carolina Space Grant Consortium and from NASA to SC State under awards NNX11AB82G and NNX13AC24G. CATE work has been supported by NASA SMD award NNX16AB92A to the National Solar Observatory. Additional details can be found at: http://physics.scsu.edu

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338 – Internships, Fellowships, & Observatory Management Training for High School Students, Majors, & Graduates Poster Session

338.01 – Summer Internships for Students through the Air Force Research Laboratory's Scholars Program

Did you know that the Air Force Research Laboratory (AFRL) has sponsored a summer research program for students for the last 15 years? The AFRL Scholars Program hires high school, undergraduate, and graduate students as payed interns for 12-18 weeks each summer to work on space science and astronomy projects at one of four AFRL locations. By now, more than 1200 students from 34 states have participated. Like advisors in other summertime astrophysics research programs, the AFRL mentors benefit from extra staff for their research efforts at no cost (the Scholars are funded centrally within AFRL). Likewise, the students benefit from summer pay, job experience in a science lab, university housing, and comradery with students from other states. Pay is based on the intern's academic level with the range being $395/week for high school up to $1115/week for recent Ph.Ds. Benefits not available from other programs include a secret clearance, socializing with a cohort exceeding 100 peers, and exposure to a pathway to a professional science career outside academia. Benefits to AFRL include persuading young people to choose science-technical-engineering-math (STEM) degrees, and roughly 89% of participants show increased interest in STEM courses following their internship.
In this poster, we present the advantages to college students (and their mentors) to participating. We outline the topic areas, 60% of which are related to space science and astronomy. We quantify the range of participants' scholastic level and majors, as well as the impact the program has on stimulating STEM careers and sight stories of students going onto rewarding careers in AFRL. To be eligible, an applicant must be a U.S. citizen, at least 16 years old, available to work a 40-hour business week, agree to a background check, and be enrolled at the time of application. To apply for the summer 2017 program, start at http://afrlscholars.usra.edu.

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Institution(s): *1. Air Force Research Lab*

338.02 – Shrinking the Gap Between Science Policy and Scientists

As an American Institute of Physics Policy intern with the House Committee on Science, Space, and Technology; I was able to work closely with staff on science policy issues currently being handled in the House of Representatives. The intersection of science and policy work is crucial to the continuation of current science programs as well as development of new opportunities as time progresses. There are a small number of people who work on these legislative topics and scientists have a responsibility to assist them in their work as the policies created and enacted today can affect the entire science community for many years to come. I will speak briefly on some of the ways in which legislation can be made, as well as the ways in which scientists, and even students in the science community, can interact effectively with policy creators to help make decisions that will benefit the science community as a whole. I will also highlight some of the most effective methods to determine who is important to keep in touch with, as well as how to maintain an open dialogue in which one can help inform him/her on relevant topics.

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338.03 – The LSSTC Data Science Fellowship Program

The Large Synoptic Survey Telescope Corporation (LSSTC) Data Science Fellowship Program (DSFP) is a unique professional development program for astronomy graduate students. DSFP students complete a series of six, one-week long training sessions over the course of two years. The sessions are cumulative, each building on the last, to allow an in-depth exploration of the topics covered: data science basics, statistics, image processing, machine learning, scalable software, data visualization, time-series analysis, and science communication. The first session was held in Aug 2016 at Northwestern University, with all materials and lectures publicly available via github and YouTube. Each session focuses on a series of technical problems which are written in iPython notebooks. The initial class of fellows includes 16 students selected from across the globe, while an additional 14 fellows will be added to the program in year 2. Future sessions of the DSFP will be hosted by a rotating cast of LSSTC member institutions. The DSFP is designed to supplement graduate education in astronomy by teaching the essential skills necessary for dealing with big data, serving as a resource for all in the LSST era. The LSSTC DSFP is made possible by the generous support of the LSST Corporation, the Data Science Initiative (DSI) at Northwestern, and CIERA.

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Contributing team(s): The LSSTC DSFP Leadership Council

338.04 – The Lowell Observatory Predoctoral Scholar Program

Lowell Observatory is pleased to solicit applications for our Predoctoral Scholar Fellowship Program. Now beginning its ninth year, this program is designed to provide unique research opportunities to graduate students in good standing, currently enrolled at Ph.D. granting institutions. Lowell staff research spans a wide range of topics, from astronomical instrumentation, to icy bodies in our solar system, exoplanet science, stellar populations, star formation, and dwarf galaxies. The Observatory's new 4.3 meter Discovery Channel Telescope is now operating at full science capacity. Student research is expected to lead to a thesis dissertation appropriate for graduation at the doctoral level at the student's home institution. For more information, see http://www2.lowell.edu/rsch/predoc.php and links therein. Applications for Fall 2017 are due by May 1, 2017; alternate application dates will be considered on an individual basis.

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Institution(s): *1. Lowell Observatory*

338.05 – Educational Programs for Graduate Level Learners and Professionals - National Radio Astronomy Observatory National and International Non-Traditional Exchange Program

The National Radio Astronomy Observatory’s (NRAO) National and International Non-Traditional Exchange (NINE) Program teaches concepts of project management and systems engineering to chosen participants within a nine-week program held at NRAO in New Mexico. Participants are typically graduate level students or professionals. Participation in the NINE Program is through a competitive process. The program includes a hands-on service project designed to increase the participants knowledge of radio astronomy. The approach demonstrate clearly to the learner the positive net effects of following methodical approaches to achieving optimal science results.

The NINE teaches participants important sustainable skills associated with constructing, operating and maintaining radio astronomy observatories. NINE Program learners are expected to return to their host sites and implement the program in their own location as a NINE Hub. This requires forming a committed relationship (through a formal Letter of Agreement), establishing a site location, and developing a program that takes into consideration the needs of the community they represent. The anticipated outcome of this program is worldwide partnerships with fast growing radio astronomy communities designed to facilitate the exchange of staff and the mentoring of under-represented groups of learners, thereby developing a strong pipeline of global talent to construct, operate and maintain radio astronomy observatories.

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339 – The Sun Poster Session

339.01 – The Evershed Effect from the Photosphere to the Chromosphere

The Evershed effect is the observed Doppler shift of spectral lines within a sunspot due to flows of plasma. In the photosphere, the Evershed effect is interpreted as a horizontal outflow of plasma with a maximum speed of 1-2 km/s, while in the chromosphere, the inverse Evershed effect is interpreted as an inflow with a speed reaching 5-6 km/s. In this project, we study the Evershed effect from the photosphere to the chromosphere in order to determine line-of-sight flow velocity and inclination. We present line-of-sight velocity maps and their azimuthal dependence based on spectroscopic observations of four different spectral lines. From the azimuthal dependence of the velocity we find flow vectors at varying radial distances from the center of the sunspot. In the photosphere, the flow speed reaches a maximum of around 1.6 km/s within the penumbra, and the outflow maintains a nearly horizontal inclination. In the chromosphere, the inflow speed reaches 3.8 km/s in the superpenumbra as it acquires a descending vertical component that tilts the flow by as much as 20° below the horizontal. Spectral observations of the boundary between the photosphere and chromosphere show slight indications of inflow at speeds less than 0.5 km/s. Our results contribute to the understanding of the inverse Evershed flow in the chromosphere, which is thought to have a different driving mechanism than the photospheric Evershed flow.

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339.02 – A Chromospheric Flare Model Consisting of Two Dynamical Layers: Critical Tests from IRIS Data of Solar Flares

Recent 1D radiative-hydrodynamic simulations of flares have shown that a heated, chromospheric compression layer and a stationary layer, just below the compression, are produced in response to high flux electron beam heating. The hot blackbody-like continuum and redshifted intensity in singly ionized chromospheric lines in these model predictions are generally consistent with broad wavelength coverage spectra of M dwarf flares and with high spectral resolution observations of solar flares, respectively. We critically test this two-component chromospheric flare model against the Fe II profiles and NUV continuum brightness for several X-class solar flares observed with the Interface Region Imaging Spectrograph (IRIS). We present several new predictions for the Daniel K. Inoue Solar Telescope (DKIST).

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339.03 – Non-Equilibrium Ionization Modeling of Coronal Mass Ejections

Coronal Mass Ejections, or CMEs, are solar events that eject plasma and magnetic flux into interplanetary space. Contemporary sources have noted that the onset of CMEs are caused by some instability of the coronal magnetic field, and further allows heating of plasma upon expansion. Additionally, plasma that leaves the lower solar corona does not remain in ionization equilibrium due to the rapid expansion of plasma. We investigate the evolution of charge states of CME plasma using non-equilibrium ionization (NEI) modeling. These NEI models include radiative cooling and serve as baseline studies for special cases where no heat is being added to the plasma. Each of the simulated CMEs have initial conditions characteristic of active regions. Various function inputs, such as initial temperature, density and final velocity, allow us to examine the influence of certain parameters on the charge state evolution. The results of our project show that plasma originating from active regions display charge state evolutions substantially dependent on initial density and temperature. The CMEs starting with higher plasma density often show an abundance of lower charge states above the freeze-in height. Simulations starting from higher temperatures often show abundance peaks at charge states with closed electron shells.

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339.04 – Three-Dimensional Potential-Field Source-Surface Modeling of the Evolution of Coronal Structures

White-light images of the solar corona indicate that, during each solar cycle, the global structure of the corona evolves as a function of cycle phase. Building a three-dimensional potential-field source-surface model of the corona, we investigate how the longitude-dependence of coronal structure varies during solar minimum. Using white-light images of the corona from the Mauna Loa Solar Observatory (MLSO) as guidance, we derive the global three-dimensional corona from our model-output as a function of Carrington rotation, focusing on the most recent three solar minima in 1986, 1996, and 2008. Longitude-dependent coronal structures seen in white-light images are reproduced by a linear combination of spherical harmonics combined with a radial boundary condition at the source-surface, taken at 2.5 solar radii. The coefficients of spherical harmonics up to the fifth degree, as well as their phase, are deduced by comparing model-output with MLSO observations. We find that (i) during typical solar minima (such as 1986, 1996), although the axial dipole dominates, small, time-varying multipole contributions are present when analyzed over a few rotations. In addition, we find that (ii) the unusual minimum in 2008 is multipole-dominated in contrast to the solar minimum corona in 1986 and 1996. (iii) The signature of a quadrupole contribution in the 1996 corona and the further increase of multipole components in the 2008 corona indicate that the departure from dipole at minimum originated during 1996. Further analysis of the present corona will likely indicate that the next solar minimum will be non-dipolar in nature. Our estimates of the variation of multipole contributions as a function of time can be used to constrain models of the three-dimensional solar dynamo.

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339.05 – Evolving Flare Ribbon Small-Scale Substructure: A Second Candidate

We present preliminary analysis on imaging and spectroscopic observations from the *Interface Region Imaging Spectrograph* (IRIS) of the evolution of the flare ribbon in the SOL2014-06-22T13:08 B-class flare event, at high spatial resolution and time cadence. IRIS is a solar observation satellite containing a high frame rate ultraviolet imaging spectrometer. This work continues the work started in Brannon et al 2015 by searching for small-scale substructure within flare ribbons, which manifest themselves as coherent quasiperiodic oscillations in both position and Doppler velocities. Using IRIS observations from October 2013 to June 2016, we selected candidate observations on the basis of physical characteristics, Si IV intensity, and shift in doppler velocity. In addition to our preliminary analysis and images, we present our techniques that can be used to find further observations also containing the periodic oscillations, and other small-substructure.

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339.06 – Data Mining Solar X-Ray Flares Triggered by Emerging Magnetic Flux

We investigate the association between emerging magnetic flux and solar X-ray flares to identify, and if possible quantify, distinguishing physical properties of flares triggered by flux emergence versus those triggered by other sources. Our study uses as its basis GOES-classified solar flares from March 2011 through June 2016 that have been identified by the Space Weather Prediction Center's flare detection algorithm. The basic X-ray flare data is then enriched with data about related EUV-spectrum flares, emerging fluxes, active regions, eruptions, and sigmoids, which are all characterized by event-specific keywords, identified via SDO feature finding tools, and archived in the Heliophysics Events Knowledgebase (HEK). Using appropriate spatial and temporal parameters for each event type to determine association, we create a catalogue of solar events associated with each GOES-classified flare. After accounting for the primitive state of many of these event detection algorithms, we statistically analyze the compiled dataset to determine the effects of an emerging flux trigger on flare properties. A two-sample Kolmogorov–Smirnov test confirms with 99.9% confidence that flares triggered by emerging flux have a different peak flux distribution than non-emerging-flux-associated flares. We observe no linear or logarithmic correlations between flares' and their associated emerging fluxes' individual properties and find flares triggered by emerging flux are ~ 10% more likely to cause an eruption inside an active region while outside of an active region, the flare's association with emerging flux has no effect on its likeliness to cause an eruption. We also compare the morphologies of the flares triggered by emerging flux and flares not via a superposed epoch analysis of lightcurves. Our results will be of interest for predicting flare behavior as a function of magnetic activity (where we can use enhanced rates of emerging flux as a proxy for heightened stellar magnetic activity).

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339.07 – Citizen CATE Experiment and Polar Plume Dynamics

During the summer of 2017, a total solar eclipse will pass over the continental United States, allowing millions of citizens the opportunity to experience a beautiful celestial event. The Citizen Continental-America Telescopic Eclipse (CATE) Experiment plans to harness the power of these many viewers by using volunteers from sites across the US to observe and record the total solar eclipse. The data acquired from each of these sites will be composed into a continuous 90-minute video, allowing the inner solar corona to be studied for an unprecedented length of time.

Observations in Indonesia of the March 2016 total solar eclipse allowed initial testing and analysis of the inner corona polar plume dynamics. Using MATLAB, a routine was developed to identify the polar coronal threads and their angle relative to the radial direction to analyze the field line behavior at the boundary of the polar coronal holes.

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Contributing team(s): Citizen CATE Team

339.08 – Methods on Efficiently Relating Data from the Sun to In-situ Data at L1: An Application to the Slow Solar Wind

Understanding space weather has become increasingly important as scientists and spacecraft extend their reach further into the universe. The solar wind is highly ionized plasma that constantly bombards the earth. It causes compression and relaxation in our magnetosphere, and affects spacecraft and astronauts in outer space. There are two types of solar wind, fast wind and slow wind. The fast wind is considered to be steady in composition and speed, and travels at speeds greater than 500 km/s. The slow solar wind is known for being highly variable in composition and speed, and travels at speeds less than 500 km/s. Fast solar wind originates from coronal hole regions on the sun, while the slow solar wind's origin is very controversial. There are currently two types of theories for slow solar wind. One theory involves wave heating dynamics, while the other contends that slow solar wind originates from magnetic reconnection that continually opens magnetic field lines. These models are currently under-constrained with both types able to reproduce the long-term, average behavior of the wind. To further constrain these models it was necessary to research small scale structure in the solar wind, however analyzing these structures pushes the limits of the current instrument capabilities. We developed techniques that provide an automated process to quickly generate results from multiple different analysis techniques, allowing the user to compare data from STEREO's Heliospheric Imager (HI) and from data taken at L1. This increases the efficiency and ability to relate data from the sun in HI and data at Earth at L1. These techniques were applied to a study on the slow solar wind which lead to possible evidence for the S-Web model.

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339.09 – Periodic Alpha Signatures and the Origins of the Slow Solar Wind

The origin of the slow solar wind has puzzled scientists for decades. Both flux tube geometry of field lines open to the heliosphere and magnetic reconnection that opens field lines that were previously closed to the heliosphere have been proposed as explanations (via the expansion factor and S-web models, respectively), but the observations to date have proven an inadequate test for distinguishing between the theories. However, short term (~hours) variability of alpha particles could provide the set of observations that tips the balance. Alpha particles compose about 4% of the solar wind, and its precise composition is determined by dynamics in the solar atmosphere. Therefore, compositional changes in the alpha to proton ratio must have originated at the Sun, making alphs tracer particles of sorts and carrying signatures of their solar creation. We examined *in situ* alpha density and proton density data from the Wind, ACE, STEREO-B, AND STEREO-A spacecraft, focusing on a pseudostreamer that occurred August 9, 2008. This case study found one clear periodic structure in the slow solar wind preceding the pseudostreamer in Wind/ACE and the same periodic structure in the *in situ* data at STEREO-B. The existence of this slow wind structure in association with a pseudostreamer directly contradicts the expansion factor model, which predicts that pseudostreamers produce fast wind. The structure's appearance at STEREO-B, which was located 30 degrees behind the Earth-Sun line, further indicates that the mechanism at the Sun is responsible for its formation was active for at least three days. Moreover, an analysis of both helmet streamer and pseudostreamer events between 2007-2009 finds that similar density structures exist in at least 35% of all streamers. This indicates that the same physical process that produces this slow solar wind occurs with a degree of frequency in association with both types of streamers. The clarity, duration, and frequency of these periodic density structures seem to support the S-web model over the expansion factor model and can provide additional constrains to slow solar wind models moving forward.

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340 – Molecular Clouds, HII Regions, Interstellar Medium & Dust Poster Session

340.01 – Mapping of the Local Interstellar Medium using Absorption Line Spectroscopy

Using the Yale SMARTS 1.5-meter telescope at CTIO and the CHIRON spectrograph, we have developed a program for mapping the local interstellar medium using a sample of over 200 newly observed B stars previously unobserved using Na I absorption lines. This sample includes stars that extend out to map beyond the local bubble to 500 pc. The sample has been observed using high resolution absorption lines, and when combined with previously observed stars with Na I and Ca II data provides a more complete picture of the local ISM than previous surveys. The distances to the stars using the new GAIA database also allows for more accurate determination of distances to features in the lcoal ISM, and new maps of the structure of the ISM hav been prepared with the data.

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340.02 – A Narrowband Emission-Line Survey of the Large Magellanic Cloud

The Large and Small Magellanic Clouds are unique in providing sites to study the interstellar medium (ISM) and its components at all scales, from small to global. The UM/CTIO Magellanic Cloud Emission-Line Survey (MCELS) began as a deep imaging survey of both of these nearby galaxies in the emission of Hα, [S II], and [O III]. These emission-line images are being used in detailed optical and multi-wavelength studies of planetary nebulae (PNe), H II regions, supernova remnants (SNRs), superbubbles, and supergiant shells. Here we present a deep and wide view of the 104 K ionized gas in the ISM of the Large Magellanic Cloud (LMC) using narrowband filters: Hα and [S II]. We present large-scale continuum subtracted optical emission-line mosaics of the 8x8 deg. central region of the LMC created from the combination of thousands of observations taken over hundreds of nights, providing a detailed view of most of the gaseous extent of the galaxy. With these mosaics in hand we conduct a systematic analysis of the physical conditions of 59 known X-ray SNRs in the LMC. For 50 of these SNRs, Hα and [S II] flux values along with [S II] / Hα emission-line ratios have been derived. All derived [S II] / Hα emission-line ratios ≥ 0.4, strengthening their identification as true remnants. We compare our values to spectroscopic values in the literature.

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Contributing team(s): MCELS Team

340.03 – Far-ultraviolet florescent molecular hydrogen emission map of the Milky Way Galaxy

We present the far-ultraviolet fluorescent molecular hydrogen (H_2) emission map observed with FIMS/SPEAR for ~76% of the sky. The fluorescent H_2 emission is found to be saturated by strong dust extinction at the optically thick, Galactic plane region. Nevertheless, the extinction-corrected intensity of the fluorescent H_2 emission is found to have strong linear correlations with the well-known tracers of the cold interstellar medium, such as the E(B-V) color excess, neutral hydrogen column density N(HI), Hα emission, and CO J=1→0 emission. The all-sky molecular hydrogen column density map is also obtained using a simple photodissociation region model with interstellar radiation fields derived from UV star catalogs. We also estimate the hydrogen molecular fraction (f_{H2}), CO-to-H_2 conversion factor (X_{CO}), and the gas-to-dust ratio of the diffuse interstellar medium. f_{H2} gradually increases from less than 1% at optically thin regions with E(B-V)<0.1 to ~50% for E(B-V) = 5. X_{CO} also tends to increase with E(B-V), but converges to the Galactic mean value of 1.8×10^{20} cm^{-2} K^{-1} km^{-1} s at optically thick regions where E(B-V) is larger than 2.0. The estimated gas-to-dust ratio is consistent with the standard value of 5.8×10^{21} atoms cm^{-2} mag^{-1}.

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340.04 – HST/STIS Observations of the Local Interstellar Medium toward Very Nearby Stars: A Detailed Analysis of the a Centuari Sight Line

The Local Interstellar Medium (LISM), a region extending about 100 parsecs and in which the Sun is currently immersed, can only be studied using UV/optical absorption features against bright background stars. Perhaps in the future in-situ measurements will be possible (e.g., the Voyager spacecraft or Breakthrough Starshot-style missions). Using high-resolution observations with the Space Telescope Imaging Spectrograph (STIS) on-board the *Hubble Space Telescope* (*HST*), we have analyzed several very nearby sight lines to measure physical properties of the LISM. The data used in this study is a part of the Advanced Spectral Library (ASTRAL) Project, an *HST* Large Treasury Project, in which we have analyzed the spectra of fourteen nearby stars. LISM absorption features in these stellar spectra reveal key information about the abundances, temperature, and turbulence in the intervening gas. We have fit ion transitions in the near-UV for MgII, FeII, CII, DI, SiII, and OII. These absorption features provide direct measurements of the radial velocity, Doppler broadening parameter, and the column density along the line of sight. The presence of multiple local minima in the deep and narrow ISM profile is evidence of multiple clouds moving at different radial velocities.

Included in our data set is the a Centauri sight line. We provide a detailed analysis of these new observations and a comparison with previous *HST* observations that were observed more than 20 years ago. A discussion of the physical properties along this line of sight is provided within the context of a Breakthrough Starshot mission. These high resolution and high signal-to-noise spectra will be important for making accurate estimations of the interstellar environment to help inform such an interstellar mission.

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340.05 – The Fan Region at 1.5 GHz with GMIMS: Polarized synchrotron emission tracing Galactic structure

Diffuse polarized radio continuum emission provides information about the structure of the Galactic magnetic field. With the Global Magneto-Ionic Medium Survey (GMIMS), we are mapping this emission from the entire sky from 300 to 1800 MHz. We will present a brief overview of the GMIMS survey.

We will focus on 1270-1750 MHz observations from the Northern hemisphere GMIMS data to determine the geometry of the magnetic field in the Fan Region. The Fan Region is one of the dominant features of the sky in polarized radio continuum, long thought to be a local (d < 500 pc) synchrotron emission feature. We find that the 1.5 GHz polarized radio emission is anti-correlated with Halpha emission from the Perseus Arm, 2 kpc away. This indicates that ionized gas in the Perseus Arm depolarizes about 30% of the Fan Region emission, indicating that some of the Fan Region emission originates in or beyond the Perseus Arm. The synchrotron emission must therefore be produced along a large path length, suggesting the presence of a coherent magnetic field in the plane in the outer Galaxy. We argue that the polarized emission from the Fan Region is a consequence of the structure of the Galactic magnetic field and ISM. We model beam depolarization due to the ISM, finding that in the presence of depolarization the rotation measure measured from polarized emission is much lower than that measured towards background point sources, explaining an observed discrepancy between the GMIMS rotation measures and background rotation measures.

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340.06 – The ALMA View of Dense Molecular Gas in 30 Doradus

At a distance of 50 kpc, the 30 Doradus region within the Large Magellanic Cloud (LMC) hosts several sites of star formation including R136, a starburst region home to dozens of evolved O stars. The intense radiation from R136 creates an extreme environment for nearby star formation in such a low-metallicity, low mass galaxy. We have targeted a star-forming region ~15 pc away from R136 within 30 Doradus using the Atacama Large Millimeter/submillimeter Array (ALMA) to map the molecular gas to study the sites of star formation. We are conducting a clump-by-clump analysis of the intensities and line ratios of dense gas (HCO^+, HCN, CS, $H^{13}CO^+$, $H^{13}CN$) and diffuse gas (CO, ^{13}CO, $C^{18}O$) tracers at sub-parsec resolution. We identify and characterize ~100 molecular clumps within the region. With the observed molecular species, we aim to determine the physical conditions of each clump (e.g. size, internal turbulence, molecular abundance). We compare the intensities and line ratios to non-LTE Radex model grids of the excitation temperature, molecular column density, and volume density of the H_2 collider to determine the physical excitation conditions within the clumps. We compare these properties of each clump to both associated and embedded star formation properties to quantify the relative importance of internal feedback from the star formation itself versus external feedback processes from R136 and determine which process dominates in this region.

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340.07 – Metallicity Structure in the Milky Way Disk

Elemental abundances are an important constraint on theories of the formation and evolution of the Milky Way. We use HII regions as a probe of the Milky Way's metallicity structure. HII regions are the brightest objects in the Galaxy at radio wavelengths and are detected across the entire Galactic disk. In thermal equilibrium, metal abundances are expected to set the nebular electron temperature with high abundances producing low temperatures. We derive the metallicity of HII regions using an empirical relation between an HII region's radio recombination line-to-continuum ratio and nebular metallicity. Our previous studies have revealed azimuthal metallicity structure in the Galactic disk, indicating that the disk may not be as well mixed as expected. To extend this work, we obtained high quality radio recombination line and radio continuum measurements of 120 HII regions across the Galactic disk using the Jansky Very Large Array. Here we describe the observations, data reduction pipeline, and preliminary results from this study.

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340.08 – The Milky Way Project: Mapping star formation in our home Galaxy, one click at a time

In the recent years, citizen science has helped astronomers comb through large data sets to identify patterns and objects that are not easily found through automated processes. The Milky Way Project (MWP), a popular citizen science initiative, presents internet users with images from the GLIMPSE, MIPSGAL, SMOG and CYGNUS-X surveys of the Galactic plane using the Spitzer Space Telescope. These citizen scientists are directed to make "classification" drawings on the images to identify targeted classes of astronomical objects. We present an updated data reduction pipeline for the MWP. Written from the ground up in Python, this data reduction pipeline allows for the aggregation of classifications made by MWP users into catalogs of infrared (IR) bubbles, IR bow shocks and “yellowballs” (which may be the early precursors of IR bubbles). Coupled with the more accurate bubble classification tool used in the latest iterations of the MWP, this pipeline enables for better accuracy in the shapes and sizes of the bubbles when compared with those listed in the first MWP data release (DR1). We obtain an initial catalog of over 4000 bubbles using 2 million user classifications made between 2012 and 2015. Combined with the classifications from the latest MWP iteration (2016-2017), we will use a database of over 4 million classifications to produce a MWP DR2 bubble catalog. We will also create the first catalog of candidate IR bow shocks identified through citizen science and an updated “yellowball” catalog. This work is supported by the National Science Foundation under grants CAREER-1454334 and AST-1411851.

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Contributing team(s): Milky Way Project Team

340.09 – The Milky Way Project: A Citizen Science Catalog of Infrared Bow Shock Nebulae

We present preliminary results from the first citizen-science search for infrared stellar-wind bow shock candidates. This search uses the Milky Way project, hosted by the Zooniverse, an online platform with over 1 million volunteer citizen scientists. Milky Way Project volunteers examine 77,000 randomly-distributed Spitzer image cutouts at varying zoom levels. Volunteers mark the infrared arc of potential bow shock candidates as well as the star likely driving the nebula. We produce lists of candidates from bow shocks flagged by multiple volunteers, which after merging and final visual review form the basis for our catalog. Comparing our new catalog to a recently-published catalog of 709 infrared bow shock candidates identified by a small team of (primarily undergraduate) researchers will allow us to assess the effectiveness of citizen science for this type of search and should yield a more complete catalog. Planned studies using these large catalogs will improve constraints on the mass-loss rates for the massive stars that create these bow shock nebulae. Mass-loss rates are highly uncertain but are a critical component of evolutionary models for massive stars. This work is supported by the National Science Foundation under grants CAREER-1454334, AST-1411851 (RUI) and AST-1412845.

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340.10 – The properties of the hot gaseous halo around the Milky Way

The hot gaseous halo around the Milky Way may accounts for a portion of the missing baryons. Previously, the density profile of the halo, which can be written as $n_o(1+(r/r_c)^2)^{-3\beta/2}$,is determined by the observation of O VII and O VIII in both emission and absorption. However, former studies failed to fully consider the optical depth effect which might be important. In this work, a radiative transfer code based on Monte Carlo method is adopted to simulate the radiation process and compare the result with observational data in the previous work in order to further constrain the parameters. Moreover, the simulation is done with and without the rotation of the halo to give a more detailed description of the hot gas halo.

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340.11 – A Multi-Wavelength View of the Environments of Extreme Clustered Star Formation

It is believed that the vast majority of, if not all, stars form within OB clusters. Most theories of star formation assume a star forms in isolation and ignore the fact that the cluster environment and, especially, the presence of extremely energetic and high mass young stellar objects nearby, may have a profound impact on the formation process of a typical cluster member. Giant HII (GHII) regions are Galactic analogs to starburst regions seen in external galaxies, hosting the most active areas of clustered star formation. As such, GHII regions represent a population of objects that can reveal a wealth of information on the environment of the earliest stages of clustered star formation and how it is affected by feedback from the most massive cluster members. This study employs new mid-infrared imaging data obtained from the airborne observatory, SOFIA, as well as archival imaging data from the near-infrared to cm radio wavelengths to create a rich multi-wavelength dataset of a dozen galactic GHII regions. These data allow quantification of the detailed physical conditions within GHII regions individually and as a population on both global and small scales.

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340.12 – A Deuteration Survey of the Clump Population in the Gemini OB1 Molecular Cloud

Recent maps of dust continuum emission from entire molecular clouds at submillimeter wavelengths have made it possible to survey and study the chemistry of entire core and clump populations within a single cloud. One very strong chemical process in star-forming regions is the fractionation of deuterium in molecules, which results in an increase in the deuterium ratio many orders of magnitude over the ISM [D]/[H] ratio and provides a chemical probe of cold, dense regions. We present a survey of DCO+ 3-2 and N2D+ 3-2 toward the clump population in the high-mass, star-forming Gemini OB1 Molecular Cloud identified from 1.1 mm continuum imaging by the Bolocam Galactic Plane Survey. The peak 1.1 mm continuum positions of 52 clumps in the range 188°≤ l ≤194° were observed with the 10m Heinrich Hertz Submillimeter Telescope. We find that DCO+ emission is detected toward 90% of the clumps with a median deuterium ratio of 0.01 while N2D+ emission is detected toward only 25% of the clumps. The DCO+ fractionation anti-correlates with gas kinetic temperature and linewidth, a measure of the amount of turbulence within the clumps. We compare the deuteration ratios of with physical properties of the clumps and their evolutionary stage.

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340.13 – WHAM Observations of the Gum Nebula and Energetic Neighbors

The Wisconsin Hα Sky Survey (WHAM-SS) reaches sensitivity levels of about 0.1 R (EM ~ 0.2 pc cm^{-6}) with emission detected toward every direction in the sky. Each pointing of the survey comprises a spatially integrated spectrum from a one-degree beam covering at least 200 km/s around the Local Standard of Rest with 12 km/s spectral resolution. WHAM was designed primarily to study the pervasive warm ionized medium component of the interstellar medium but also reveals many large-scale, locally-ionized regions throughout the Galaxy. In this work, we focus on the complex network of shell-like and filamentary emission from the Vela-Puppis-Antlia regions of the Galaxy (l = 240° to 290°, b = -30° to +35°). Several smaller supernovae remnants (Vela, Vela Jr., Puppis; r < 5°) are superimposed near (or perhaps embedded within) several larger structures (Gum, Antlia; r > 10°) that dominate the diffuse Hα sky. This impressive collection of extended ionized structures is notably adjacent to two other large, local Galactic features: the Orion-Eridanus superbubble and the Monogem Ring supernova remnant. Leveraging the kinematic and multiline (including [S II], [N II], [O III], & Hβ) capabilities of WHAM, we report on our early efforts to disentangle the objects, their environment, and their history. WHAM has been designed, built, and operated primarily through support of the National Science Foundation. The current research presented here is funded by award AST-1108911.

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340.14 – The impact of galactic environment on star formation

While spiral arms are the most prominent sites for star formation in disk galaxies, interarm star formation contributes significantly to the overall star formation budget. However, it is still an open question if the star formation proceeds differently in the arm and inter-arm environment. We use deep VLT/MUSE optical IFU spectroscopy to resolve and fully characterize the physical properties of 428 interarm and arm HII regions in the nearby grand design spiral galaxy NGC 628. Unlike molecular clouds (the fuel for star formation) which exhibit a clear dependence on galactic environment, we find that most HII region properties (luminosity, size, metallicity, ionization parameter) are independent of environment. One clear exception is the diffuse ionized gas (DIG) contribution to the arm and interarm flux (traced via the temperature sensitive [SII]/Halpha line ratio inside and outside of the HII region boundaries). We find a systematically higher DIG background within HII regions, particularly on the spiral arms. Correcting for this DIG contamination can result in significant (70%) changes to the star formation rate measured. We also show preliminary results comparing well-corrected star formation rates from our MUSE HII regions to ALMA CO(2-1) molecular gas observations at matched 1"=50pc resolution, tracing the Kennicutt-Schmidt star formation law at the scales relevant to the physics of star formation. We estimate the timescales relevant for GMC evolution using distance from the spiral arm as a proxy for age, and test whether star formation feedback or galactic-scale dynamical processes dominate GMC disruption.

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Contributing team(s): SFNG Collaboration

340.15 – Properties of Low Metallicity Molecular Clouds: A 0.3 Parsec Resolution Map of SMC B1 #1

Stars form in molecular clouds, therefore understanding their structure is important in understanding this key process in galaxy evolution. Studies of clouds in the Milky Way have provided insight to their internal structures, but until recently we have not been able to study clouds in low metallicity conditions at the same resolution. We use the Atacama Large Millimeter Array to map a molecular cloud in the nearby, low metallicity galaxy the SMC at 0.3 pc spatial resolution in 12CO (2-1). We use the CPROPS algorithm (Rosolowsky & Leroy 2006) to measure structural properties of the cloud (mass, size, velocity dispersion, temperature) and compare to molecular clouds in the Milky Way observed at comparable resolution. We present the results of this comparison and discuss the CO-to-H2 conversion factor, virial parameter and mass-radius-velocity dispersion relationships (i.e. Larson's Laws) for the cloud.

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340.16 – Examining Gaseous Behavior of Galaxies and their Environments

The development of galaxies hinges upon the behavior of the gas within and around them, as this is paramount to understanding the regulation of star formation. To investigate these processes, we analyzed data from the MaNGA survey for two galaxies with nearby background quasars for which Hubble Space Telescope data exists. We plotted and analyzed spectra for various elemental transitions, especially [N II] , [O III], and H-alpha, to gain information about gas properties such as temperature, ionization fraction, and star formation. We also plotted velocity fields based upon the gas motions as determined through Doppler shift. One of the galaxies displayed signs of heavy star formation and the other displayed signs of Active Galactic Nucleus activity. The stellar and gaseous velocity fields of the AGN galaxy were very disparate which suggests some sort of interaction with another galaxy in the galaxy's past. The properties of the gas in these galaxies could potentially teach us more about the evolutionary path of the Milky Way, which forms stars itself while interacting heavily with other galaxies. This work base on data from the forth-generation Sloan Digital Sky Survey (SDSS-IV)/Mapping Nearby Galaxies at Apache Point Observatory (MaNGA), and is part of the Project No.0034 in SDSS-IV.

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340.17 – Discovering the Lowest Metallicty z<1 Galaxies

Through the use of the NII/Hα ratio, an empirical method used in calculating metallicity, a sample of single emission line galaxies from the DEEP2 survey (472 Objects) was examined in the pursuit of finding extremely metal poor (XMP) galaxies. We calculate the upper limits for the NII flux against our measurements of Hα for each object. Of the 166 objects containing Hα and NII wavelength coverage, one galaxy at z=0.08 is a terrific candidate, having maximum 12+log(O/H) ≤ 7.7.

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340.18 – Spectroscopic Study of Low Mass Members of NGC 2244

The results of a near-infrared spectroscopic study of low-mass stars in open cluster NGC 2244 are presented. JH spectra of the stars were obtained using the FLAMINGOS instrument at KPNO. To determine cluster membership, we used *Spitzer Space Telescope* mid-infrared photometry along with X-ray detections from the *Chandra X-ray Observatory*. The stars were spectral typed using absorption line ratios and spectral shapes. The stars were then plotted on an H-R diagram along with theoretical isochrones. We discuss these results in context of cluster evolution in the Rosette Molecular Complex. Work supported, in part, by the Dr. John W. Martin Summer Science Research Institute at Bridgewater College.

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340.20 – *Herschel* Far Infrared Spectra of Dusty Star-Forming Galaxies

We stack archival spectra from the Herschel Space Observatory's SPIRE Spectrometer in three redshift bins from low redshifts ($z < 0.2$), through intermediate redshifts ($0.2 < z < 1$), and up to high redshifts ($z > 1$) in order to determine the average properties of the gas and dust in dusty, star-forming galaxies and (U)LIRGs. In the lower-redshift stack, we detect a host of water and carbon monoxide rotational transition lines, as well as some fine structure lines such as [NII]. At intermediate redshifts, only a [CII] line appears. The high-redshift stack displays strong [CII] emission, as well as faint emission from [OI] and [OIII]. The observed emission lines are used to model the average number density and radiation field strength in the photodissociation regions of our high-redshift sample, and the spectral line energy distributions of CO rotational transitions from the low-redshift stack are presented.

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340.21 – The Vertical Structure of Diffuse Ionized Gas in Galactic Spiral Arms

The Wisconsin H-Alpha Mapper provides the most sensitive velocity resolved observations of diffuse Hα, [S II] λ6716, and [N II] λ6584 emission in the Galaxy, tracing the warm (~8000K) ionized component of the interstellar medium. The vertical extent of this diffuse gas can directly impact the midplane pressure, influencing cold molecular clouds and star formation in the disk. Here, we analyze the vertical structure of the warm ionized medium around multiple spiral arm components of the Galaxy. Diffuse halo emission is isolated using longitude varying velocity channels guided by CO emission tracing cold molecular gas in the disk. We find exponential electron density squared (or emission measure) scale heights and analyze its behavior as a function of Galactocentric radius and the presence of cold molecular clouds and star forming regions in the disk. Statistical analysis of the behavior of [S II]/Hα and [N II]/Hα line ratios along some of these spiral arms disentangle the complex physical conditions of the warm ionized gas as a function of height and in-situ electron density. Some spiral arm sections, in particular the far Carina arm, have significantly larger (>3x) scale heights than previously studied arms that tend to increase as a function of Galactocentric radius.

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340.22 – Aggregate growth in a protoplanetary disk

We present a method to model the growth of neutral and charged dusts in a turbulent protoplanetary disk, and analyze their collision probabilities. Coagulation of dust aggregates plays an important role in the formation of planets and is of key importance to the evolution of protoplanetary disks. In our method, the temporal evolution of the dusts is followed by Monte Carlo algorithm, and the inter-particle interactions are calculated by Aggregate_Builder (AB), which is a code used to model the collision process of aggregates. First an aggregate library is built and all the aggregates are binned according to their sizes. In each iteration, the collision rate for aggregates from any two bins are computed, which determines the time it takes for the next collision to happen and which two aggregates are selected for collision. Then the AB codes are used to calculate the interaction of the two aggregates. The relative velocity between the two aggregates is the vector sum of Brownian velocity and the turbulent velocity. The latter is calculated by ATHENA, which is a grid-based code for astrophysical magnetohydrodynamics. In each iteration, it's determined whether the two aggregates hit or miss. In the case of hit, it either sticks or bounces as determined by the critical velocity. As a result, the neutral aggregates are more porous than the charged ones. For a certain size of incoming aggregates, the neutral ones have a higher collision probability than the charged ones. Also, similarly-sized aggregates have lower collision probabilities than aggregates with large size dispersions. This research enables us to determine which physical properties have a greater impact on the collision rate. By tracing the dust size distribution, we can identify the stage when they settle out to the mid-plane and how long it takes to develop to that stage. In the hit-stick regime, our results are consistent with the experiments which shows that when the velocity is smaller than the critical bouncing velocity, the dust aggregates grow to very fluffy structures, and larger aggregates have a lower bouncing velocity. However, our model doesn't include dust restructuring and fragmentation, which will be considered in future work.

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340.23 – Properties of compact HII regions and their host clumps in the inner vs outer Galaxy - early results from SASSy

We present a catalog of compact and ultracompact HII regions for all Galactocentric radii. Previous catalogs focus on the inner Galaxy (Rgal ≤ 8 kpc) but the recent SASSy 870 μm survey allows us to identify regions out to ~20 kpc. Early samples are also filled with false classifications leading to uncertainty when deriving star formation efficiencies in Galactic models. These objects have similar mid-IR colours to HII regions. Urquhart et al. (2013) found that they could use mid-IR, submm, and radio data to identify the genuine compact HII regions, avoiding confusion. They used this method on a small portion of the Galaxy ($10 < l < 60$), identifying 213 HII regions embedded in 170 clumps. We use ATLASGAL and SASSy, crossmatched with RMS, to sample the remaining galactic longitudes out to Rgal = 20 kpc. We derive the properties of the identified compact HII regions and their host clumps while addressing the implications for recent massive star formation in the outer Galaxy. Observations towards nearby galaxies are biased towards massive stars, affecting simulations and overestimating models for galactic evolution and star formation rates. The Milky Way provides the ideal template for studying factors affecting massive star formation rates and efficiencies at high resolution, thus fine-tuning those models. We find that there is no significant change in the rate of massive star formation in the outer vs inner Galaxy. Despite some peaks in known complexes and possible correlation with spiral arms, the outer Galaxy appears to produce massive stars as efficiently as the inner regions. However, many of the potential star forming SASSy clumps have no available radio counterpart to confirm the presence of an HII region or other star formation tracer. Follow-up observations will be required to verify this conclusion and are currently in progress.

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340.24 – Determining properties of halo dust for the Herschel EDGE-on galaxy Survey (HEDGES)

The Herschel EDGE-on galaxy Survey (HEDGES) is studying the distribution of dust in the halos of nearby spiral galaxies. More specifically, its goals are to determine the physical characteristics of this dust, what relationship there might be between halo dust content and star formation activity, how halo dust might expose information about the far-infrared (FIR)-Radio correlation, and how the physical distribution of this dust might relate to that of other gas tracers. The work presented here aims to investigate the physical characteristics of this halo dust and how they change with height above and below the plane of the six galaxies in the HEDGES sample: NGC 0891, NGC 3628, NGC 4244, NGC 4517, NGC 4565 and NGC 4631. To achieve this goal, code has been written that, for each galaxy, can extract vertical profiles and photometric data from nine different bands (taken using the Herschel Space Observatory and the Spitzer Space Telescope) in the FIR part of the electromagnetic spectrum. These photometric data are then used to construct a spectral energy distribution (SED) that is fit to dust models.

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340.25 – Realistic Models for Filling Factors in HII Regions

One of the parameters used to describe HII regions and other ionized parts of the interstellar medium is the filling factor, defined as the volume fraction of an HII region occupied by matter. The best observational evidence for the existence of a filling factor less than unity is a discrepancy between the electron density derived from density-sensitive line ratios and the root mean square density obtained from emission measure measurements. Following the early, influential study by Osterbrock and Flather (ApJ 129, 26, 1959), most investigations of HII regions envision these objects as a group of isolated cells of high gas density embedded in a vacuum. This picture is at serious odds with more direct measurements of other astrophysical plasmas like the solar wind, where the density follows a less extreme probability distribution function (pdf) such as an exponential or lognormal. We have carried out a set of simulations in which model HII regions are created with different density pdfs such as exponential and lognormal as well as the extreme case of two delta functions. We calculate the electron density as inferred from spectroscopic line ratios and emission measures for all lines of sight through the model nebulas. In the cases of exponential and lognormal pdfs, the spectroscopically derived densities are higher than those obtained by the emission measures by factors of 20 to 100 percent. These are considerably smaller than values often reported in the literature, which can be an order of magnitude or greater. We will discuss possible ways to reconcile realistic density pdfs such as measured in space and laboratory plasmas with the results from astronomical spectroscopic measurements. Finally, we point out that for the Orion Nebula, the density discrepancy is due to geometry, not filling factor (O'Dell, ARAA 39, 99, 2001).

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340.26 – The Southern HII Region Discovery Survey: Preliminary Results

HII regions are some of the brightest sources at radio frequencies in the Milky Way and are the sites of massive O and B-type star formation. They have relatively short (< 10 Myr) lifetimes compared to other Galactic objects and therefore reveal information about spiral structure and the chemical evolution of the Galaxy. The HII Region Discovery Surveys (HRDS) discovered about 800 new HII regions in the Galactic longitude range -20 degrees to 270 degrees using primarily the Green Bank Telescope. Candidate HII regions were selected from mid-infrared emission coincident with radio continuum emission, and confirmed as HII regions by the detection of radio recombination lines. Here we discuss the Southern HII Region Discovery Survey (SHRDS), a continuation of the HRDS using the Australia Telescope Compact Array over the Galactic longitude range 230 to 360 degrees. We have reduced and analyzed a small sub-set of the SHRDS sources and discuss preliminary results, including kinematic distances and metallicities.

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340.27 – *HST* STIS Observations of Interstellar Chlorine

Among the dominant ions of abundant elements in the diffuse interstellar medium, only chlorine (Cl II) has a rapid exothermic reaction with molecular hydrogen (H_2) that should lead to the dominance of its atomic form (Cl I) in clouds where most of the hydrogen is in H_2. We present the results of an archival study of the interstellar Cl I λ1347.24 absorption observed at high spectral resolution toward 41 stars with the Space Telescope Imaging Spectrograph (STIS) onboard the *Hubble Space Telescope* (*HST*). Our key goals in this survey are to explore the relationship between interstellar N(Cl I) and N(H_2) with a larger sample and a larger N(H_2) range (16.44 < log N(H_2) < 20.87) than the *Copernicus* interstellar survey of Moomey et al. (2012). We additionally contrast it with the high-z QSO damped Lyman-alpha system (DLA) findings of Balashev et al. (2015). We find that for log N(H_2) > 19.0, the *HST* STIS sample is consistent with the *Copernicus* data and high-z DLA samples in indicating a linear trend of increasing N(Cl I) with increasing N(H_2). Furthermore, all of the interstellar sightlines with log f(H_2) > -0.5 have log N(Cl I) > 13.5, and those with log f(H_2) < -1.5 have log N(Cl I) < 13.5, where f(H_2)=2N(H_2)/[2N(H_2)+N(H I)] is the fractional amount of H_2 in H. Consequently, observations of interstellar Cl I can potentially trace the H_2 fraction of the "CO-dark" gas marking the transition between diffuse atomic and dense CO molecular clouds.

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340.28 – Formation of Interstellar OH and CH

From the absorption spectra of bright UV-emitting stars, column densities of interstellar OH (3078 and 3082 Å) and CH (3886 and 3890 Å) have been measured simultaneously along about 20 sightlines. In order to understand the physical and chemical environments in which these two molecules exist, we perform numerical simulations by using *Astrochem,* a publically available astrochemical reaction code. We investigate the effect of cosmic ray, grain, environmental photon, and initial composition on the formation of these two molecules. We also compare our simulated results with observations of molecule-forming objects such as supernova remnants, molecular clouds, and evolved stars along the observed sightlines.

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340.29 – Galaxy bachelors, couples, spouses: Star formation in interacting galaxies

We investigate the star formation activity in three galaxy systems in different stages of interaction to determine how the environment of galaxies affects their star forming ability and potential. These systems include an isolated galaxy, a pair of interacting galaxies, and a pair of merging galaxies. All of the target galaxies in these systems have similar stellar masses and similar radii and are at similar redshifts. We trace the star formation activity over the past 1-2 Gyr using spatially and kinematically resolved H-alpha emission, H-alpha equivalent width, and 4000-Angstrom break maps. This work is based on data from the fourth-generation Sloan Digital Sky Survey (SDSS-IV)/Mapping Nearby Galaxies at Apache Point Observatory (MaNGA), and is part of the Project No.0285 in SDSS-IV.

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Contributing team(s): SDSS-IV/MaNGA

340.30 – Mapping the Heiles Supershell GSH 90-28-17

Large-diameter shells of neutral gas called superbubbles were first detected by the 21-cm radio surveys of Heiles (1979,1984) and are likely formed by stellar winds and supernova explosions. Some of these interstellar voids (including GSH 90-28-17) span more than 10 degrees of the sky. However, only a few studies have been able to identify the power source of a particular Heiles shell. The problem is that HI 21cm emission can arise at all distances along a given sight-line, so while we many know the speed at which neutral gas is moving, we do not know the distance of this gas. Indeed, a given line of sight may penetrate multiple shell walls making the interpretation of the radio data very challenging.

Here we report on an absorption study of the interstellar absorption lines of NaI, CaII, CaI, CH and CH+ detected towards nine stellar continuum sources with sight-line distances increasing from 90 pc to >1kpc in the direction of the supershell GSH 90-28-17. Our observations, recorded with the Sandiford echelle spectrograph on the 2.1m telescope at the McDonald Observatory (Texas) in August 2016, reveal gas components with velocities between -10 and -50 km/s orginating from distances >400 pc that we can associate with the expansion of the GSH 90-28-17 shell.

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340.31 – Continuing the Search for Flickering Ultracompact HII Regions: EVLA Observations of W49A

Recent observations of the Galactic Center massive star forming region Sgr B2 indicate that approximately 5% of the ultracompact (UC) HII regions detected there have changed significantly in flux density over a 20 year period (De Pree et al. 2014, 2015). One explanation of these changes in flux density is provided by a massive star formation model in which accretion proceeds through the early formation of UC HII regions, causing the regions to change in brightness ("flicker") on short timescales. To search for flickering in another Galactic star forming region, we have recently used the EVLA (2015-16) to make a multi-configuration image of the W49A region (D~11.5 kpc). We present 8.309 GHz images from the A+B+C configuration data to compare to images with the same frequency, bandwidth and resolution made with the VLA in 1996. We also present an A+B+C+D configuration image with higher spatial resolution and sensitivity than the 1996 data. We present these initial continuum images and H92α radio recombination line (RRL) spectra from selected UC HII regions. This study is part of an ongoing campaign to search for variability in UC HII regions, as predicted by models of unsteady accretion flows (Peters et al. 2010).

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340.32 – Probing Planck Cold Clump Sightlines through HST STIS UV Spectroscopy

The Planck Catalogue of Galactic Cold Clumps (PGCC) has provided a wealth of information about the cold, dusty ISM across the entire sky, identifying regions ranging from relatively diffuse cold clouds to pre-stellar cores in giant molecular clouds. This catalogue uses sub-millimeter emission arising from cold dust to determine the physical properties, morphology, and temperature of these regions. Combining this information with the diagnostic capabilities of UV absorption line spectroscopy allows us to better characterize the interstellar gas associated with these dusty regions. We have identified numerous target stars with STIS high-resolution UV spectra in the Hubble Space Telescope data archive whose sightlines lie in the sky vicinity of PGCC objects. By analyzing select interstellar absorption lines along these target sightlines, we can investigate several important cloud properties. Here we investigate the gas thermal pressure using C I fine structure excitation, and find a similar distribution to previous studies of the broader diffuse ISM. We also investigate the potential destruction of dust grains by shock processing by determining abundance ratios of heavily depleted elements to those that are typically lightly depleted.

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340.33 – Hydrodynamical Modeling of the Local Interstellar Medium

Studies of the Local Interstellar Medium (LISM) provide us with the opportunity to make progress in understanding a wide range of physical processes that operate in the diffuse insterstellar medium (ISM) of galaxies. The LISM includes a large bubble of hot, supernova created gas, known as the Local Bubble, and several low density, warm clouds close to the Sun, known as the Complex of Local Insterstellar Clouds (CLIC). The CLIC includes the Local Interstellar Cloud that surrounds and confines the heliosphere and is the source of neutral H and He that has been detected flowing into the Solar System. Several important questions remain unanswered about the LISM including how the Local Bubble formed, how the CLIC got to be inside the Local Bubble, and what are the ongoing interactions of the hot gas with the CLIC gas. We report on our progress in creating numerical hydrodynamical models of the LISM that aim to help us to understand the wide range of observations we have of the CLIC and the Local Bubble and the origins and evolution of the LISM.

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340.34 – Measuring the local ISM along the sight lines of the two *Voyager* spacecraft with *HST/STIS*

In August 2012, *Voyager 1* crossed the heliopause, becoming the first human-made object to exit the Solar System. This milestone signifies the beginning of an important new era for local interstellar medium (LISM) discoveries. We present measurements of the structure and composition of the LISM by using high-resolution *Hubble Space Telescope* spectra of nearby stars that lie along the same lines of sight as the respective paths of the Voyager spacecraft. We provide a comprehensive inventory of LISM absorption in the near-ultraviolet (2600-2800Å) and the far-ultraviolet (1200-1500Å). The LISM absorption profiles are used to make comparisons between each pair of closely spaced (<15°) sight lines. With these fits, we can make measurements of the physical properties of the LISM, including temperature, turbulence, electron density, and dust composition. As both *HST* and *Voyager* reach the end of their lifetimes, we now have the opportunity to synthesize their respective independent and complementary observations, combining in-situ measurements with the shortest possible line-of-sight measurements to provide an unprecedented study of the galactic ISM surrounding the Sun.

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340.35 – VLA Observations of the Magnetic Field of the Smith High Velocity Cloud

High velocity clouds (HVCs) are hydrogen gas clouds around galaxies with velocities inconsistent with Galactic rotation. HVCs may fuel future star formation and drive galaxy evolution. The Smith Cloud is an HVC with an orbit suggesting it has made at least one passage through the disk. A measured magnetic field suggests how it survived passage through the Galactic halo. The Faraday rotation measure (RM) provides information about the strength and direction of the magnetic field. We use the Karl G. Jansky Very Large Array (VLA) to obtain reliable RMs towards ~950 background point sources to measure the geometry of the magnetic field of the Smith Cloud. These RMs constrain the strength of the magnetic field at the head, tail, and body of the Smith Cloud while RMs directly behind the Smith Cloud suggest there is ionized gas associated with the cloud that has not previously been detected. The confirmation of the magnetic field of the Smith Cloud along with a detailed morphology of the magnetic field structure will constrain how HVCs pass through the Galactic halo without losing their gas and survive the passage through the intergalactic and interstellar media.

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340.36 – Properties of Cold HI Emission Clouds in the Inner-Galaxy ALFA Survey

Star formation, a critical process within galaxies, occurs in the coldest, densest interstellar clouds, whose gas and dust content are observed primarily at radio and infrared wavelengths. The formation of molecular hydrogen (H2) from neutral atomic hydrogen (HI) is an essential early step in the condensation of these clouds from the ambient interstellar medium, but it is not yet completely understood, e.g., what is the predominant trigger? Even more troubling, the abundance of H2 may be severely underestimated by standard tracers like CO, implying significant "dark" H2, and the quantity of HI may also be in error if opacity effects are neglected. We have developed an automated method to account for both HI and H2 in cold, diffuse clouds traced by narrow-line HI 21-cm emission in the Arecibo Inner-Galaxy ALFA (I-GALFA) survey. Our algorithm fits narrow (2-5 km/s), isolated HI line profiles to determine their spin temperature, optical depth, and true column density. We then estimate the "visible" H2 column in the same clouds with CfA and Planck CO data and the total gas column from dust emission measured by Planck, IRAS, and other surveys. Together, these provide constraints on the dark H2 abundance, which we examine in relation to other cloud properties and stages of development. Our aim is to build a database of H2-forming regions with significant dark gas to aid future analyses of coalescing interstellar clouds. We acknowledge support from NSF, NASA, Western Kentucky University, and Williams College. I-GALFA is a GALFA-HI survey observed with the 7-beam ALFA receiver on the 305-meter William E. Gordon Telescope. The Arecibo Observatory is a U.S. National Science Foundation facility operated under sequential cooperative agreements with Cornell University and SRI International, the latter in alliance with the Ana G. Mendez-Universidad Metropolitana and the Universities Space Research Association.

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341 – Supernovae Poster Session

341.01 – SALT Spectroscopy of ASASSN-15lh: The Most Luminous Supernova?

In August 2015, ASASSN-15lh was discovered as the most luminous supernova (SN) ever found (Dong et al. 2016), more than twice as bright as other so-called super-luminous supernovae (SLSN). However, the spectral evolution of the transient is unlike any known supernova. To better understand this object, we have observed ASASSN-15lh with the Southern African Large Telescope (SALT). We obtained spectroscopic data in July 2016 and reduced and calibrated the spectrum for comparison with other supernovae. The new pectrum did not show strong supernova features and was dominated by light from the host galaxy. We used this late spectrum as a galaxy template, subtracting it from earlier data. However, we still find that ASASSN-15lh does not clearly resemble any known supernova. Either it is unique, or perhaps an alternate explanation is needed (e.g., a tidal disruption event; Leloudas et al. 2016). This Research Experience for Undergraduates project in the Department of Physics and Astronomy at Rutgers University has been supported by funding from National Science Foundation grants PHY-1263280 and PHY-1560077.

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341.02 – SOUSA Supernova Surprises

The Swift Optical/Ultraviolet Supernova Archive is an effort to make public the Swift UVOT images and final photometry of as many supernovae as possible. These include many of the nearest, brightest, and most exciting supernovae of the last decade. Hiding within the archive, however, are supernovae you have never heard of, which never the less show extremes in color or luminosity or interesting light curve behavior in the ultraviolet. I will highlight some of the extreme objects of different subtypes and puzzling objects which warrant further study.

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341.03 – Fast and Furious: Analysis of the Luminous and Rapidly-Evolving Type Ic-BL Supernova iPTF16asu

Wide-field surveys have discovered a growing number of rapidly-evolving supernovae and transients in the luminosity gap between regular core-collapse and super-luminous supernovae. The physical origin of these events is not yet well understood. Here, we present data and analysis of iPTF16asu, a rapidly-evolving Type Ic-BL supernova in this luminosity gap. With a rest-frame rise-time of just 4 days and a peak absolute magnitude of -20.4 mag, iPTF16asu's light curve is somewhat more luminous but otherwise similar to previous events, including SN2011kl which was associated with an ultra-long gamma-ray burst. The spectrum of iPTF16asu near peak shows a featureless, blue continuum, again similar to previous events, and develops into a Ic-BL spectrum on the decline. Combining information from the light curve, spectroscopy, and X-ray and radio upper limits, we compare iPTF16asu to other events in this part of transient phase-space, and also to physical models proposed to explain rapidly-evolving supernovae.

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341.04 – SN 2013fs & SN 2013fr: Filling the gaps between Type IIn and Type IIP supernovae

Type IIn supernovae (SNe IIn), characterized by narrow lines in their spectra, display some of the greatest diversity in environments and explosion characteristics, despite representing only about 9% of all core collapse supernovae. The narrow lines are indicative of circumstellar material (CSM) ejected by the progenitor during the late stages of massive star evolution. Consequently, SNe IIn can be attributed to a wide range of progenitors with strong mass loss. Previous research has suggested a continuum between

Type IIn and IIP, and Type IIP and IIL supernovae. We present early time photometry and spectroscopy of SN 2013fs and SN 2013fr, both objects initially classified as type IIn supernovae, across a wide range of wavelengths. These both exhibit signs of early time CSM interaction and are spectroscopically similar at discovery, but rapidly diverge as they evolve. We discuss the implications of this highly divergent evolution on the efforts to link SNe IIn and SNe IIP, as SN 2013fs and SN 2013fr both occupy positions in between very bright SNe IIn like SN 1998S and more typical SNe IIP like SN 1999em.

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Contributing team(s): LOSS, PESSTO, LCOGT

341.05 – The Extinction properties of and distance to the highly reddened Type~Ia supernova SN 2012cu

Correction of Type Ia SN brightnesses for extinction by dust has proven to be a vexing problem. Here we study the dust foreground to the highly reddened SN 2012cu, which is projected onto a dust lane in the galaxy NGC 4772. The analysis is based on multi-epoch, spectrophotometric observations spanning 3,300 - 9,200 A, obtained by the Nearby Supernova Factory. Phase-matched comparison of the spectroscopically twinned SN 2012cu and SN 2011fe across 10 epochs results in the best-fit color excess of (E(B – V), RMS) = (1.00, 0.03) and total-to-selective extinction ratio of (RV , RMS) = (2.95, 0.09) toward SN 2012cu within its host galaxy. We further identify several diffuse interstellar bands, and compare the 5780 A band with the dust-to-band ratio for the Milky Way. Overall, we find the foreground dust-extinction properties for SN 2012cu to be consistent with those of the Milky Way. Furthermore we find no evidence for significant time variation in any of these extinction tracers. We also compare the dust extinction curves of Cardelli et al. (1989), O'Donnell (1994), and Fitzpatrick (1999), and find the predictions of Fitzpatrick (1999) fit SN 2012cu the best. Finally, the distance to NGC4772, the host of SN 2012cu, at a redshift of z = 0.0035, often assigned to the Virgo Southern Extension, is determined to be 16.6±1.1 Mpc. We compare this result with distance measurements in the literature.

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341.06 – Two New Calcium-Rich Gap Transients in Group and Cluster Environments

Calcium-rich gap transients are a recently discovered class of transients, characterized by peak luminosities in the "gap" between supernovae and novae, rapid photometric and spectroscopic evolution, and a nebular spectrum dominated by [Ca II] emisison. We present two new events discovered by the Palomar Transient Factory: PTF11kmb and PTF12bho. A striking feature of both transients are their host environments: PTF12bho is an intra-cluster transient in the Coma Cluster, while PTF11kmb is located in a loose galaxy group, and both are offset >20 kpc from any plausible host galaxy. Deep imaging from Subaru and the Hubble Space Telescope constrains the presence of any underlying faint galaxies or globular clusters at the locations of the transients. We discuss the offset distribution and host galaxy demographics of Ca-rich gap transients as a class, showing that both are more extreme than that observed for either Type Ia SNe and even short-duration gamma-ray bursts, and that the majority of events found to date are found in galaxy groups or clusters. Finally, we discuss the implications for the progenitor systems of Ca-rich gap transients.

Author(s): Ragnhild Lunnan[1], Mansi M. Kasliwal[1], Yi Cao[5], Laura Hangard[4], Ofer Yaron[6], Jerod Parrent[2], Yagi Masafumi[3]
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Contributing team(s): Intermediate Palomar Transient Factory

341.07 – Supernova Classification Using Swift UVOT Photometry

With the great influx of supernova discoveries over the past few years, the observation time needed to acquire the spectroscopic data needed to classify supernova by type has become unobtainable. Instead, using the photometry of supernovae could greatly reduce the amount of time between discovery and classification. For this project we looked at the relationship between colors and supernova types through machine learning packages in Python. Using data from the Swift Ultraviolet/Optical Telescope (UVOT), each photometric point was assigned values corresponding to colors, absolute magnitudes, and the relative times from the peak brightness in several filters. These values were fed into three classifying methods, the nearest neighbors, decision tree, and random forest methods. We will discuss the success of these classification systems, the optimal filters for photometric classification, and ways to improve the classification.

Author(s): Madison Smith[1], Peter J Brown[2]
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341.08 – See Change: the Supernova Sample from the Supernova Cosmology Project High Redshift Cluster Supernova Survey

The Supernova Cosmology Project has finished executing a large (174 orbits, cycles 22-23) Hubble Space Telescope program, which has measured ~30 type Ia Supernovae above z~1 in the highest-redshift, most massive galaxy clusters known to date. Our SN Ia sample closely matches our pre-survey predictions; this sample will improve the constraint by a factor of 3 on the Dark Energy equation of state above z~1, allowing an unprecedented probe of Dark Energy time variation. When combined with the improved cluster mass calibration from gravitational lensing provided by the deep WFC3-IR observations of the clusters, See Change will triple the Dark Energy Task Force Figure of Merit. With the primary observing campaign completed, we present the preliminary supernova sample and our path forward to the supernova cosmology results. We also compare the number of SNe Ia discovered in each cluster with our pre-survey expectations based on cluster mass and SFR estimates. Our extensive HST and ground-based campaign has already produced unique results; we have confirmed several of the highest redshift cluster members known to date, confirmed the redshift of one of the most massive galaxy clusters at z~1.2 expected across the entire sky, and characterized one of the most extreme starburst environments yet known in a z~1.7 cluster. We have also discovered a lensed SN Ia at z=2.22 magnified by a factor of ~2.7, which is the highest spectroscopic redshift SN Ia currently known.

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341.09 – New Cosmology Results from The Pan-STARRS Type Ia Supernova Sample

We present a complete cosmology analysis of the full spectroscopically confirmed set of Type Ia Supernovae (SNIa) from the Pan-STARRs sample. We also combine this sample with multiple other supernova samples to create the largest SNIa sample analyzed for cosmology. Importantly, this is the first analysis to cross-calibrate all of the surveys onto a homgeneous photometric system. It also is the first to include recently developed distance bias corrections which significantly reduce systematic uncertainties in the lightcurve parameters. We present new constraints on cosmological parameters and discuss tension with other datasets.

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Contributing team(s): Pan-STARRS Transients Team

341.10 – The Supernova Key Project

Las Cumbres Observatory is a global network of robotic telescopes specializing in time domain astronomy. It currently has nine 1m telescopes, two 2m telescopes, and seven 0.4m telescopes. The Supernova Key Project is a 3 year program to obtain light curves and spectra of 500 supernovae with Las Cumbres Observatory. Here we show recent results, detail plans for the next Supernova Key Project, and explain how the US community can get involved.

Author(s): Dale Andrew Howell[1]
Institution(s): *1. Las Cumbres Global Telescope Network, Inc.*

341.11 – Studies of Machine Learning Photometric Classification of Supernovae

We studied the use of machine learning for the photometuric classification of Type Ia (SNIa) and core collapse (SNcc) supernovae. We used a combination of simulated data for the Dark Energy survey (DES) and real data from SDSS and chose our metrics to be the sample purity and the efficiency of identifying SNIa supernovae. Our focus was to quantify the effects of varying the training and parameters for random-forest decision-tree algorithms.

Author(s): Joseph Nicholas Macaluso[2], John Cunningham[2], Stephen Kuhlmann[1], Ravi Gupta[1], Eve Kovacs[1]
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341.12 – Calibration and Simulation of the Foundation Supernova Survey

A major limiting factor in Type Ia supernova (SNIa) cosmological analyses is the heterogeneity and systematic uncertainties of the current low-z SNIa sample. The Foundation Supernova Survey aims to improve upon this by utilizing the extremely well calibrated Pan-STARRS telescope to obtain a large, high-fidelity, and homogeneous sample. Already the largest published low-z SNIa sample on a single system, systematic uncertainties of Foundation are 2-3 times lower than those of previous surveys. A number of tests have been performed to ensure the most accurate calibration of Foundation. We determine the consistency in the photometric systems between PS1 and Foundation. We also improve the absolute calibration of the photometric system using HST Calspec standards. Finally, we present the first simulations of the Foundation survey and predict distance biases of our supernovae.

Author(s): Michael Foley[8], Ryan Foley[6], Daniel Scolnic7, Armin Rest5, Adam G. Riess[2], Saurabh W Jha4, Robert Kirshner[1], Ori Dosovitz Fox5, Yen-Chen Pan[6], Steven Smartt3
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Johns Hopkins University, 3. Queen's University Belfast, 4. Rutgers University, 5. Space Telescope Science Institute, 6. University of California Santa Cruz, 7. University of Chicago, 8. University of Notre Dame*

341.13 – Understanding how Supernova Light Curves are Affected by the Density Profiles of Extended Material

The light curve of a supernova can provide important clues about the structure of the exploding progenitor. When extended material is present, shock cooling of this material can lead to a prominent early peak distinct from the main radioactive nickel peak, as seen in some Type IIb supernovae. We explore whether the density profile of the extended material plays a role in shaping these light curves. We perform a series of numerical supernova simulations with a range of extended mass configurations. We find that steeper density profiles for the extended material shrink the width and decrease the luminosity of the early peak of the light curve. We conclude that light curves with a distinct, early peak do not imply a particular structure, but rather may arise from several distinct mass configurations. This places limits on how much can be inferred about the progenitor's structure from its light curve.

Author(s): Marc Mühleisen[1], Anthony Piro[1]
Institution(s): *1. Carnegie Observatories*

341.14 – On the Nebular-Phase Spectra of Type Ia Supernovae

Here we present nebular-phase spectra of 8 Type Ia supernovae. These objects have large host-galaxy offsets and have been observed and studied at early times by LCOGT and KAIT. The nebular-phase spectra presented here were obtained using the Gemini South and Keck telescopes. By analyzing early-time observations and verifying previous predictions for the nebular phase, we hope to gain insights into the progenitor systems and determine the accuracy of early-time subclassifications of these objects. Several of our supernovae exhibit double-peaked spectral lines, which may indicate a violent merger progenitor system. We also remark on interesting spectral features and compare our sample of objects to other well-observed Type Ia supernovae presented in other papers.

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341.15 – A Systematic Study of Mid-Infrared Emission

from Core-Collapse Supernovae with SPIRITS

Late-time mid-infrared emission from core-collpase supernovae tells stories of circumstellar interaction and dust formation. We present a systematic study of mid-infrared emission from 141 nearby supernovae observed with *Spitzer*/IRAC as part of the ongoing SPIRITS survey. We detect 8 Type Ia and 36 core-collapse SNe. While all SNe-Ia fade away within 3 years post explosion, about 20% of SNe-II remain detectable. Five SNe-II are detected two decades after discovery (SN 1974E, 1979C, 1980K, 1986J, and 1993J). From the two-band photometry, we can fit for IR luminosity and temperature, and the inferred dust mass assuming that all mid-IR emission comes from an optically thin shell of warm dust. We derive warm dust masses between 10^{-6} and 10^{-2} \msol and dust color temperatures between 200 and 1280 K. This observed warm dust could be pre-existing or newly created. We note that either case represents a lower limit to the dust mass because cooler dust may be present. We present three case studies of extreme SNe. SN 2011ja (II-P) was over-luminous ([4.5] = -15.6 mag) at 900 days post-explosion with increasing hot dust mass, suggesting either an episode of dust formation or intensifying CSM interactions heating up pre-existing dust. SN 2014bi (II-P) showed a factor of 10 decrease in dust mass over one month suggesting either dust destruction or reduced dust heating. The IR luminosity of SN 2014C (Ib) stays constant over 800 days, possibly due to strong CSM interaction with H rich shell, which is rare among stripped-envelope SNe. The observations suggest that this CSM shell originated from an LBV-like eruption roughly 100 years pre-explosion. The observed diversity demonstrates the power of mid-IR observations of a large sample of SNe.

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Contributing team(s): SPIRITS

341.16 – Bolometric Lightcurves of Peculiar Type II-P Supernovae

We examine the bolometric lightcurves of five Type II-P supernovae (SNe 1998A, 2000cb, 2006V, 2006au and 2009E) which are thought to originate from blue supergiant progenitors using a new python package named SuperBoL. With this code, we calculate SNe lightcurves using three different techniques common in the literature: the quasi-bolometric method, which integrates the observed photometry, the direct integration method, which additionally corrects for unobserved flux in the UV and IR, and the bolometric correction method, which uses correlations between observed colors and V-band bolometric corrections. We present here the lightcurves calculated by SuperBoL along with previously published lightcurves, as well as peak luminosities and ^{56}Ni yields. We find that the direct integration and bolometric correction lightcurves largely agree with previously published lightcurves, but with what we believe to be more robust error calculations, with $0.2 \leq \delta L/L \leq 0.5$. Peak luminosities and ^{56}Ni masses are similarly comparable to previous work. SN 2000cb remains an unusual member of this sub-group, owing to the faster rise and flatter plateau than the other supernovae in the sample. Initial comparisons with the NLTE atmosphere code PHOENIX show that the direct integration technique reproduces the luminosity of a model supernova spectrum to ~5% when given synthetic photometry of the spectrum as input. Our code is publicly available. The ability to produce bolometric lightcurves from observed sets of broad-band light curves should be helpful in the interpretation of other types of supernovae, particularly those that are not well characterized, such as extremely luminous supernovae and faint fast objects.

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341.17 – Studying white dwarf merger remnants with FLASH

There is still uncertainty as to the progenitor systems of type Ia supernova (SN Ia). Both single and double degenerate systems have been suggested as progenitors. In a double degenerate system a merger between the two white dwarfs, with total mass at or exceeding the Chandrasekhar mass, leads to the supernova. If the explosion occurs during the merging process it is a violent merger. If an explosion doesn't occur while the stars merge the system becomes a white dwarf of unstable mass. For mergers of this type with differing starting masses it has been shown that during the viscous evolution carbon burning starts far from the center and stably converts the star to oxygen and neon. In this case the star will eventually collapse to a neutron star and not produce an SN Ia. The case of similar mass mergers has been much less explored. Using the results of a smooth particle hydrodynamic merger we simulate the viscous evolution of models of different mass ratios with FLASH. These simulations test if a similar mass merger can lead to an SN Ia, and begin to probe where the transition from similar to dissimilar mass occurs.

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341.18 – Estimating Type Ia Supernova Metallicities Using Neural Networks

Normal Type Ia supernovae (SNe) can be used as standardizable candles because their progenitors, white dwarfs, are a fairly homogenous class of objects. However, intrinsic variability in these events arise from a number of factors, including metallicity. Recent studies have investigated the effects of metallicity on Type Ia SNe observables from both a theoretical approach, by tuning model metallicity to analyze spectral features, and an observational approach, by studying the effect of host metallicity on light curves. In this work, we take a new, data-driven approach to the problem. Inspired by the success of neural networks in the field of image processing, we aim to estimate the metallicities of Type Ia SNe progenitors from their near-maximum spectra using feed-forward neural networks. We first collect a sample of near-maximum Type Ia SNe spectra from the literature to be smoothed and down-sampled. We then estimate the metallicities of the SNe hosts using the B-band magnitudes. We build a multilayer perceptron to generate a model that takes as input the down-sampled spectra and returns a scalar metallicity. Finally, we discuss basic considerations to be taken when working with spectral (as opposed to image) data using neural networks.

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341.19 – Type Ia Supernova Modeling with Spectrophotometric Data from the Nearby Supernova Factory

Type Ia supernova cosmology is currently limited by dispersion in standardized magnitudes, driven by a combination of calibration uncertainty and so-called ‘intrinsic dispersion.' This intrinsic dispersion is caused by supernova behavior that the current lightcurve fitters do not account for, and it can involve systematic trends. Using data from the Nearby Supernova Factory, we have developed an empirical model that captures a wider range of Type Ia supernova behavior and can be used to improve standardized magnitude dispersion. To do this, Gaussian Processes and Expectation Maximization Factor Analysis are used to generate spectral time series templates that can be combined linearly. Variations of this model are optimized, alternatively for supernova standardization or for maximum accuracy in the description of supernova spectral features. We present these models along with interpretation of the model components. Methods are discussed for the most efficient application of the models in cosmological surveys.

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Contributing team(s): The Nearby Supernova Factory

341.20 – Identifying Type Ia Supernova Mechanisms in Dwarf Spheroidal Galaxies through Analysis of Iron-peak Elemental Abundances

Through the fusion of nucleons to produce elements heavier than hydrogen and helium, stellar nucleosynthesis produces most of the elements in the universe. Such is the case in a supernova explosion, which creates most of the elements on the periodic table—including iron-peak elements, atomic numbers 21 through 30—through nucleosynthesis and ejects them into the interstellar medium. In this study, we determine the best theoretical supernova model appropriate for the stars in the dwarf spheroidal galaxies Sculptor, Fornax, Ursa Minor, and Leo II by calculating the abundances of iron-peak elements in these stars. To determine iron-peak elemental abundances, we compare synthesized spectra with observed spectra from medium-resolution spectroscopy and determine the best-fitting spectrum by way of a chi-squared minimization. Through inspecting the relationship between the iron-peak element abundances and the abundance of iron itself and by comparing them to previously hypothesized supernova model theories, we discover that the near-Chandrasekhar mass "n1" model, as predicted by Seitenzahl et al., most accurately represents the trends and patterns within our data, presenting new insight into Type Ia supernovae mechanisms within the Milky Way and beyond.

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341.21 – Uncertainty in Explosive Yields of Core-Collapse Supernovae

The chemical composition of the ejecta from the violent explosions of massive stars has been vital for probing the nature of the explosions and their effect on galactic chemical evolution and universal chemical composition. The sensitivity of numerical explosive nucleosynthetic yields in core-collapse supernovae to several key parameters is examined in one dimension. This uncertainty study is applied to 15, 20, and 25 solar mass stars with different energy prescriptions for shock revival. The effects of the resolution of the temperature and density profiles run through the NuGrid nuclear network are explored, as well as the differences between large and small isotope networks for the initial conditions of the explosion calculations.

Author(s): Sydney Andrews[2], Chris Fryer[2], Wesley P. Even[2], Samuel Jones[1], Marco Pignatari3
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Contributing team(s): NuGrid Collaboration

341.22 – r-Process Nucleosynthesis in Jet-driven Core-Collapse Supernovae

We investigate rapidly rotating, strongly magnetized core-collapse supernova (CCSN) explosions as a site for the production of heavy elements through r-process nucleosynthesis. While CCSNe have long been considered a potential astrophysical site of this process explaining the origin of observed abundances for stable nuclei heavier than iron, the neutron-rich conditions necessary have not been robustly produced in simulations. There remain large uncertainties in quantifying the fraction of all core-collapse events that produce r-process material and the quantity of ejected material in a typical explosion.
We perform three-dimensional (3D) dynamical-spacetime general-relativistic magnetohydrodynamic (GRMHD) simulations of jet-driven CCSNe. These simulations are run using the Einstein toolkit, an open-source community-driven numerical relativity and computational relativistic astrophysics code. They include microphysical finite-temperature equation of state effects and employ a leakage scheme that captures the overall energetics and lepton number exchange due to postbounce neutrino emission. The nuclear products of the simulated explosions are then calculated using SkyNet, a self-heating nuclear reaction network. We explore the robustness of r-process production in magnetorotational core-collapse and the properties of the ejected material.

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342 – Cosmology & CMB Poster Session

342.01 – The HST Frontier Fields: Complete High-Level Science Data Products for All 6 Clusters

The Hubble Space Telescope Frontier Fields program (PI: J. Lotz) is a large Director's Discretionary program of 840 orbits, to obtain ultra-deep observations of six strong lensing clusters of galaxies, together with parallel deep blank fields, making use of the strong lensing amplification by these clusters of distant background galaxies to detect the faintest galaxies currently observable in the high-redshift universe. The entire program has now completed successfully for all 6 clusters, namely Abell 2744, Abell S1063, Abell 370, MACS J0416.1-2403, MACS J0717.5+3745 and MACS J1149.5+2223,. Each of these was observed over two epochs, to a total depth of 140 orbits on the main cluster and an associated parallel field, obtaining images in ACS (F435W, F606W, F814W) and WFC3/IR (F105W, F125W, F140W, F160W) on both the main cluster and the parallel field in all cases. Full sets of high-level science products have been generated for all these clusters by the team at STScI, including cumulative-depth data releases during each epoch, as well as full-depth releases after the completion of each epoch. These products include all the full-depth distortion-corrected drizzled mosaics and associated products for each cluster, which are science-ready to facilitate the construction of lensing models as well as enabling a wide range of other science projects. Many improvements beyond default calibration for ACS and WFC3/IR are implemented in these data products, including corrections for persistence, time-variable sky, and low-level dark current residuals, as well as improvements in astrometric alignment to achieve milliarcsecond-level accuracy. The full set of resulting high-level science products and mosaics are publicly delivered to the community via the Mikulski Archive for Space Telescopes (MAST) to enable the widest scientific use of these data, as well as ensuring a public legacy dataset of the highest possible quality that is of lasting value to the entire community.

Author(s): Anton M. Koekemoer[1], Jennifer Mack[1], Jennifer M. Lotz[1], David Borncamp[1], Harish G. Khandrika[1], Ray A. Lucas[1], Catherine Martlin[1], Blair Porterfield[1], Ben Sunnquist[1], Jay Anderson[1], Roberto J. Avila[1], Elizabeth A. Barker[1], Norman A. Grogin[1], Heather C. Gunning[1], Bryan Hilbert[1], Sara Ogaz[1], Massimo Robberto[1], Kenneth Sembach[1], Kathryn Flanagan[1], Matt Mountain[1]
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Contributing team(s): HST Frontier Fields Team

342.02 – Detecting Massive, High-Redshift Galaxy Clusters Using the Thermal Sunyaev-Zel'dovich Effect

We develop the thermal Sunyaev-Zel'dovich (SZ) effect as a direct astrophysical measure of the mass distribution of dark matter halos. The SZ effect increases with cosmological distance, a unique astronomical property, and is highly sensitive to halo mass. We find that this presents a powerful methodology for distinguishing between competing models of the halo mass function distribution, particularly in the high-redshift domain just a few hundred million years after the Big Bang. Recent surveys designed to probe this epoch of initial galaxy formation such as CANDELS and SPLASH report an over-abundance of highly massive halos as inferred from stellar ultraviolet (UV) luminosities and the stellar mass to halo mass ratio estimated from nearby galaxies. If these UV luminosity to halo mass relations hold to high-redshift, observations estimate several orders of magnitude more highly massive halos than predicted by hierarchical merging and the standard cosmological paradigm. Strong constraints on the masses of these galaxy clusters are essential to resolving the current tension between observation and theory. We conclude that detections of thermal SZ sources are plausible at high-redshift only for the halo masses inferred from observation. Therefore, future SZ surveys will provide a robust determination between theoretical and observational predictions.

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342.03 – The Suppression of Star Formation in Low-Mass Galaxies Caused by the Reionization of their Local Patch

The first stars and galaxies released enough ionizing radiation into the intergalactic medium (IGM) to ionize almost all the hydrogen atoms there by redshift z ~ 6. This process was "patchy" --- ionized zones grew in size over time until they overlapped to finish reionization.
The photoheating associated with reionization caused a negative feedback on the galactic sources of reionization that suppressed star formation in low-mass galactic halos, especially those below 10^9 $M_\odot$. To establish the causal connection between reionization and this suppression, we analyze the results of CoDa ("Cosmic Dawn"), the first fully-coupled radiation-hydrodynamical simulation of reionization and galaxy formation in the Local Universe, in a volume large enough to model reionization globally but with enough resolving power to follow all the atomic-cooling galactic halos in that volume. A 90 Mpc box was simulated from a constrained realization of primordial fluctuations, chosen to reproduce present-day features of the Local Group, including the Milky Way and M31, and the local universe beyond, including the Virgo cluster, with 4096^3 N-body particles for the dark matter and 4096^3 cells for the atomic gas and ionizing radiation. We use these results to show that the star formation rate in haloes below 10^9 $M_\odot$ in different patches of the universe declined when each patch was reionized. Star formation in much more massive haloes continued, however. As a result, the earliest patches to develop structure and reionize ultimately produced more stars than they needed to reionize themselves, exporting their starlight to help reionize the regions that developed structure late.

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342.04 – Time delay in the variability of multiply lensed QSOs HS0810+2554 and Q2237+030

We present time delay in variability between the brightest lensed images of two multiply lensed QSO systems, HS0810+2554 and Q2237+030. This data can help constrain the mass distribution of the lensing galaxies, and perhaps on Hubble's Constant as well. Observations were made with the Towson University 0.4m telescope.

Author(s): Alex Storrs[1], Sergio Lainez[1]
Institution(s): *1. Towson Univ.*

342.05 – Deep Generative Models of Galaxy Images for the Calibration of the Next Generation of Weak Lensing Surveys

Weak gravitational lensing has long been identified as one of the most powerful probes to investigate the nature of dark energy. As such, weak lensing is at the heart of the next generation of cosmological surveys such as LSST, Euclid or WFIRST.
One particularly crititcal source of systematic errors in these surveys comes from the shape measurement algorithms tasked with estimating galaxy shapes. GREAT3, the last community challenge to assess the quality of state-of-the-art shape measurement algorithms has in particular demonstrated that all current methods are biased to various degrees and, more importantly, that these biases depend on the details of the galaxy morphologies. These biases can be measured and calibrated by generating mock observations where a known lensing signal has been introduced and comparing the resulting measurements to the ground-truth. Producing these mock observations however requires input galaxy images of higher resolution and S/N than the simulated survey, which typically implies acquiring extremely expensive space-based observations.
The goal of this work is to train a deep generative model on already available Hubble Space Telescope data which can then be used to sample new galaxy images conditioned on parameters such as magnitude, size or redshift and exhibiting complex morphologies. Such model can allow us to inexpensively produce large set of realistic realistic images for calibration purposes.
We implement a conditional generative model based on state-of-the-art deep learning methods and fit it to deep galaxy images from the COSMOS survey. The quality of the model is assessed by computing an extensive set of galaxy morphology statistics on the generated images. Beyond simple second moment statistics such as size and ellipticity, we apply more complex statistics specifically designed to be sensitive to disturbed galaxy morphologies. We find excellent agreement between the morphologies of real and model generated galaxies.
Our results suggest that such deep generative models represent a reliable alternative to the acquisition of expensive high quality observations for generating the calibration data needed by the next generation of weak lensing surveys.

Author(s): Francois Lanusse[1], Siamak Ravanbakhsh[1], Rachel Mandelbaum[1], Jeff Schneider[1], Barnabas Poczos[1]
Institution(s): *1. Carnegie Mellon University*

342.06 – Simulating Type 1a Supernova Populations Using Host Mass Information

Multiple studies have shown that Type Ia Supernova luminosities depend on properties of the SN host galaxies. Using the software analysis package SNANA, we simulated Type Ia SNe populations with realistic host galaxy mass values and their corresponding relations with the lightcurve stretch and color. For multiple surveys including SDSS, SNLS, PS1 and a cumulative Low-z survey, we introduced luminosity - mass step relations as our inputs and traced how they would be recovered in a conventional analysis. We determined the size of the bias of the recovered mass step, and discuss methods to improve our determination.

Author(s): Jared Hand[1], Daniel Scolnic[2]
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342.07 – Analyses in Support of the WFIRST Supernova Survey

The Wide-Field Infrared Survey Telescope (WFIRST) is a future optical-NIR space telescope with science spanning astrophysics and cosmology. The combination of wide-field IR imaging and optical-NIR integral-field spectroscopy enables a SN cosmology experiment with excellent systematics control. The Science Definition Team (SDT) presented a first concept of such a survey with 2700 SNe to z=1.7. We make several key improvements to the SDT analysis, including a significantly improved exposure-time calculator, evaluations of host-galaxy background light, supernova typing simulations, all combined with spectrophotometric cosmology analysis built on a Bayesian hierarchal model. Our work will be useful for deriving accurate cosmological forecasts, optimizing the survey, and the evaluation of calibration, resolution, and stability requirements.

Author(s): David Rubin3, Greg Scott Aldering[2], Baltay Charles5, Kyle H. Barbary[2], Miles Currie[1], Susana E. Deustua3, Parker Fagrelius[2], Ori Dosovitz Fox3, Andrew S. Fruchter3, David R. Law3, Saul Perlmutter[2], Klaus Pontoppidan3, David L. Rabinowitz5, Masao Sako4
Institution(s): *1. Florida state university, 2. lawrence Berkeley National Laboratory, 3. Space Telescope Science Institute, 4. U Penn, 5. Yale*

342.09 – The tethered galaxy problem: a possible window to explore cosmological models

In the tethered galaxy problem, a hypothetical galaxy is being held at a fixed proper distance. Contrary to Newtonian intuition, it has been shown that this tethered galaxy can have a nonzero redshift. However, constant proper distance has been suggested as unphysical in a cosmological setting and therefore other definitions have been suggested. The tethered galaxy problem is therefore reviewed in Friedmann cosmology. In this work, different tethers are considered as possible local cosmological discriminators.

Author(s): Matipon Tangmatitham[1], Robert J. Nemiroff[1]
Institution(s): *1. Michigan Technical University*

342.10 – On the Shape of Dark Matter Halos in Milky Way-like Galaxies

Recent constraints on the shape of the Milky Way's gravitational potential show that its dark matter halo is close to spherical, inconsistent with the predictions from collisionless N-body simulations of cosmological structure formation. Motivated by this result, we measure the shape of the dark matter halo in *Eris*, a 120pc-resolution cosmological hydrodynamical simulation of a close analogy of the Milky Way. We construct a set of bi-orthogonal density-potential pair bases by solving the Sturm-Liouville equation, and apply them to represent compactly the detailed structure of the Eris gravitational potential. Assuming that the isodensity and isopotential contours are elliptical, we measure their shape as a function of radius and find that dissipation increases their sphericity beyond what is found in collisionless simulations. We also analyze the Eris halo shape as a function of redshift, demonstrating that the shape has been stable for more than a billion years.

Author(s): Biwei Dai[1], Brant E. Robertson[2], Piero Madau[2]
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342.11 – Improved linear kinetic Sunyaev-Zel'dovich effect constraints on the observed Local Void

A class of large, gigaparsec (Gpc)-scale local void models has been ruled out by linear kinetic Sunyaev-Zel'dovich (kSZ) effect constraints from the South Pole Telescope and the Atacama Cosmology Telescope. However, there is substantial and growing observational evidence from the normalized luminosity density in the near-infrared that the local universe may be under-dense on scales of several hundred Megaparsecs. Theoretically, a small void model would relieve tension in observational challenges to the standard Friedmann-Lemaître-Robertson-Walker (FLRW) cosmological model. Thus, we decided to test whether a small void described by a parameterization of the observational data could be ruled out by the latest linear kSZ constraints. Instead, we find that the previous linear kSZ constraints as well as new ones from the South Pole Telescope are fully compatible with the existence of a small void of the size suggested by the luminosity density observations. The presence of such a void could have cosmologically significant implications.

Author(s): Benjamin L Hoscheit[2], Amy J. Barger[1]
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342.12 – The rarity of Dark Matter Halos in medium-sized walls of the cosmic web

In 2014, Marshall McCall mapped out our Local Sheet, the cosmic wall containing the Milky Way and Andromeda galaxies. We use the large new Bolshoi-Planck cosmological simulation to investigate how rare our type of Local Sheet is, with 2 nearby halos like those of Milky Way and Andromeda. The conclusion of our investigation is that the occurrence of a pair of galaxies the size of Milky Way and Andromeda near the center of a wall 8 mpc in diameter, with the pair of galaxies within 0.7 mpc/h of each other, is very rare : it makes up only 0.05% of all walls in the simulation.

Author(s): Tze Goh[1], Joel R. Primack4, Christoph Lee4, Miguel A Aragon-Calvo[2], Peter Behroozi3
Institution(s): *1. Columbia Univeristy, 2. Universidad Nacional Autonoma de Mexico, 3. University of California, Berkeley, 4. University of California, Santa Cruz*

342.13 – Superconducting microstripline diplexer for CMB studies in the 200-300 GHz atmospheric window

The B-mode polarization signals of the Cosmic Microwave Background are obscured by astrophysical foregrounds. Future ground-based measurement programs such as CMB-S4 will remove foregrounds by placing at least two observing bands in each of the atmospheric windows, from about 30 GHz to about 300 GHz. We designed a superconducting microstripline filter to split the highest frequency window, from about 200 - 300 GHz, into two bands. We chose the centers of the bands to optimize removal of foreground radiation from Galactic dust. We present electromagnetic simulations of the design and measurements of a scale model of the filter.

Author(s): Elizabeth Dabrowski[1], Peter T. Timbie[2]
Institution(s): *1. University of Puget Sound, 2. University of Wisconsin - Madison*

342.14 – Variable-delay Polarization Modulators for the CLASS Telescopes

The search for primordial gravitational waves, imprinted on the polarization of the cosmic microwave background (CMB), has galvanized the development of polarization modulators for microwave wavelengths. Variable-delay Polarization Modulators (VPMs) are a scaleable, novel type of modulator that can be placed at the front end of a telescope. VPMs consist of a linear polarizer in front of a movable flat mirror which creates a changing phase delay between orthogonal polarization states and modulates between linear and circular polarizations. Rapid, front-end polarization modulation significantly increases instrument stability and facilitates rejection of systematic effects of due to instrument polarization.

VPMs are integral to the design of the Cosmology Large Angular Scale Surveyor (CLASS) telescopes, with each of the four CLASS telescopes having a 60 cm aperture VPM as their first optical element. The CLASS VPM grids use 50 μm diameter copper plated tungsten wires spaced 150 μm apart across 62 cm. Behind the wire grid is a 60 cm flat honeycomb aluminum mirror. Rotational flexure hinges assembled into a four-bar linkage configuration allow mirror motion while constraining the parallelism with respect to the wire grid. Mirror motion is driven by a voice coil and the grid-mirror distance is measured using three 0.1 μm resolution encoders, read out synchronously with the detectors. A second, identical, reaction-canceling axis eliminates the vibrations induced by mirror motion. The 40 GHz CLASS telescope, including VPM, has been installed at the CLASS site in the Chilean Atacama Desert and production of the next three CLASS VPMs is ongoing.

Author(s): Kathleen Harrington[1]
Institution(s): *1. Johns Hopkins University*
Contributing team(s): CLASS Collaboration

343 – Star Associations, Star Clusters - Galactic & Extragalactic Poster Session

343.01 – The Open Cluster Chemical Abundances and Mapping (OCCAM) Survey: Overview and Membership Methods

The Open Cluster Chemical Analysis and Mapping (OCCAM) survey aims to produce a comprehensive, uniform, infrared-based data set for hundreds of open clusters, and constrain key Galactic dynamical and chemical parameters using the SDSS/APOGEE survey. We present the sample and methods being used by the survey to determine membership for the few-star sampling for most clusters as observed by the SDSS/APOGEE. We present verification of the membership method using the DR13 sample, and show an extension of the method by incorporation of proper motion and parallax data from the ESA Gaia mission.
This work is supported by an NSF AAG grant AST-1311835.

Author(s): John Donor[6], Peter M. Frinchaboy[6], Julia O'Connell[6], Katia M. L. Cunha[3], Benjamin A. Thompson[6], Matthew Melendez[6], Matthew D. Shetrone[9], Steven R. Majewski[8], Gail Zasowski[5], Carlos Allende-Prieto[1], Marc H. Pinsonneault[4], Alexandre Roman-Lopes[7], Mathias Schultheis [2], Keivan G. Stassun[10]
Institution(s): *1. IAC, 2. Observatoire de la Cote d' Azur, 3. Observatorio Nacional, 4. Ohio State Univ., 5. STSci, 6. Texas Christian University, 7. U. La Serena, 8. Univ. of Virginia, 9. University of Texas, 10. Vanderbilt*
Contributing team(s): Apogee Team

343.02 – The Open Cluster Chemical Abundances and Mapping (OCCAM) Survey: Galactic Gradients using SDSS-IV/DR13 and Gaia

The Open Cluster Chemical Analysis and Mapping (OCCAM) survey aims to produce a comprehensive, uniform, infrared-based data set for
hundreds of open clusters, and constrain key Galactic dynamical and chemical parameters using the SDSS/APOGEE survey. We report on multi-element radial abundance gradients obtained from a sample of over 30 disk open clusters. The chemical abundances were derived automatically by the ASPCAP pipeline and these are part of the SDSS IV Data Release 13. The open cluster sample studied spans a significant range in age allowing exploration of the evolution of the Galactic abundance gradient.
This work is supported by an NSF AAG grant AST-1311835.

Author(s): Peter M. Frinchaboy[11], John Donor[11], Julia O'Connell[11], Katia M. L. Cunha[7], Benjamin A. Thompson[11], Matthew Melendez[11], Matthew D. Shetrone[14], Steven R. Majewski[16], Gail Zasowski[10], Carlos Allende-Prieto[2], Ricardo Carrera[2], Ana García Pérez[2], Michael R. Hayden[6], Fred R. Hearty[9], Jon A. Holtzman[4], Jennifer Johnson[8], Szabolcs Meszaros[1], David L. Nidever[12], Marc H. Pinsonneault[8], Alexandre Roman-Lopes[13], Ricardo P. Schiavon[3], Mathias Schultheis [6], Verne V. Smith[5], Jennifer Sobeck[15], Keivan G. Stassun[17]
Institution(s): *1. ELTE Gothard Astrophysical Obs., 2. IAC, 3. Liverpool John Moores, 4. New Mexico State U., 5. NOAO, 6. Observatoire de la Cote d' Azur, 7. Observatorio Nacional, 8. Ohio State U., 9. Penn State U., 10. STScI, 11. Texas Christian Univ. (TCU), 12. U. Arizona, 13. U. La Serena, 14. U. Texas, 15. U. Washington, 16. Univ. of Virginia, 17. Vanderbilt U.*
Contributing team(s): APOGEE Team

343.03 – The Open Cluster Chemical Abundances and Mapping (OCCAM) Survey: Optical Extension for Neutron Capture Elements

The Open Cluster Chemical Abundance & Mapping (OCCAM) survey is a systematic survey of Galactic open clusters using data primarily from the SDSS-III/APOGEE-1 survey. However, neutron capture elements are very limited in the IR region covered by APOGEE. In an effort to fully study detailed Galactic chemical evolution, we are conducting a high resolution (R~60,000) spectroscopic abundance analysis of neutron capture elements for OCCAM clusters in the optical regime to complement the APOGEE results. As part of this effort, we present Ba II, La II, Ce II and Eu II results for a few open clusters without previous abundance measurements using data obtained at McDonald Observatory with the 2.1m Otto Struve telescope and Sandiford Echelle Spectrograph.
This work is supported by an NSF AAG grant AST-1311835.

Author(s): Matthew Melendez[4], Julia O'Connell[4], Peter M. Frinchaboy[4], John Donor[4], Katia M. L. Cunha[1], Matthew D. Shetrone[6], Steven R. Majewski[7], Gail Zasowski[3], Marc H. Pinsonneault[2], Alexandre Roman-Lopes[5], Keivan G. Stassun[8]
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Contributing team(s): APOGEE Team

343.04 – Barium Abundances in Omega Centauri Candidate Stars

The "globular cluster" omega Centauri has several peculiar features that set it apart from other Milky Way globular clusters, such as its large mass, extended size, oblate shape, internal rotation, large age and metallicity spreads, and retrograde orbit. Because of these properties it is thought that Omega Cen may be a heavily stripped remnant of a Milky Way-captured dwarf spheroidal galaxy, now currently orbiting (backwards) near the Galactic plane (e.g., Lee et al. 1999, Majewski et al. 2000). A previous search within a large, all-sky low resolution spectroscopic and photometric catalog of giant stars by Majewski et al. (2012) identified candidate retrograde stars near that plane also having kinematics consistent with being stripped debris from omega Cen, based on tidal destruction models of the system. To confirm their status as omega Centauri members, high resolution spectroscopy was undertaken of a subsample of a dozen of these candidates, and most were found by Majewski et al. to exhibit very high relative Ba abundances (as measured by the 5854 transition) — a peculiar characteristic of the omega Centauri system as originally shown by Smith et al. (2000) and Norris & Da Costa (1998). Thus, these results showed the likelihood of a connection between these widely distributed field stars and omega Centauri.

We have continued this spectroscopic investigation with an expanded sample of candidate tidally-stripped omega Cen giant stars. High-resolution spectra were obtained in the wavelength region (4140~6210A) with the Ultraviolet Visual Echelle Spectrograph (UVES) on the 8.0-m Very Large Telescope (VLT) for additional candidates. For these data, we have employed multiple transitions to derive reliable [Ba/Fe] ratios. We will compare these and other derived abundances to those of the omega Cen core, other globular cluster and field stars. Any additionally-confirmed omega Cen debris stars to combine with those from the previous studies will allow for a more complete mapping of omega Cen tidal debris and shed further light upon its complex chemical and dynamical evolution.

Author(s): Joy Nicole Skipper[3], Jennifer Sobeck[3], Steven R. Majewski[3], Christian Rochford Hayes[3], Katia M. L. Cunha[2], Verne V. Smith[1], Guillermo Damke[3], Ana García Pérez[3], David L. Nidever[1]
Institution(s): *1. NOAO, 2. Observatorio Nacional, 3. University of Virginia*

343.05 – Searching for the Progenitor Galaxy of Omega Centauri Using RR Lyrae Spectra

Radial velocities of 32 RR Lyrae stars from the Catalina Real-time Transient Survey in the neighborhood of Omega Centauri were measured from low-resolution spectra taken by the Goodman Spectrograph on SOAR, Cerro Pachón, Chile. An over-density of stars with the same velocity as the cluster would imply that these stars were once part of ω Cen but have since been tidally stripped, supporting the hypothesis that ω Cen is the remain of a nucleated dwarf galaxy. This study is the most complete of any one similar, covering an area of 100 sq. degrees around the cluster and using RR Lyrae stars known to have similar distance to the cluster. Statistical tests comparing the distribution of RR Lyrae velocities to the expected distribution of velocities of halo stars show no over-density of stars at the velocity of ω Cen or any other velocity, discarding the presence of any substructure in this part of the sky.

Author(s): Natalia Carignano4, Anna Katherina Vivas2, Marcio Catelan3, Gabriel Torrealba5, Jose Gregorio Fernandez Trincado1
Institution(s): *1. Besancon Astronomical Observatory, 2. Cerro Tololo Inter-American Observatory, 3. Pontificia Universidad Católica de Chile, 4. Smith College, 5. University of Cambridge*

343.06 – Low-Resolution Spectroscopic Study of the Intriguing Globular Cluster NGC 2808: Chemical Abundance Patterns among Subpopulations

The presence of multiple stellar populations is now well established in most globular clusters (GCs) in the Milky Way. The origin of this phenomenon, however, is yet to be understood. In this respect, the study of NGC 2808, an intriguing GC which hosts subpopulations with extreme helium and light-element abundances, would help to understand this phenomenon. In order to investigate chemical abundance patterns among different subpopulations, we have performed low-resolution spectroscopy for the red-giant-branch stars and measured CN & CH bands, and Ca line strength. We have identified at least three subpopulations from the CN band strength. The CN band strength appears to be more efficient than Na abundance in separating earlier populations. We also find that this GC shows the CN-CH anti-correlation following the general trend of most GCs which are less affected by supernovae enrichment.

Author(s): Seungsoo Hong2, Dongwook Lim2, Sang-Il Han1, Young-Wook Lee2
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343.07 – The Trigonometric Parallax of the Globular Cluster M4

We have identified five stars from the Tycho-Gaia Astrometric Solution catalog as highly probable members of the globular cluster M4 (NGC 6121). A weighted average of the parallax of these five stars results in a cluster parallax of 0.55 ± 0.14 mas, corresponding to a distance of 1.82 ± 0.46 kpc and an absolute distance modulus of 11.30 ± 0.55. Examination of the Gaia DR1 astrometric validation maps of Lindegren et al. (2016) suggests that the systematic errors they identify are likely to be less than 0.1 mas for the immediate region near M4. The reddest of the five stars is also the most distant from the cluster center. This star is somewhat discrepant in both parallax and proper motion compared to the other four. Excluding this star gives a cluster parallax of 0.50 ± 0.15 mas, corresponding to a distance of 2.01 ± 0.62 kpc and an absolute distance modulus of 11.52 ± 0.67. The good agreement with previous measurements of the distance to M4 indicates that either the systematic errors are small or that diverse distance measurement techniques are seriously flawed. While the uncertainties at this point are too large to decide between the differing ground-based distance determinations, the results at this early stage bode well for future globular cluster parallaxes from Gaia. To our knowledge, this is the first measurement of the trigonometric parallax of a globular cluster.

Author(s): Richard F. Rees1, Kyle M. Cudworth2
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343.08 – Interstellar Extinction toward the Young Open Cluster NGC 1502

We present new multi-wavelength polarization measurements of 20 stars in the direction of the open cluster NGC 1502. Polarimetric results are combined with *uvby*β photometric data to obtain precise estimates of the total-to-selective extinction and distance for each star. NGC 1502 is located at the periphery of the Cam OB1 association and probably within the Orion Spur, with published distance estimates varying between 0.7 and 1.5 kpc. Our analysis suggests that the stars studied here form two concentrations along the line of sight. If a value of 3.2 for the total-to-selective extinction is assumed, the stars group at 0.8 ± 0.02 kpc and 1.1 ± 0.05 kpc. However, using the wavelength of maximum polarization to calculate the total-to-selective extinction for each star yields 0.9 ± 0.03 kpc and 1.3 ± 0.04 kpc, respectively. This approach indicates that combining polarimetric and uvbyβ data provides a more detailed stellar distribution of this region. Acknowledgments: Part of this work was supported by NSF grant AST-1516932.

Author(s): Gregory A. Topasna2, Nadia Kaltcheva1
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343.09 – H-alpha and H-beta Standard Stars in M 67 and NGC 752

The BYU H-alpha photometric system was defined in Joner and Hintz (2015, AJ, 150, 204) using multiple years of spectroscopic observations. The spectrophotometric methods used to form the new index were also utilized to produce an H-beta index for each of the newly established H-alpha standard stars. We present H-alpha and H-beta filter photometry for stars in the open clusters M 67 and NGC 752 that has been carefully transformed to the standard systems. These stars are suitable to use as standards for transforming CCD observations to the H-alpha and H-beta photometric systems.

Author(s): Michael D. Joner1, Clint A. Saylor 1, Maureen Hintz1, Eric G. Hintz1
Institution(s): *1. Brigham Young Univ.*

343.10 – H-alpha Monitoring of the Star Field around Cygnus OB2

Cygnus OB2 is a young stellar association located at RA: 20:33:12 and Dec: +41:19. Given the significant number of O and B stars, with the potential to be emission line objects, this is an ideal field to test the monitoring capabilities of the H-Alpha filters discussed by Joner & Hintz (2015). From August 2013 to July 2016 we collected 50 nights of data through narrow and wide H-alpha filters using the BYU West Mountain Observatory 0.9-m telescope with a Finger Lakes PL3041 CCD. This provided 0.62 arcsec/pixel with a field of view of 21' on a side. Photometry was obtained from these frames using DAOPhot in order to minimize contamination from nearby stars. The index was then created by subtracting the magnitude in the wide filter from that in the narrow filter. Each night was then carefully zeropointed to allow for examination of long term variation. In total we examined 580 stars to check for variability in the H-alpha emission line. We will present our preliminary results for variations seen in a number of individual stars.

Author(s): Seth Clarke1, Eric G. Hintz1, Michael D. Joner1
Institution(s): *1. Brigham Young University*

343.11 – Variable Stars in M92 and M15

We present the details of a search for variable stars in the Galactic globular clusters M92 and M15, using images collected over a 12 year baseline from April 2003 to September 2015. Preliminary variable candidates are identified by large standard deviations in the time-series photometry and periodicity of the candidates is the confirmed using the NASA Periodogram Service. We have found 24 variable stars for M92 and 101 variable stars for M15. Of the 24 variable stars found in M92, 4 are newly discovered and 20 were previously known. The periods found for previously confirmed variable stars are provided. For M92, 50 stars were detected that have significant variability, however no accurate period was determined. For M15, 16 of the 101 variable stars are newly discovered. The remaining 85 variable stars were discovered in earlier studies, our periods for these stars are provided. For M15, there are 221 stars that are possible variables based on the significant variability in their photometry, however, precise periods have not yet been determined for these stars.

Author(s): Riley Jordan1, Nathaniel Paust1
Institution(s): *1. Whitman College*

343.12 – Stellar Variability in the Intermediate Age Cluster NGC 1846

The existence of multiple stellar populations in Galactic globular clusters is considered a widespread phenomenon, with only a few possible exceptions. In the LMC intermediate-age globular clusters, the presence of extended main sequence turn off points (MSTOs), initially interpreted as evidence for multiple stellar populations, is now under scrutiny and stellar rotation has emerged as an alternative explanation. Here we propose yet another ingredient to this puzzle: the fact that the MSTO of these clusters passes through the instability strip making stellar variability a new alternative to explain this phenomenon. We report the first in-depth characterization of the variability, at the MSTO level, in any LMC cluster, and assess the role of variability masquerading as multiple stellar populations. We used the Gemini-S/GMOS to obtain time series photometry of NGC 1846. Using differencing image analysis, we identified 90 variables in the r-band, 68 of which were also found in the g-band. Of these 68, 57 were δ-scuti—with 35 having full phase coverage and 22 without. The average full period (P_{full}) was 1.93 ± 0.79 hours. Furthermore, two eclipsing binaries and two RR Lyrae identified by OGLE were recovered. We conclude that not enough variables were found to provide a statistically significant impact on the extended MSTO, nor to explain the bifurcation of MSTO in NGC 1846. But the effect of variable stars could still be a viable explanation on clusters where only a hint of a MS extension is seen.

Author(s): Michael A Pajkos[1], Ricardo Salinas3, Anna Katherina Vivas[2], Jay Strader4, Rodrigo Contreras5
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343.13 – From the Ultraviolet to the Infrared: The Stellar Population of the Globular Cluster M70

Because of their dense stellar environments, globular clusters are an important place for investigating stellar evolution and stellar dynamics, but there is much yet to learn about their formation. In this project, we considered the globular cluster NGC 6681 (M70) with the goal of characterizing its stellar population. We used archival data from the Hubble Space Telescope's Advanced Camera for Surveys. The data was drawn from thirteen different filters ranging from the far-UV to the near infrared. Using this range of filters, we constructed spectral energy distributions (SEDs) for each of the sources in our field of view. We then generated color-magnitude diagrams (CMDs) in a variety of wavelengths which we used to identify a number of sources that fell outside the regions occupied by normal stars. We determined the likely stellar type of several of these unusual sources using the CMDs and by comparing their SEDs to a number of synthesized SEDs.

Author(s): Sabrina Appel[2], David Zurek[1], Nathan Leigh[1]
Institution(s): *1. American Museum of Natural History, 2. Reed College*

343.14 – Deep WIYN Imaging of the Globular Cluster System of the Lenticular Galaxy NGC 3607

Globular clusters serve as relics of a galaxy's past history, because they are thought to be among the first objects to form in a galaxy. Measuring the properties of the globular cluster population of a galaxy — in particular the total number, spatial distribution, and color distribution of the clusters — can provide important clues about the formation and evolution of that galaxy. Here we present results from the analysis of the globular cluster population of NGC 3607, an S0 galaxy with M_V = -21.9 that is ~23 Mpc away and is the brightest member of the Leo II group. We used images from the Minimosaic camera on the WIYN 3.5-m telescope with total exposure times of 6300, 6000, and 5400 seconds in the B, V, and R filters, respectively, to image the globular cluster system of NGC 3607 well past its apparent radial extent of 6.3' (41 kpc). Point-source globular clusters are selected with three-filter photometry to help eliminate foreground stars and background galaxies. The excellent seeing in our WIYN images (0.6" to 0.9") also helped reduce contamination in the globular cluster candidate sample. Artificial star tests yielded 50% completeness levels of B = 25.4, V=25.2, and R=24.1 and we observed approximately 41% of the galaxy's Globular Cluster Luminosity Function. We estimate the total number of globular clusters in NGC 3607 is 1000+/-50, which translates to specific frequency values of S_N = 1.7+/-0.3 and T = 2.6+/-0.3 for this galaxy's luminosity and stellar mass. This research was supported in part by NSF REU grant AST-1358980 and the Nantucket Maria Mitchell Association.

Author(s): Derrick Carr[1], Katherine L. Rhode[2], Regina Jorgenson3
Institution(s): *1. Haverford College, 2. Indiana University, 3. Maria Mitchell Association*

343.16 – Photometric Calibrations of Gemini Images of NGC 6253

We present preliminary results of our analysis of the metal-rich open cluster NGC 6253 using imaging data from GMOS on the Gemini-South Observatory. These data are part of a larger project to observe the effects of high metallicity on white dwarf cooling processes, especially the white dwarf cooling age, which have important implications on the processes of stellar evolution. To standardize the Gemini photometry, we have also secured imaging data of both the cluster and standard star fields using the 0.6-m SARA Observatory at CTIO. By analyzing and comparing the standard star fields of both the SARA data and the published Gemini zero-points of the standard star fields, we will calibrate the data obtained for the cluster. These calibrations are an important part of the project to obtain a standardized deep color-magnitude diagram to analyze the cluster. We present the process of verifying our standardization process. With a standardized CMD, we also present an analysis of the cluster's main sequence turn off age.

Author(s): Sean Pearce[1], Elizabeth Jeffery[1]
Institution(s): *1. Brigham Young University*

343.17 – The Role of Dynamics in the Formation of Cataclysmic Variables in Globular Clusters

Internal dynamics and stellar interactions in the high-density environments of globular clusters are likely to play a key role in the formation and evolution of X-ray sources in these stellar systems. Observational evidence in support of the role dynamical interactions in the formation of X-ray sources comes from a number of observational studies showing that the number of X-ray sources in globular clusters is correlated with the cluster stellar encounter rate.
We present here the results of a survey of Monte-Carlo simulations exploring the role of dynamics in the formation of cataclysmic variables (CVs). Our simulations show a correlation between the number of CVs and the stellar encounter rate as found in observational studies and illustrate the dynamical path leading to this correlation.
We also study the spatial distribution of CVs in clusters and find that they are more concentrated than single stars with masses close to those of turn-off stars at 12 Gyr. This trend is stronger for the population of CVs formed from primordial binaries undergoing exchange encounters.

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343.18 – Stellar Parameters of A- and B-type Members of the Scorpius-Centaurus OB Association

Advances in high-contrast imaging and radio interferometry are allowing new avenues for circumstellar disk studies as well as direct imaging exoplanet searches. The most promising targets in these studies are intermediate mass B/A/F type members of the Scorpius-Centaurus OB association at a distance of ~100-200 pc and an age of 10-20 Myr old. However, many of the most interesting stellar members of Sco-Cen have poorly constrained stellar properties, including luminosities, distances and masses. In order to address this, we have obtained low resolution spectra from the SMARTS 1.5 m telescope and have obtained new spectral classifications for 106 stars. Using these new spectral classifications along with visual and near-infrared photometry from GAIA, Hipparcos, Tycho2, APASS and 2MASS, we obtained new reddening and extinction estimates. We then placed the stars on a Hertzsprung-Russell diagram and compared with stellar evolutionary tracks to obtain individual masses and ages. These improved stellar parameters will provide essential data for improving our understanding of high contrast imaging targets of B/A/F type members within the nearest OB association. We acknowledge support from NSF awards AST-1008908 and AST-1313029.

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343.19 – Star Cluster Mass Functions and Hierarchical Clustering: Learning from Koposov 1 and 2

We present photometry of two halo star clusters, Koposov 1 and 2. Found as over-densities in the Sloan Digital Sky Survey, these clusters were intially believed to be heavily stripped globular clusters, given the small number of stars per cluster. In this work, we have used isochrone fitting to determine the age, distance, and metallicity of the clusters. These results confirm tha tthe clusters are in the halo but also reveal surprisingly young ages and high metallicities. Investigation of the cluster mass functions reveals a steep negatively-sloped present day mass function in contrast to the flatish positively-sloped mass functions seen in heavily stripped Galactic globular clusters. The mass function slope, proximity to the Sagittarius stream, and common metallicity with M54, which is related to the Sagittarius dwarf, leads to a very interesting conclusion: Koposov 1 and 2 are open clusters removed from the Sagittarius dwarf through tidal stripping.

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343.20 – New insight on the chemical evolution in proto-globular clusters

In order to investigate the origin of multiple stellar populations in the halo and bulge of the Milky Way, we have constructed chemical evolution models for the low-mass proto-Galactic subsystems such as globular clusters (GCs). Unlike previous studies, we assume that supernova blast waves undergo blowout without expelling the pre-enriched gas, while relatively slow winds of massive stars, together with the winds and ejecta from low and intermediate mass asymptotic-giant-branch stars, are all locally retained in these less massive systems. We first applied these models to investigate the origin of super-helium-rich red clump stars in the metal-rich bulge as recently suggested by Lee et al. (2015). We find that chemical enrichments by the winds of massive stars can naturally reproduce the required helium enhancement ($dY/dZ = 6$) for the second generation stars. Disruption of these “building blocks” in a hierarchical merging paradigm would have provided helium enhanced stars to the bulge field. Interestingly, we also find that the observed Na-O anti-correlation in metal-poor GCs can be reproduced, when multiple episodes of starbursts are allowed to continue in these subsystems. Specific star formation history with decreasing time intervals between the stellar generations, however, is required to obtain this result, as would be expected from the orbital evolution of these subsystems in a proto-Galaxy. The “mass budget problem” is also much alleviated by our models without ad-hoc assumptions on star formation efficiency and initial mass function.

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343.21 – Spectroscopy of globular clusters in the outer halo of M81

We present integrated spectroscopy of two globular clusters and two globular cluster candidates in the central region of the dynamically active M81 group of galaxies. These spectra were obtained from the OSIRIS instrument at the 10.4m Gran Telescopio Canarias (GTC). The target clusters are located in the halo between M81, M82, and NGC3077, which contains a significant amount of young stars and HI gas as a result of interactions between these galaxies. The spectra of the target clusters show spectral features of globular clusters, confirming their globular cluster nature. One of the two clusters is located 400 kpc away from M81, making it the most isolated globular cluster in the local universe. However, the origin of these clusters is still largely a mystery. We use their spectra to study their kinematics, ages, and metallicities to better understand the impact of galaxy interactions on the process of galaxy formation and evolution.

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343.22 – The Extended Globular Cluster System of NGC3923

In the LambdaCMD paradigm of galaxy formation galaxy halos and their globular clusters systems build up over time by the accretion of small satellites. We can learn about this process in detail by observing systems with ongoing accretion events and comparing the data with simulations. Elliptical shell galaxies are systems that are thought to be due to ongoing or recent minor mergers. We present preliminary results of an investigation of the entire globular cluster system of the shell galaxy NGC3923 from deep DECam g and i-band imaging. Cluster candidates are selected using Principal Component Analysis of Sextractor/PSFEx parameters. We will present the 2D and radial distributions of the globular cluster candidates out to a projected radius of about 130kpc, or 26Re, making this one of the most extended cluster systems studied. We find that the bluer globular cluster candidates have a shallower radial distribution than the red cluster candidates, in agreement with many previous studies.

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343.23 – Star Clusters within FIRE

In this work, we analyze the environments surrounding star clusters of simulated merging galaxies. Our framework employs Feedback In Realistic Environments (FIRE) model (Hopkins et al., 2014). The FIRE project is a high resolution cosmological simulation that resolves star forming regions and incorporates stellar feedback in a physically realistic way. The project focuses on analyzing the properties of the star clusters formed in merging galaxies. The locations of these star clusters are identified with astrodendro.py, a publicly available dendrogram algorithm. Once star cluster properties are extracted, they will be used to create a sub-grid (smaller than the resolution scale of FIRE) of gas confinement in these clusters. Then, we can examine how the star clusters interact with these available gas reservoirs (either by accreting this mass or blowing it out via feedback), which will determine many properties of the cluster (star formation history, compact object accretion, etc). These simulations will further our understanding of star formation within stellar clusters during galaxy evolution. In the future, we aim to enhance sub-grid prescriptions for feedback specific to processes within star clusters; such as, interaction with stellar winds and gas accretion onto black holes and neutron stars.

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343.24 – Tidal Tales II: Molecular Gas and Star Formation in the Tidal Tails of Minor Mergers

While major mergers and their tidal debris are well studied, equal

mass galaxy mergers are relatively rare compared to minor mergers (mass ratio <0.3).
Minor mergers are less energetic than major mergers, but more common in the observable universe, and thus likely played a pivotal role in the formation of most large galaxies. Tidal debris regions have large amounts of neutral gas but a lower gas density and may have higher turbulence. We use star formation tracers such as young star cluster populations and H-alpha and CII emission to determine the different factors that may influence star formation in tidal debris. These tracers were compared to the reservoirs of molecular and neutral gas available for star formation to estimate the star formation efficiency (SFE). The SFR in tidal debris can reach up to 50% of the total star formation in the system. The SFE of tidal tails in minor mergers can range over orders of magnitude on both local and global scales. From the tidal debris environments in our study, this variance appears to stem from the formation conditions of the debris. Current surveys of the 2.12 micron line of molecular hydrogen, CO(1-0), and HI for 15 minor mergers, are providing a larger sample of environments to study the threshold for star formation that can inform star formation models, particularly at low densities.

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344 – X-Ray & Eclipsing Binaries, Multiple Star Systems Poster Session

344.01 – The Spectrum of SS 433 in the H and K Bands

SS 433 is an X-ray binary and the source of sub-relativistic, precessing, baryonic jets. We present high-resolution spectrograms of SS 433 in the infrared H and K bands. The spectrum is dominated by hydrogen and helium emission lines. The precession phase of the emission lines from the jet continues to be described by a constant period. The limit on any secularly changing period is $|dP/dt| \leq 10^{-5}$. The He I λ2.0587 μm line has complex and variable P-Cygni absorption features produced by an inhomogeneous wind with a maximum outflow velocity near 900 km s^{-1}. The He II emission lines in the spectrum also arise in this wind. The higher members of the hydrogen Brackett lines show a double-peaked profile with symmetric wings extending more than ±1500 km s^{-1} from the line center. The lines display radial velocity variations in phase with the radial velocity variation expected of the compact star, and they show a distortion during disk eclipse that we interpret as rotational distortion. We fit the line profiles with a model in which the emission comes from the surface of a symmetric, Keplerian accretion disk around the compact object. The outer edge of the disk has velocities that vary from 110 to 190 km s^{-1}. These comparatively low velocities place a strong constraint on the mass of the compact star: Its mass must be less than 2.2 $M_\odot$ and is probably less than 1.6 $M_\odot$.

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344.02 – The Distorted Winds of V444 Cygni: New Insights from Spectropolarimetry

V444 Cygni is a close, eclipsing WR+O binary system characterized by strong X-ray emission and colliding winds whose shapes are distorted by its rapid orbital velocity and powerful radiative forces. It also exhibits periodic polarimetric variability both in the continuum and in the strong emission lines of He II λ4686, Hα+He I λ6560, and N IV λ7125; these line polarization variations probe the distribution of line formation regions in the complex winds. Sparse spectropolarimetric coverage has limited the reliability of the line polarization analysis in past studies. We here present new line polarization curves that incorporate 11 recent observations of V444 Cyg, obtained with the HPOL spectropolarimeter at the University of Toledo's Ritter Observatory, into the existing dataset. Because most of these data were taken with the blue grating, we focus primarily on the improved He II λ4686 polarization curve. Although the data display significant stochastic variability by virtue of spanning 27 years, the addition of the new observations allows a more robust analysis than was previously possible. We discuss our interpretation of the updated curves in light of current models for V444 Cyg and other WR+O binary systems. Accurately characterizing the structures of the wind collision regions in such systems is key to understanding the evolution of such massive binary systems and properly accounting for their contribution to the supernova (and possible GRB) progenitor population.

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344.03 – The Structures of X-ray Binary Systems V801 Ara and Cyg X-3 from Doppler Tomography

We present spectroscopic observations of two X-ray binary systems, V801 Ara and Cyg X-3. We observed V801 Ara in the optical in 2014 with IMACS on the Magellan/Baade telescope at Las Campanas Observatory and Cyg X-3 in the near-infrared in 2015 with GNIRS on the Gemini North telescope. Both spectra contain strong emission features that are suitable for tomography, allowing us to map the systems in velocity space. Our tomograms show continuous emission of H_alpha and H_beta from V801 Ara's accretion disk. The center of the accretion disk does not coincide with the neutron star's estimated center of mass (estimated using K1 = 102 km s-1 and K2 = 360 km s-1 from Casares et al. 2006, MNRAS, 373, 1235), possibly indicating eccentricity in the disk. The tomograms also do not show a hot spot where the accretion stream hits the disk, implying a low accretion rate. Due to insufficient orbital phase coverage in our GNIRS observations, we are unable to produce significant tomograms of Cyg X-3.

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344.04 – X-Ray Analysis of a Pulsating Source in the 3XMM Catalogue with a Period of 6.8 Minutes

The *3XMM Serendipitous Source Catalogue* (3XMM-SSC) contains over 500 thousand source detections from the XMM-Newton EPIC instruments. Along with a database search of the catalogue for unidentified objects of interest, we carry out a detailed study on one pulsating source, which was previously suggested to be a slow pulsar with an approximate period of 400s. We refine the period of the source to 407.88575(1) seconds based on the phase-connection analysis from the XMM-Newton and Swift observations spanning across nine years. The source shows stable X-ray properties (temperature and flux) during the observation epochs, the X-ray spectra is best described by a 2 keV blackbody emission plus 2 faint Fe lines at 6.4 keV and 6.7 keV, respectively. We also search for a possible counterpart in multi-wavebands. The low-mass counterpart candidate, together with the X-ray properties, suggests that the source is probably a low-mass X-ray binary at a distance around 1.5 kpc.

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344.05 – Selection effects on the orbital period distribution of Low Mass X-ray Binaries

Observations show a lack of Low Mass Black Hole Binaries with orbital periods below 4 hours. While it is known that Black Hole Binaries (BHBs) tend to have lower peak luminosities in outburst compared to their Neutron Star counterparts, it is unclear if selection effects can account for the difference in the numbers. Studying the effect of these selection biases is important for binary population studies. Here we report on the implications for the inferred orbital period distribution of these BHBs after a simulation that accounts for extinction of the optical counterpart, absorption of X-ray counts and detectability of the outburst.

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344.06 – X-ray Luminosity Functions of Subgalactic Regions in the Whirlpool Galaxy (M51)

We present X-ray luminosity functions (XLFs) of X-ray binary (XRB) populations in subgalactic regions in M51, which were selected to have varying levels of low-mass XRBs (LMXBs) and high-mass XRBs (HMXBs). Previous studies have found that the total X-ray luminosity of a galaxy is correlated with its star formation rate (SFR) and stellar mass (M*) according to the equation $Lx = \alpha M^* + \beta SFR$, where α and β are scaling constants. This result is based on integrated galaxy-wide X-ray luminosities, SFRs, and stellar masses. Here, our goal is to determine this relationship using XLFs within multiple subregions, selected by specific star-formation rate (SFR/M*), of one galaxy (M51). This selection allows us to decompose contributions from LMXB and HMXB populations separately. From this decomposition, we find similar scaling relations to Lehmer et al. (2010), and also find XLF shapes and normalizations that are consistent with past studies of elliptical galaxies (LMXB XLF) and star-forming active galaxies (HMXB XLF). This suggests that our technique is effective and that the star formation history of M51 does not deviate significantly from the average galaxy in the local Universe.

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344.07 – Multi-color Photometric Study of the Contact Eclipsing Binary V1062 Her

We observed the short-period contact eclipsing binary of V1062 Her using SARA 0.9 meter telescope at Kitt Peak National Observatory on July 4, 2015. In this study, we obtained the system's full phase coverage *BVRI* CCD light curves, analyzed the orbital period variation, and extracted the orbital parameters. We calculated the linear and quadratic ephemeris to observe the star's change in period. By using the updated Wilson & Devinney program, we found the orbital parameters of V21062 Her, which, in turn, enables us to calculate the degree of contact factor. We will predict any changes in its degree of contact to see how the star will evolve with time.

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344.08 – Artificial Neural Network Solutions to Eclipsing Binary Lightcurves from the Kepler Space Telescope Database

Fully automated methods of data analysis are necessary for surpassing the human bottleneck in astrophysical data processing and maximizing scientific results from the great volume of observations to be taken over the next few decades. Prsa et al. (2008, ApJ, 687:542) addressed this issue by introducing an artificial neural network (ANN) which estimates the principal parameters of detached eclipsing binary (EB) stars. Parameters obtained by the process can be passed on to advanced modeling engines to produce a qualified EB database. The ANN was originally developed and trained for the OGLE EBs. Our project focuses on retraining this ANN for EBs from NASA's Kepler Space Telescope database and serves as an extension to the eclipsing binaries via artificial intelligence (EBAI) project. The Kepler photometry is much more precise than photometry available from OGLE and other previous ground-based studies.. For our training set, we generated theoretical lightcurves via a Monte Carlo based Python script utilizing PHOEBE which samples EB parameter values according to prior distribution functions. Novel to our analysis is the use of chi-squared statistical tests which serve to qualify the overlap between the calculated exemplars and observed data. This enables the trained ANN to more accurately parameterize each EB. We describe our training process, present principal parameter estimates of Kepler EBs obtained by the ANNs, and discuss ongoing endeavors to refine those solutions. This research was supported by the National Science Foundation grant #1517474 which we gratefully acknowledge.

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344.09 – Using Gaussian Processes to Model Noise in Eclipsing Binary Light Curves

The most precise data we have at hand arguably comes from NASA's *Kepler* mission, for which there is no good flux calibration available since it was designed to measure *relative* flux changes down to ~20ppm level. Instrumental artifacts thus abound in the data, and they vary with the module, location on the CCD, target brightness, electronic cross-talk, etc. In addition, *Kepler*'s near-uninterrupted mode of observation reveals astrophysical signals and transient phenomena (i.e. spots, flares, protuberances, pulsations, magnetic field features, etc) that are not accounted for in the models. These "nuisance" signals, along with instrumental artifacts, are considered noise when modeling light curves; this noise is highly correlated and it cannot be considered poissonian or gaussian. Detrending non-white noise from light curve data has been an ongoing challenge in modeling eclipsing binary star and exoplanet transit light curves. Here we present an approach using Gaussian Processes (GP) to model noise as part of the overall likelihood function. The likelihood function consists of the eclipsing binary light curve generator PHOEBE, correlated noise model using GP, and a poissonian (shot) noise attributed to the actual stochastic component of the entire noise model. We consider GP parameters and poissonian noise amplitude as free parameters that are being sampled within the likelihood function, so the end result is the posterior probability not only for eclipsing binary model parameters, but for the noise parameters as well. We show that the posteriors of principal parameters are significantly more robust when noise is modeled rigorously compared to modeling detrended data with an eclipsing binary model alone. This work has been funded by NSF grant #1517460.

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344.10 – The Galactic Distribution of Contact Eclipsing Binaries

The number of eclipsing contact binaries in different galactic latitudes and longitudes show peak distributions in the number per square degree in two latitudinal zones (-30 degrees to -25 degrees and +25 degrees to +30 degrees) and large fluctuations in longitude (Huang and Wade 1966, ApJ, 143, 146). Semi-detached or detached binaries are largely concentrated in the galactic plane as shown by Paczynski et al. (MNRAS, 368, 1311), different from the distribution of contact eclipsing binaries. The differences in distributions of different types of eclipsing binaries may be related to either distances or interstellar reddening. We will present a method to calculate photometric distances of W Urase Majoris systems (W UMa; used as a proxy for contact binaries) from 2MASS J and K magnitudes and interstellar reddening models (Schlafly and Finkbeiner 2011, ApJ. 737, 103). We compare the distances to those calculated from the period-luminosity-color relationship described by Rucinski (2004, NewAR, 48, 703). The W

UMa systems are taken from the General Catalog of Variable Stars.

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344.11 – COS Spectroscopy of White Dwarf Companions to Blue Stragglers

Complete membership studies of open stellar clusters reveal that 25% of the evolved stars follow alternative pathways in stellar evolution, meaning something in the history of these stars changed their composition or mass (or both). In order to draw a complete picture of stellar evolution we must include these canonically "strange" stars in our definition of standard stellar populations. The formation mechanism of blue straggler stars, traditionally defined to be brighter and bluer than the main sequence turnoff in a star cluster, has been an outstanding question for almost six decades. Recent Hubble Space Telescope (HST) far-ultraviolet (far-UV) observations directly reveal that the blue straggler stars in the old (7 Gyr) open cluster NGC 188 are predominantly formed through mass transfer. We will present HST far-UV COS spectroscopy of white dwarf companions to blue stragglers. These white dwarfs are the remnants of the mass transfer formation process. The effective temperatures and surface gravities of the white dwarfs delineate the timeline of blue straggler formation in this cluster. The existence of these binaries in a well-studied cluster environment provides an unprecedented opportunity to observationally constrain mass transfer models and inform our understanding of many other alternative pathway stellar products.

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344.12 – K-KIDS: Companioins to K Dwarfs Within 50 Parsecs

How many K dwarfs have “kids?” Stellar multiplicity fractions have been obtained for most spectral types, most recently by Raghavan et al. (2010) and Winters et al. (2015), finding rates of 50% for solar-type stars and 27% for M dwarfs, respectively. These findings will be crucial to improving our understanding of solar-system formation, but there has not yet been a statistically significant survey for K dwarfs to bridge the gap between G and M stars. To create a sample for a robust multiplicity survey, an initial set of 1048 K dwarfs was built using the Hipparcos and 2MASS catalogs, the companions of which are called “K-KIDS.” Future releases from Gaia will help us to expand K-KIDS into a volume-complete sample out to 50-pc, and we project that the final sample will contain over 3000 stars, making this the largest volume-complete multiplicity survey ever undertaken. For observational purposes, the targeted K dwarfs are confined equatorially to -30 < DEC < +30 to ensure all stars are observable from either hemisphere. The survey for K-KIDS is split into three companion-separation regimes: small (0.02 – 2.00 arcseconds), medium (2.00 – 10.00 arcseconds), and distant (10.00+ arcseconds). Small separation companions are resolved using the Differential Speckle Survey Instrument, with which we have observed 964 out of 1048 systems to date, already finding 135 new K-KIDS. Medium separation companions are observed via a series of three observations per star at the CTIO 0.9-m telescope, integrating for 3, 30, and 300 seconds to reveal companions of various brightnesses. Finally, a common proper-motion search is used to find companions at distant separations via blinking of digitialized images in the SuperCOSMOS archive, in addition to a large-scale literature survey for previously-discovered multiples. The small and distant surveys are nearing completion, and continued progress on the medium survey ensures that a statistically significant multiplicity rate for K dwarfs will soon be in achieved. Furthermore, a new RV survey is planned using the CHIRON high-resolution spectrograph to find companions that cannot be directly imaged. This effort has been supported by the NSF through grants AST-1412026 and AST-1517413.

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Contributing team(s): The RECONS Institute

344.13 – The K-KIDS Sample: K Dwarfs within 50 Parsecs and the Search for their Closest Companions with CHIRON

To understand fundamental aspects of stellar populations, astronomers need carefully vetted, volume-complete samples. In our K-KIDS effort, our goal is to survey a large sample of K dwarfs for their "kids", companions that may be stellar, brown dwarf, or planetary in nature. Four surveys for companions orbiting an initial set of 1048 K dwarfs with declinations between +30 and -30 have begun. Companions are being detected with separations less than 1 AU out to 10000 AU. Fortuitously, the combination of Hipparcos and Gaia DR1 astrometry with optical photometry from APASS and infrared photometry from 2MASS now allows us to create an effectively volume-complete sample of K dwarfs to a horizon of 50 pc. This sample facilitates rigorous studies of the luminosity and mass functions, as well as comprehensive mapping of the companions orbiting K dwarfs that have never before been possible.

Here we present two important results. First, we find that our initial sample of ~1000 K dwarfs can be expanded to 2000-3000 stars in what is an effectively volume-complete sample. This population is sufficiently large to provide superb statistics on the outcomes of star and planet formation processes. Second, initial results from our high-precision radial velocity survey of K dwarfs with the CHIRON spectrograph on the CTIO/SMARTS 1.5m reveal its short-term precision and indicate that stellar, brown dwarf and Jovian planets will be detectable. We present radial velocity curves for an inital sample of 8 K dwarfs with V = 7-10 using cross-correlation techniques on R=80,000 spectra, and illustrate the stability of CHIRON over hours, days, and weeks. Ultimately, the combination of all four surveys will provide an unprecedented portrait of K dwarfs and their kids.

This effort has been supported by the NSF through grants AST-1412026 and AST-1517413, and via observations made possible by the SMARTS Consortium

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Contributing team(s): RECONS Team

344.14 – New Low-Mass Wide Companions to Members of the Sco-Cen OB Association

We have conducted a survey for wide common proper motion companions to 512 members of the Upper Cen-Lup (UCL) and Lower Cen-Cru (LCC) subgroups of the Sco-Cen OB association using astrometry and photometry from the SPM4 catalog. Companion candidates were selected within 3 arcminutes (23 kau = 0.11 pc at d = 130 pc). We find that 12% of the Sco-Cen members have stellar companions in the separation range 3-20 kau. Optical spectra of 16 candidate companions were taken with the new COSMOS spectrograph on the Blanco 4-m telescope and the Wide Field Spectrograph on the Australian National University 2.3-m telescope. The spectroscopic survey yielded 14 M-type stars with Na I surface gravity index indicative of pre-MS status, of which half were Li-rich (along with two background giant interlopers). Seven stars in the range M1-M4.5 appear to be Li depleted, but otherwise seem to be pre-MS due to their chromospheric activity, low surface gravity via the Na I index, and their co- movement with other young stars in Sco-Cen. We suggest that these stars represent the Li depletion boundary for UCL and LCC. We acknowledge support from NSF award AST-1313029 and the REU Site in Physics and Astrophysics at the University of Rochester supported by NSF award PHY-1156339.

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344.15 – An All-Sky Search for Wide Binaries in the SUPERBLINK Proper Motion Catalog

We present initial results from an all-sky search for Common Proper Motion (CPM) binaries in the SUPERBLINK all-sky proper motion catalog of 2.8 million stars with proper motions greater than 40 mas/yr, which has been recently enhanced with data from the GAIA mission. We initially search the SUPERBLINK catalog for pairs of stars with angular separations up to 1 degree and proper motion difference less than 40 mas/yr. In order to determine which of these pairs are real binaries, we develop a Bayesian analysis to calculate probabilities of true companionship based on a combination of proper motion magnitude, angular separation, and proper motion differences. The analysis reveals that the SUPERBLINK catalog most likely contains ~40,000 genuine common proper motion binaries. We provide initial estimates of the distances and projected physical separations of these wide binaries.

Author(s): Zachary Hartman[1], Sebastien Lepine[1]
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344.16 – Assessing the fundamental limits of multiple star formation: An imaging search for the lowest mass stellar companions to intermediate-mass stars

Stellar binaries are a common byproduct of star formation and therefore inform us on the processes of collapse and fragmentation of prestellar cores. While multiplicity surveys generally reveal an extensive diversity of multiple systems, with broad ranges of semi-major axis, mass ratio and eccentricities, one remarkable feature that was identified in the last two decades is the so-called brown dwarf desert, i.e., the apparent paucity of (non-planetary) substellar companions to solar-type stars. This "desert" was primarily identified among spectroscopic binaries but also appears to be a significant feature of wider, visual binaries. The physical origin of this feature has not been fully accounted for but is likely established during the formation of the systems. One way to shed new light on this question is to study the frequency of low-mass stellar companions to intermediate-mass star (late-B type, or 3-5 Msun), as those form through a similar, albeit scaled-up, mechanism as solar-type stars. Here we present preliminary results from two adaptive-optics based surveys to search for such multiple systems. Specifically, we are using the new ShaneAO system on the Lick3m telescope (~100 stars observed to date) and the Gemini Planet Imager (45 stars observed). We are targeting stars located both in open clusters and scattered in the Galactic field to search for potential evidence of dynamic evolution. To identify candidate low-mass companions as close in to target stars, we use advanced point spread function (PSF) subtraction algorithms, specifically implementations of the LOCI and KLIP algorithms. In the case of the ShaneAO observations, which do not allow for field rotation, we use LOCI in combination with Reference Differential Imaging (ADI), using our library of science images as input for PSF subtraction. In this contribution, we will discuss the potential of ShaneAO to reveal faint, subarcsecond companions in this context and present candidate companions from both surveys.

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344.17 – Analyzing Age-Rotation-Activity Relationships in Wide Binary Systems

We present an analysis of flare activity among equal mass wide binary pairs using a combination of value-added data sets from the NASA Kepler mission. Wide binary twins form from the same molecular cloud and are therefore coeval, making them ideal benchmarks for stellar evolution and formation studies. This implies that their magnetic activity should decay at the same rate, causing a similar decrease in flare activity over time. The first data set is the list of known wide binary candidates in the Kepler field, and contains pairs of stars that have similar proper motions. We then crossmatch these systems with data on relative flare luminosity for ~200,000 stars in the original Kepler field, provided by an automated flare-finding algorithm. This combined data set allows us to compare flare activity, mass, and pair separation between stars in binary pairs. We preliminarily find that the flare rates for these stars do not show strong correlation, indicating either a large intrinsic scatter in the flare rate as these stars age, or that the formation mechanism of wide binaries somehow affects their dynamo evolution. As a goal for future development of this work, we hope to compare flare rates with gyrochronology in these key systems.

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344.18 – Searching for Long-Period Companions and False Positives within the APOGEE Catalog of Companion Candidates

The Sloan Digital Sky Survey (SDSS) Apache Point Observatory Galactic Evolution Experiment (APOGEE) is a large-scale, high-resolution, H-band, spectroscopic survey that has acquired high S/N spectra of 146,000 stars distributed across the Galactic bulge, disk, and halo with a radial velocity (RV) precision of ~100 m/s. We follow up stellar companion detections from the APOGEE DR12 catalog of 382 total APOGEE-identified companions, of which 376 are previously unknown companion candidates. The APOGEE team strives not only to continue expanding the census of extrasolar companions, but also to confirm and characterize our RV detections through a variety of means.

We present findings from our investigation of the Kozai mechanism, which explains the development of close-orbiting binaries through an ejected third companion. To do so, we are undertaking a targeted search for long-period companions with hopes to provide further evidence for the Kozai mechanism. This hunt for longer period companions begins with a search for long-term RV trends within the APOGEE data. We have also obtained diffraction-limited imaging using speckle interferometry at WIYN and Gemini North Observatories, as well as AO LMIRcam images from the LBT, to make direct searches for long-period stellar companions.

It is critical to purge our companion candidate detections of false positives, and we discuss several methods we are pursuing to do this. For example, highly active stars have been observed to mimic RV measurements. We have obtained optical high-resolution spectral follow-ups from the ARC 3.5m, the HET, and MMT to analyze potential stellar activity indicators such as Calcium H and K. Emission detected in these well-known stellar activity indicators suggests a false radial velocity measurement.

Author(s): Duy Nguyen[1], Nicholas William Troup[1], Steven R. Majewski[1]
Institution(s): *1. University of Virginia*

344.19 – The APOGEE DR13 Catalog of Stellar and Substellar Companion Candidates

The SDSS Apache Point Observatory Galactic Evolution Experiment (APOGEE), expanding beyond its original intent as a Galactic structure survey, has demonstrated its capability as a radial velocity (RV) machine with the publication of a catalog of stellar and substellar companion candidates based on SDSS's 12th data release (DR12). We expand upon this work by taking advantage of the improved parameters and additional information provided in APOGEE's latest data release (DR13) to build an improved catalog of stellar and substellar companions. The newly available rotational velocity measurements provides an additional check against false-positive orbital solutions, and aids investigations of the role of tidal interactions in shaping the brown dwarf desert. In addition, we present initial tests of an automated cross-corellation function (CCF) bisector analysis code that allows us to detect spectrally unresolved companions and, in some cases, break the inclination degeneracy of RV detections. Finally, we present analysis of the detailed chemical abundances of the host stars in our sample. In particular, we use this abundance information to disentangle the formation mechanisms of brown dwarf companions from those of gas giant planets and low mass stellar companions.

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Contributing team(s): APOGEE RV Variability Working Group

344.20 – APOGEE/Kepler Overlap Yields Orbital Solutions for a Variety of Eclipsing Binaries

We present orbital solutions, masses, and radii for a set of eclipsing spectroscopic binaries observed by both Kepler and APOGEE. Kepler's primary mission is to find earth-like planets, but several of the observed stars are instead eclipsing binaries with a range of properties. The Apache Point Observatory Galactic Evolution Experiment (APOGEE) has observed many of these same systems during its near-infrared spectroscopic survey. In this work, we combine Kepler light curves and radial velocities extracted from APOGEE spectra to yield binary orbital solutions, stellar masses, and stellar radii. We select binaries that have at least three good-quality APOGEE visits, are sufficiently bright, are listed in the Kepler Eclipsing Binary Catalog (Kirk et al. 2016), show both a primary and a secondary eclipse, and have well- or semi-detached light curve morphologies. We identify a total of 50 promising targets, and present results for a subset of these. Once radial velocity solutions for both stars in each system are found, we combine them with Kepler light curves to solve for mass and radius. These inferences are especially rare for longer-period binaries, and will contribute to our knowledge of fundamental stellar parameters and binary star statistics. This work is supported the SDSS Faculty and Student (FAST) initiative.

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344.21 – The Complex Circumstellar and Circumbinary Environment of V356 Sgr

The eclipsing, interacting binary star V356 Sgr is a particularly exciting object for analysis due to its probable nonconservative mass loss and the possible progenitor link between Roche-lobe overflow systems and core-collapse supernovae. We present the results of 45 spectropolarimetric observations of V356 Sgr taken over 21 years, which we used to characterize the geometry of the system's circumstellar material. We find that V356 Sgr exhibits a large intrinsic polarization signature arising from electron scattering. The lack of repeatable eclipses in the polarization phase curves indicates the presence of a substantial pool of scatterers not occulted by either star. We suggest that these scatterers form either a circumbinary disk coplanar with the gainer's accretion disk, or an elongated structure perpendicular to the orbital plane of V356 Sgr, possibly formed by bipolar outflows.

We also observe small-scale, cycle-to-cycle variations in the magnitude of intrinsic polarization at individual phases. These may indicate a mass transfer or mass loss rate that varies on the time-scale of the system's orbital period. Finally, we present a comparison of V356 Sgr with the well studied beta Lyr system; the significant differences observed between the two systems suggests diversity in the basic circumstellar geometry of Roche-lobe overflow binaries.

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344.22 – Robust Modeling of Stellar Triples in PHOEBE

The number of known mutually-eclipsing stellar triple and multiple systems has increased greatly during the Kepler era. These systems provide significant opportunities to both determine fundamental stellar parameters of benchmark systems to unprecedented precision as well as to study the dynamical interaction and formation mechanisms of stellar and planetary systems. Modeling these systems to their full potential, however, has not been feasible until recently. Most existing available codes are restricted to the two-body binary case and those that do provide N-body support for more components make sacrifices in precision by assuming no stellar surface distortion. We have completely redesigned and rewritten the PHOEBE binary modeling code to incorporate support for triple and higher-order systems while also robustly modeling data with Kepler precision. Here we present our approach, demonstrate several test cases based on real data, and discuss the current status of PHOEBE's support for modeling these types of systems. PHOEBE is funded in part by NSF grant #1517474.

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344.23 – Heat Redistribution and Misaligned Orbit Models in PHOEBE

Reflection and aligned Roche geometry have been long supported in modeling codes that synthesize light and radial velocity curves of eclipsing binary stars. However, recent advances in observational data, mostly in terms of precision and temporal baseline, demonstrated that the assumptions of these two effects are frequently violated. Reflection treatment neglected the energy absorbed by the irradiated star, and Roche geometry assumed aligned vectors of spin and orbital angular momentum. Observations of night- and day-side brightness variation of cooler stellar and substellar companions point to a clear deficiency in treating heat redistribution, and the break in symmetry of the Rossiter-McLaughlin effect points to misaligned stellar spins w.r.t. orbital plane. The framework of existing codes did not allow for revising these effects while keeping the rest of the logic intact, which prompted a complete rewrite of the modeling code PHOEBE (PHysics Of Eclipsing BinariEs). Here we present the basic considerations and proof-of-concept examples of the revised reflection effect and misaligned spin-orbit support. Reflection has been extended with heat absorption and consequent redistribution, which can be local, longitudinal or global. Misaligned spin-orbit vectors are supported by deriving the equation of the Roche potential that allows misaligned rotational axes and are provided by the corresponding Euler angles. This research is supported by the NSF grant #1517474.

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344.24 – Determination of the Fundamental Properties of the Eclipsing Binary V541 Cygni

We report new high-resolution spectroscopic observations of the B-type detached spectroscopic eclipsing binary V541 Cygni (e = 0.465 and P =15.34 days). We combine analysis of these new spectra with analysis of V-band photometry from the literature to obtain the most precise measurements of the fundamental properties of the stars to date (yielding ~1% errors in the masses and ~2% for the radii). A comparison with current stellar evolution models indicates good fits for an age of ~ 200 million years and [Fe/H] ~ -0.2. Available eclipse timings gathered over 40 years were used to re-determine the apsidal motion of the system, $d\omega/dt$ = 0.993 degs/cent, which is larger than what theory suggests.

The SAO REU program was funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. 1262851, and by the Smithsonian Institution.

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Contributing team(s): the KELT collaboration

345 – Circumstellar & Debris Disks Poster Session

345.01 – A New All-Sky Catalogue of Candidate Protoplanetary Disks from Aggregated Optical and Infrared Surveys

We present a catalogue of 199,460 sources with optical and infrared colors that are consistent with protoplanetary disks. First, a list of known protoplanetary disks is compiled from the literature, and lists of field stars are selected from regions presumed to have little ongoing star formation. Optical and infrared magnitudes from multiple photometric surveys, covering up to 14 different bands, are then combined for these sources and used to define color-color cuts that reliably distinguish stars with known disks from other field objects. These cuts are applied in an all-sky search of the AllWISE catalogue. Of the sources returned by this query, 11.4% are listed in SIMBAD; their classifications and aggregated magnitudes are used to define additional color-color cuts that efficiently distinguish known young stellar objects from sources of various other types. These further cuts are applied to all targets either not listed in SIMBAD or with inconclusive SIMBAD types to form the new catalogue of 199,460 stars with likely warm circumstellar disks. An estimated false positive rate of 36.1% implies the detection of approximately 127,000 heretofore unidentified protoplanetary disks. The positions of these candidates on the sky are largely consistent with a spatial distribution in the young Galactic disk, showing a high density of sources in the Galactic plane and a low density in the Galactic bulge and at high Galactic latitudes. In addition, a number of nearby star-forming regions are successfully recovered through this process, and they include many sources not previously reported to be young stellar objects.

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Institution(s): *1. Georgia State University*

345.03 – An ALMA Survey of Planet Forming Disks in Rho Ophiuchus

Relatively evolved (~ 1 Myr old) protostars with little residual natal envelope, but massive disks, are commonly assumed to be the sites of ongoing planet formation. Critical to our study of these objects is information about the available mass reservior and dust structure, as they directly tie in to how much mass is available for planets as well as the modes of planet formation that occur (i.e., core-accretion vs. gravitational instability). Millimeter-wave observations provide this critical information as continuum emission is relatively optically thin, allowing for mass estimates, and the availability of high-resolution interferometry, allowing structure constraints. We present high-resolution observations of the population of Class II protostars in the Rho-Ophiuchus cloud (d ~ 130 pc). Our survey observed ~50 of these older protostars at 870μm, using the Atacama Large Millimeter/submillimeter Array (ALMA). Out of these sources, there are ~10 transition disks, where we see a ring of dust emission surrounding the central protostar -- indicative of ongoing planet formation -- as well as many binary systems. Both of these stages have implications for star and planet formation. We present results from both 1-D and 2-D disk modeling, where we try to understand disk substructure that might indicate on-going planet formation, in particular, transition disk cavities, disk gaps, and asymmetries in the dust emission.

Author(s): Erin Guilfoil Cox[8], Leslie Looney[8], Robert J. Harris[8], Jiayin Dong[8], Dominique Segura-Cox[8], John J. Tobin[9], Sarah Sadavoy[2], Zhi-Yun Li[10], Michael Dunham[5], Laura M. Perez[1], Claire J. Chandler[4], Kaitlin M. Kratter[6], Carl Melis[7], Hsin-Fang Chiang[3]
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345.04 – Protoplanetary disks in Taurus: Probing the role of multiplicity with ALMA observations

We present results from an ALMA survey of single and multiple young systems in Taurus designed to probe how protoplanetary disk mass depends on both stellar mass and multiplicity. In observations taken in Cycles 0 and 2, we detect over 25 new disks. These detections include disks around stars in both single and multiple systems and are predominantly around lower mass stars with spectral types from M0 to M6. Combined with previous detections, these observations reveal a wide range of disk mass around both primary and companion stars, and allow us to test if the relation previously seen between disk and stellar mass continues at lower stellar masses. We find that within multiple systems the ratio of primary to secondary stellar mass is not correlated with the ratio of primary to secondary disk mass. In some cases, the secondary star hosts the more massive disk, contrary to theoretical predictions. We will discuss the implications of these results for the process of planet formation in multiple systems.

This work makes use of the following ALMA data: ADS/JAO.ALMA#2011.0.00150.S. and ADS/JAO.ALMA#2013.1.00105.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada) and NSC and ASIAA (Taiwan), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Author(s): Stefan Laos[2], Rachel L. Akeson[1], Eric L. N. Jensen[2]
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345.05 – Disk Sizes and Grain Growth across the Brown Dwarf Boundary from the Taurus Boundary of Stellar/Substellar (TBOSS) Survey

With a combination of submm/mm observations from ALMA, CSO, and PdBI, we are investigating the properties of disks around low mass stars and brown dwarfs in the Taurus star-forming region. Disk sizes and spectral slopes are important properties to assess the formation scenarios for brown dwarfs and the viability of planet formation in the disks. The ALMA maps have a beam size of approximately 0.3arcseconds and a number of the sources are spatially resolved in the continuum and CO(3-2) line measurements. For most of the resolved systems, the gas disks are more extended than the dust disks, similar to previous results from observations of more massive stars. From the multi-wavelength data, we are measuring the spectral slope of the emission to search for the signature of initial grain growth that is encoded in the slope of the spectral energy distribution in order to test the hypothesis of enhanced radial drift in disks around substellarobjects. Theoretical studies have suggested that fast radial drift could prevent the growth of dust particles up to large bodies in brown dwarf disks, and our program is designed to obtain a set of measurements for objects across the stellar/substellar transition.

Author(s): Jenny Patience[1], Kimberly Ward-Duong[1], Joanna Bulger5, Gerrit van der Plas[6], Francois Menard[2], Christophe Pinte[2], Geoffrey Bryden3, Neal J. Turner3, Alan Patrick Jackson[1], Paul M. Harvey7, Antonio Hales4
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345.06 – Carbon Monoxide Emissions in Middle Aged Debris Disks

Circumstellar disks greater than 10 Myr old, referred to as debris disks, are expected to be gas poor. The original gas and dust in these disks is thought to be accreted onto the host stars, used up in the formation of planets and other bodies, or blown out of the disks via stellar radiation. However, recent ALMA observations at millimeter wavelengths have led to the detection of carbon monoxide (J=2-1) emission in a few debris disks, prompting further investigation.
Using ALMA data, two separate models of gas genesis were tested against observations of the CO emissions in the disks around HIP 73145, HIP 76310, and HIP 84881 in the Upper Sco association. One of these models was built on the hypothesis that the gas in these debris disks is left over from stellar formation and has persisted over uncommonly long periods of time. The other model is built on the hypothesis that this gas is of secondary nature, produced by collisions between planetary bodies in the debris disks. Model emissions were calculated using the Line Modeling Engine (LIME) radiative transfer code and were compared with observational data to infer gas masses under both production scenarios. The implications of the masses of carbon monoxide in the disks suggested by each of the two models are discussed.

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345.07 –
Differential polarization direct imaging of FU Ori type YSO

FU Orionis objects (FUors) are distinguished from other young stellar objects due to their outbursts. They can surge in brightness by multiple magnitudes in a short time. Thus FUors have always been considered the strongest evidence which suggests unsteady accretion process in low mass young stellar objects (YSO). However the accreting process of FUors are not well understood. We present high resolution (~0.1 arcseconds) observations of 5 FUors (FU Ori, V1057cyg, V1515cyg, V1735cyg, Z Cma) in near infrared bandpasses (J,H,K) using the Subaru telescope. Through using polarization differential imaging and coronagraphy techniques, we were able to obtain high contrast images of circumstellar environment around central young stars. After image processing, we found interesting structures (stream, tail, fragment, etc) in the circumstellar disks. These structures are indications for dynamical interaction, potential outflow cavities and disk fragmentation. More importantly, these disk features can provide us with insight into the accretion process and where outbursts originate.

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345.08 – The correlation between HCN/H2O flux ratios and disk mass: evidence for protoplanet formation

We analyze hydrogen cyanide (HCN) and water vapor flux ratios in protoplanetary disks as a way to trace planet formation. Analyzing only disks in the Taurus molecular cloud, Najita et al. (2013) found a tentative correlation between protoplanetary disk mass and the HCN/H2O line flux ratio in Spitzer-IRS emission spectra. They interpret this correlation to be a consequence of more massive disks forming planetesimals more efficiently than smaller disks, as the formation of large planetesimals may lock up water ice in the cool outer disk region and prevent it from migrating, drying out the inner disk. The sequestering of water (and therefore oxygen) in the outer disk may also increase the carbon-to- oxygen ratio in the inner disk, leading to enhanced organic molecule (e.g. HCN) emission. To confirm this trend, we expand the Najita et al. sample by calculating HCN/H2O line flux ratios for 8 more sources with known disk masses from clusters besides Taurus. We find agreement with the Najita et al. trend, suggesting that this is a widespread phenomenon. In addition, we find HCN/H2O line flux ratios for 17 more sources that await disk mass measurements, which should become commonplace in the ALMA era. Finally, we investigate linear fits and outliers to this trend, and discuss possible causes.

Author(s): Caitlin Rose[1], Colette Salyk[1]
Institution(s): *1. Vassar College*

345.09 – A CO Spectral Analysis of Protoplanetary Disks

We present a spectral analysis describing the absorbing components of four stars with known protoplanetary disks: V1057 Cygni, W3 IRS5, LkHα 225S, and IRAS 19110+1045. Keck NIRSPEC observations of the M-band of the four sources allowed for the analysis of the P- and R-branch fundamental rovibrational absorption lines of carbon monoxide, as well as the H I Pfund-β emission line when present. These lines act as tracers of disk evolution and accretion, respectively, and allow us to determine the structure and physical features of the absorbing components. We find high temperatures, column densities and intense blueshifts in the spectra of V1057 Cygni, W3 IRS5, and LkHα 225S, which we tentatively determine to be indicative of absorption through polar outflows. IRAS 19110+11045 presents a lower column density, small redshift, moderate temperature, and high accretion rate. We surmise that the absorption spectrum in IRAS 19110+1045 is due to the disk itself as it is heated by accretion.

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345.10 – Variability of Disk Emission in Pre-main Sequence and Related Stars. IV. Occultation Events from the Innermost Disk Region of the Herbig AE Star HD 163296 = MWC 275

We studied the structure and the dynamics of the innermost region of the circumstellar disk around the star HD 163296, MWC 275. We extracted the emission line strengths of Pa beta and Br gamma and calculated the line fluxes, from which we then computed the mass accretion rates onto the star. We investigated the brightness drop at visible wavelengths in 2001 using the Monte Carlo Radiative Transfer Code, hochunk3d. Since the star has bipolar outflows, we looked at whether changes in the outflow, with dust entrained with the gas, could produce such a drop in brightness. We fitted data from 2001 and 2005 onto SED and temperature-density models of the disk and generated JHK disk images, then noted the changes in image brightness and in SED plots.

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345.11 – Variability of Disk Emission in Pre-main

Sequence and Related Stars. V. Changes in the Innermost Disk Structure of the Herbig AE Star HD 31648 = MWC 480

We present five epochs of near IR observations of the protoplanetary disk around HD 31648 (MWC 480). A mass accretion rate of approximately 1.1×10^{-7} M_{sun}/year was derived from Brγ and Paβ lines. The spectral energy distribution (SED) reveals a variability of about 30% between 1.5 and 10 microns. We present the theoretical modeling analysis of the disk in HD 31648 using Monte-Carlo Radiation Transfer Code (MRTC). We find that varying the height of the inner rim successfully produces a shift in the NIR flux.

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345.12 – The Transiting Exocomets in the HD 172555 System

The Earth is thought to have formed dry, in a part of the Solar Nebula deficient in organic material, and to have acquired its water and organics through bombardment by minor bodies. Observations of this process in well-dated systems can provide insight into the probable origin and composition of the bombarding parent bodies. Transiting cometary activity has previously been reported in Ca II for the late-A member of the ~23 Myr old Beta Pictoris Moving Group member, HD 172555. We present HST STIS and COS spectra of HD 172555 which demonstrate that the star has chromospheric emission and variable infalling gas features in transitions of silicon and carbon ions at times when no Fe II absorption is seen in the UV data, and no Ca II absorption is seen in contemporary optical spectra. We discuss apparent optical depths for the infall features. The lack of CO absorption and stable gas absorption at the system velocity is consistent with the absence of a cold Kuiper belt analog in this system. The presence of infall in some species at one epoch and others at different epochs suggests that, like beta Pictoris, there may be more than one family of exocomets. If perturbed into star-grazing orbits by the same mechanism as for beta Pic, these data suggest that the wide planet frequency among A-early F stars in the BPMG is at least 37.5%, well above the frequency estimated for young moving groups independent of host star spectral type.

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345.13 – Placing Limits on the Mass of the DH Tau b Circumplanetary Disk

We present a circumplanetary disk mass limit for the DH Tau b planetary mass companion. NOEMA observations in the millimeter allow us to place constraints on the disk mass for both DH Tau b and the primary in a regime where the disks will appear optically thin. We find a conservative disk mass upper limit of 0.31 $M_{\oplus}$ for DH Tau b, assuming that the disk temperature is dominated by irradiation from the central star. However, given the environment of the circumplanetary disk, variable illumination from the primary or the equilibrium temperature of the surrounding cloud would lead to even lower disk mass estimates. The circumstellar disk of DH Tau A is unresolved in our observations, with an estimated disk mass of $\sim 40 \, M_{\oplus}$.

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345.14 – The Shadow Knows: Using Shadows to Investigate the Structure of the Pretransitional Disk of HD 00453

With the advent of extreme AO instruments we have begun to obtain more detailed images of circumstellar disks. Recently these images have revealed several disks which contain azimuthally-localized dark features, such as HD 100453, some of which have been interpreted as shadows cast by an inner disk component which is not coplanar with the outer disk. Through careful study of these dark features we are able to probe the structure of the disk and make testable predictions using a 3D Monte Carlo radiative transfer code. Through the use of this code and comparison to recent SPHERE and GPI images we have determined that the shadows seen in the circumstellar disk of HD 100453 are caused by a misinclined inner disk which is at an inclination approximately 45� from coplanarity. In order to cause this misinclination the disk must have undergone a signicant torqueing event such as giant planet-giant planet scattering.

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Contributing team(s): the SEEDS Consortium

345.15 – Investigating FP Tau's protoplanetary disk structure through modeling

This project presents a study aiming to understand the structure of the protoplanetary disk around FP Tau, a very young, very low mass star in the Taurus star-forming region. We have gathered existing optical, Spitzer, Herschel and submillimeter observations to construct the spectral energy distribution (SED) of FP Tau. We have used the D'Alessio et al (2006) physically self-consistent irradiated accretion disk model including dust settling to model the disk of FP Tau. Using this method, the best fit for the SED of FP Tau is a model that includes a gap located 10-20 AU away from the star. This gap is filled with optically thin dust that separates the optically thick dust in the outer disk from the optically thick dust in the inner disk. These characteristics indicate that FP Tau's protostellar system is best classified as a pre-transitional disk. Near-infrared interferometry in the K-Band from Willson et al 2016 indicates that FP Tau has a small gap located 10-20 AU from the star, which is consistent with the model we produced, lending further support to the pre-transitional disk interpretation. The most likely explanation for the existence of a gap in the disk is a forming planet.

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345.16 – Migration of Gas Giant Planets in a Gravitationally Unstable Disk

Understanding the migration of giant planets in gravitationally unstable protoplanetary disks is important for understanding planetary system architecture, especially the existence of planets orbiting close to and at large distances from their stars. Migration rates can determine the efficiency of planet formation and survival rates of planets. We present results from simulations of 0.3, 1, and 3 Jupiter-mass planets in a 0.14 $M_{\odot}$ protoplanetary disk around a 1 $M_{\odot}$ star, where the disk is marginally unstable to gravitational instabilities (GIs). Each planet is simulated separately. We use CHYMERA, a radiative 3D hydrodynamics code developed by the Indiana University Hydrodynamics Group. The simulations include radiative cooling governed by realistic dust opacities. The planets are inserted into the disk, once the disk has settled into its quasi-steady GI-active phase. We simulate each of the 0.3, 1, and 3 Jupiter-mass planets by inserting it at three different locations in the disk, at the corotation radius and at the inner and outer Lindblad resonances. No matter where placed, the 3 Jupiter-mass planets tend to drift inexorably inward but with a rate that slows after many orbital periods. The 1 Jupiter-mass planets migrate mostly inward, but their motion can be delayed or reversed near the corotation of the two-armed wave. The 0.3 Jupiter-mass planets are much less predictable and frequently migrate outward. We analyze how the density of matter and waves in the disk at different azimuthal locations affect the migration.

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345.17 – Effect of External Photoevaporation on the Radial Transport of Volatiles and the Water Snowline in the Solar Nebula

The Sun was likely born in a high mass star forming region [1]. Such a birth environment with a proximity to a nearby O or B star would photoevaporate the sun's protoplanetary disk and cause an outward mass flow from the outer edge, as well as truncation of the disk, as seen in the Orion proplyds (although not as intensely)[2]. Photoevaporation likely explains the currently observed ~47 AU edge of the Kuiper Belt in our solar system [3], and more compellingly, the origin of certain short-lived radionuclides (such as Fe60), which cannot be successfully explained by a nebular origin [4][5]. Such a mass loss mechanism should affect the radial transport processes in the snowline region and along with temperature, has the potential to alter the location of the snowline. In this context, and in the light of recent ALMA observational results indicative of non-traditional behavior of snowlines and volatile transport in disks [6][7], this work studies what effect a photoevaporative mass loss from the outer disk may have on the volatile transport around the snowline region between ~1-10 AU in the disk. We build on the model of [8] and explore the effects of a steep photoevaporated non-uniform α disk on radial transport of volatiles and small icy solids by incorporating the advection-diffusion equations as in [9] and condensation/evaporation of volatiles. We present results of these simulations, including volatile mass fluxes, ice/rock ratios, and snow line locations, in protoplanetary disks like the solar nebula.
References: [1] Adams, F.C., 2010, ARAA 48,47 [2] Henney, W.J., & O'Dell, C.R., 1999, AJ, 118, 2350 [3] Trujillo,C.A. & Brown,M.E., 2001, ApJL,554,L95 [4] Hester, J.J., & Desch, S.J., 2005,ASPC, 341,107 [5] Wadhwa, M. et al. , 2007, Protostars & Planets V, 835 [5 [6] Cieza, L.A., et al., 2016, Nature,535,258 [7] Huang, J, et al. et al., 2016, ApJL, 823, L18 [8] Kalyaan, A., et al., 2015, ApJ, 815, 112 [9] Desch, S.J., et al., (in review).

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345.18 – Understanding Gas-Phase Ammonia Chemistry in Protoplanetary Disks

Protoplanetary disks are dynamic regions of gas and dust around young stars, the remnants of star formation, that evolve and coagulate over millions of years in order to ultimately form planets. The chemical composition of protoplanetary disks is affected by both the chemical and physical conditions in which they develop, including the initial molecular abundances in the birth cloud, the spectrum and intensity of radiation from the host star and nearby systems, and mixing and turbulence within the disk. A more complete understanding of the chemical evolution of disks enables a more complete understanding of the chemical composition of planets that may form within them, and of their capability to support life. One element known to be essential for life on Earth is nitrogen, which often is present in the form of ammonia (NH3). Recent observations by Salinas et al. (2016) reveal a theoretical discrepancy in the gas-phase and ice-phase ammonia abundances in protoplanetary disks; while observations of comets and protostars estimate the ice-phase NH3/H2O ratio in disks to be 5%, Salinas reports a gas-phase NH3/H2O ratio of ~7-84% in the disk surrounding TW Hydra, a young nearby star. Through computational chemical modeling of the TW Hydra disk using a reaction network of over 5000 chemical reactions, I am investigating the possible sources of excess gas-phase NH3 by determining the primary reaction pathways of NH3 production; the downstream chemical effects of ionization by ultraviolet photons, X-rays, and cosmic rays; and the effects of altering the initial abundances of key molecules such as N and N2. Beyond providing a theoretical explanation for the NH3 ice/gas discrepancy, this new model may lead to fuller understanding of the gas-phase formation processes of all nitrogen hydrides (NHx), and thus fuller understanding of the nitrogen-bearing molecules that are fundamental for life as we know it.

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345.19 – Chemistry of protostellar envelopes and disks: computational testing of 2D abundances

Molecule formation is dynamic during the protostar collapse phase, driven by changes in temperature, density, and UV radiation as gas and dust flows from the envelope onto the forming protoplanetary disk. In this work, we use a chemistry model to generate fractional abundances of water and carbon monoxide using primarily as input parameters the temperature and density profile produced by the dust radiative transfer model HOCHUNK3D (Whitney et al. 2013). Contour maps are presented showing the meridional temperature, density, and fractional abundance at different outer radii. High concentrations of gas phase molecules are found within 5 AU of the star along with high temperatures in the same spatial region. Shielding by the disk leads to colder temperatures outside 10 AU near the disk mid-plane. In this region, CO freezes out onto grains and shows a much reduced abundance. Water remains solid almost everywhere during the infall and evaporates within ~10 AU.

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345.20 – Dust coagulation and magnetic field strength in a planet-induced gap subject to MRI turbulence

We investigate the coagulation of dust particles in and around a gap opened by a Jupiter-mass planet. To this end, we carry out a high-resolution magnetohydrodynamic (MHD) simulation of the gap environment, which is turbulent due to the magneto rotational instability. From the MHD simulation, we obtain values of the gas velocities, densities and turbulent stresses close to the gap edge, in one of the two gas streams that accrete onto the planet, and inside the low-density gap. The MHD values are then supplied to a Monte Carlo dust coagulation algorithm, which models grain sticking, compaction and bouncing. We consider two dust populations for each region: one whose initial size distribution is monodisperse, with monomer radius equal to 1 micron, and another one whose initial size distribution follows the Mathis-Rumpl-Nordsieck distribution for interstellar dust grains, with an initial range of monomer radii between 0.5 and 10 microns. Without bouncing, our Monte Carlo calculations show steady growth of dust aggregates in all regions, and the mass-weighted (MW) average porosity of the initially mono disperse population reaches extremely high final values of 98%. The final MW porosities in all other cases without bouncing range from 30% to 82%. The efficiency of compaction is due to high turbulent relative speeds between dust particles. When bouncing is introduced, growth is slowed down in the planetary wake and inside the gap.

We also analyze the strength of the magnetic field threading the gaps opened by planets of different sub-Jovian masses. Preliminary results show that, in a gap opened by a large-mass planet (~ 1 M_J), the time-averaged radial profile of the vertical component of the field (B_Z) increases sharply inside the gap, and less sharply in the case of less massive planets. In gaps opened by intermediate-mass planets (~ 0.5 — 0.75 M_J), the radial profile of B_Z exhibits local maxima in the vicinity of the planet, but not at the gap center.

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346 – Galaxy Clusters Poster Session

346.01 – The Nature of Red-Sequence Cluster Spiral Galaxies

Preliminary analysis of the red-sequence galaxy population from a sample of 57 low-redshift galaxy clusters observed using the KPNO 0.9m telescope and 74 clusters from the WINGS dataset, indicates that a small fraction of red-sequence galaxies have a morphology consistent with spiral systems. For spiral galaxies to acquire the color of elliptical/S0s at a similar luminosity, they must either have been stripped of their star-forming gas at an earlier epoch, or contain a larger than normal fraction of dust. To test these ideas we have compiled a sample of red-sequence spiral galaxies and examined their infrared properties as measured by 2MASS, WISE, Spitzer, and Herschel. These IR data allows us to estimate the amount of dust in each of our red-sequence spiral galaxies. We compare the estimated dust mass in each of these red-sequence late-type galaxies with spiral galaxies located in the same cluster field but having colors inconsistent with the red-sequence. We thus provide a statistical measure to discriminate between purely passive spiral galaxy evolution and dusty spirals to explain the presence of these late-type systems in cluster red-sequences.

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346.02 – Galaxy Groups within 3500 km s^{-1}

We present an algorithm to find nearby galaxy groups within 3,500 km s^{-1} (~45 Mpc). Our algorithm is based on the direct observed scaling relations that relate luminosity, velocity dispersion and dimensions of groups. Using these scaling relations, in an iterative process, galaxies with almost the same radial velocities and in close angular proximity fall into groups. Since peculiar velocities and Hubble expansion rate are comparable at these local distances, radial velocities are not very good proxies for galaxies distances. Therefore, further manual investigations of the identified groups is inevitable to discard interlopers and/or to resolve confusing cases in crowded regions. The goal of this study is to explore the nature of smallest galaxy groups and to investigate the halo mass function below 8x10^{12} solar mass.

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346.03 – Constraining the Mass of A Galaxy Cluster

Accurate cluster masses are critical for understanding dark matter and for using clusters to constrain cosmological parameters. We use the observed surface number density profile and velocity dispersion profile of galaxies in the Coma cluster to constrain its mass profile via Jeans analysis. In particular, we evaluate the robustness of the mass estimate M_200 by using different parametric forms for the distribution of mass and galaxies as well as different models of the orbital anisotropy parameter β (r) . Allowing for variation between the scale radii of the mass profile and the galaxy profile (i.e. relaxing the assumption that galaxies trace mass) does not significantly change the estimate of M 200 . We use a Bayesian approach to construct probability distribution functions of M 200, scale radius, and beta via Markov Chain Monte Carlo (MCMC) sampling. We apply this approach to ensemble clusters stacked by either their Sunyaev-Zel'dovich (SZ) signals or X-ray luminosities to measure the scaling relations of dynamical mass estimates with these mass proxies. Specifically, we test the hypothesis that the apparent deficit of SZ clusters (compared to predictions based on observations of the microwave background) can be explained by a bias of ~ 60% in the normalization of the scaling relation between SZ signal and mass.

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346.04 – The mass of high-z massive galaxy cluster, SPT-CL J2106-5844 using weak-lensing analysis with HST observations

We present a weak-lensing analysis of the galaxy cluster SPT-CL J2106-5844 at z~1.132 using images from the Advanced Camera for Surveys (ACS) and Wide Field Camera 3 (WFC3) on-board on the Hubble Space Telescope (HST). This cluster discovered in the South Pole Telescope Sunyaev-Zel'dovich (SPT-SZ) survey is known to be the most massive system at z > 1 in the survey. Within the current ΛCDM hierarchical structure formation paradigm, the mass of the cluster at such a high redshift inferred by SZ, X-ray, and galaxy velocity dispersion data is somewhat unusual. The previous mass estimates, however, rely on assumptions on the dynamical state of the system, which may become questionable when the universe was young (about 40% of the current age). In this work, we present the first weak-lensing mass estimates of this interesting cluster. We describe how we derive a mass from the HST/ACS and HST/WFC3 deep imaging data and show a two-dimensional mass reconstruction. We find that the mass distribution of the cluster is unimodal with a centroid consistent (~1σ) with both galaxy luminosity and number density distributions. Based on tangential shear fitting with an NFW halo assumption, our weak-lensing mass estimates agree well with the previous estimates.

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346.05 – Discovery and Characterization of Gravitationally Lensed X-ray Sources in the CLASH Sample

We present the discovery of ~20 gravitationally lensed X-ray sources in the Cluster Lensing And Supernova survey with Hubble (CLASH) survey, a sample of massive clusters of galaxies between z ~ 0.2-0.9 observed with the *Hubble Space Telescope* (*HST*). By combining CLASH imaging with *Chandra X-ray Observatory* observations of the same clusters, we select those sources in the *HST* images which are gravitationally lensed X-ray sources behind the clusters. Of those discovered sources, we determine various properties including source redshifts and magnifications, as well as performing X-ray spectral fits to determine source fluxes and luminosities. Prior to this study, only four lensed X-ray sources behind clusters have been found, thus to the best of our knowledge, our program is the first to systematically categorize lensed X-ray sources behind galaxy clusters.

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346.06 – Chandra Observation of the WAT Radio Source/ICM Interaction in Abell 623

Galaxy clusters are important objects for studying the physics of the intracluster medium (ICM), galaxy formation and evolution, and cosmological parameters. Clusters containing wide-angle tail (WAT) radio sources are particularly valuable for studies of the interaction between these sources and the surrounding ICM. These sources are thought to form when the ram pressure from the ICM caused by the relative motion between the host radio galaxy and the cluster bends the radio lobes into a distinct wide-angle morphology. We present our results from the analysis of a Chandra observation of the nearby WAT hosting galaxy cluster Abell 623. A clear decrement in X-ray emission is coincident with the southern radio lobe, consistent with being a cavity carved out by the radio source. We present profiles of surface brightness, temperature, density, and pressure and find evidence for a possible shock. Based on the X-ray pressure in the vicinity of the radio lobes and assumptions about the content of the lobes, we estimate the relative ICM velocity required to bend the lobes into the observed angle. We also present spectral model fits to the overall diffuse cluster emission and see no strong signature for a cool core. The sum of the evidence indicates that Abell 623 may be undergoing a large scale cluster-cluster merger.

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346.07 – Algorithms for Finding Substructure in Galaxy Clusters

In order to better understand the role of environment in determining the properties of galaxies, we present statistical approaches to identifying substructure in galaxy clusters and groups. A subgroup is composed of a set of galaxies within a galaxy cluster that share similar attributes. To create subgroups from galaxies in a cluster, we explored several different clustering algorithms: Agglomerative Hierarchical Clustering, Spectral Clustering, and K-Means Clustering. We evaluate the strengths and weaknesses of these algorithms by applying them both to data from the Antlia Cluster, as well as to output from simulated galaxy clusters. We also examined how subgroups and the properties of the galaxies in those subgroups changed over time through analysis of data from simulations that extend over a long time scale. We synthesize these results to provide a perspective on how these analyses contribute to our understanding of galactic evolution.

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346.08 – The Impact of Large Scale Environments on Cluster Entropy Profiles

We perform a systematic analysis of 21 clusters imaged by the Suzaku satellite to determine the relation between the richness of cluster environments and entropy at large radii. Entropy profiles for clusters are expected to follow a power-law, but Suzaku observations show that the entropy profiles of many clusters are significantly flattened beyond 0.3 R_{vir}. While the entropy at the outskirts of clusters is thought to be highly dependent on the large scale cluster environment, the exact nature of the environment/entropy relation is unclear. Using the Sloan Digital Sky Survey and 6dF Galaxy Survey, we study the 20 Mpc large scale environment for all clusters in our sample. We find no strong relation between the entropy deviations at the virial radius and the total luminosity of the cluster surroundings, indicating that accretion and mergers have a more complex and indirect influence on the properties of the gas at large radii. We see a possible anti-correlation between virial temperature and richness of the cluster environment and find that density excess appears to play a larger role in the entropy flattening than temperature, suggesting that clumps of gas can lower entropy.

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346.09 – Undergraduate ALFALFA Team: Analysis of Spatially-Resolved Star-Formation in Nearby Galaxy Groups and Clusters

As part of the Undergraduate ALFALFA Team, we are conducting a survey of the gas and star-formation properties of galaxies in 36 groups and clusters in the local universe. The galaxies in our sample span a large range of galactic environments, from the centers of galaxy groups and clusters to the surrounding infall regions. One goal of the project is to map the spatial distribution of star-formation; the relative extent of the star-forming and stellar disks provides important information about the internal and external processes that deplete gas and thus drive galaxy evolution. We obtained wide-field H-alpha observations with the WIYN 0.9m telescope at Kitt Peak National Observatory for galaxies in the vicinity of the MKW11 and NRGb004 galaxy groups and the Abell 1367 cluster. We present a preliminary analysis of the relative size of the star-forming and stellar disks as a function of galaxy morphology and local galaxy density, and we calculate gas depletion times using star-formation rates and HI gas mass. We will combine these results with those from other UAT members to determine if and how environmentally-driven gas depletion varies with the mass and X-ray properties of the host group or cluster. This work has supported by NSF grants AST-0847430, AST-1211005 and AST-1637339.

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Contributing team(s): Undergraduate ALFALFA Team

346.10 – Star Formation in Undergraduate ALFALFA Team Galaxy Groups and Clusters

The Undergraduate ALFALFA Team (UAT) Groups project is a coordinated study of gas and star formation properties of galaxies in and around 36 nearby ($z<0.03$) groups and clusters of varied richness, morphological type mix, and X-ray luminosity. By studying a large range of environments and considering the spatial distributions of star formation, we probe mechanisms of gas depletion and morphological transformation. The project uses ALFALFA HI observations, optical observations, and digital databases like SDSS, and incorporates work undertaken by faculty and students at different institutions within the UAT. Here we present results from our wide area Hα and broadband R imaging project carried out with the WIYN 0.9m+MOSAIC/HDI at KPNO, including an analysis of radial star formation rates and extents of galaxies in the NGC 5846, Abell 779, NRGb331, and HCG 69 groups/clusters. This work has been supported by NSF grant AST-1211005 and AST-1637339.

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Contributing team(s): Undergraduate ALFALFA Team, ALFALFA Team

346.11 – The Gas in Virgo's "Red and Dead" Dwarf Elliptical Galaxies

As star-forming dwarf irregulars and faint spirals fall onto a cluster, their gas content is easily and quickly removed by ram-pressure stripping or other cluster forces. Residual signs of star formation cease within 100 Myr, and only after approximately 1 Gyr do their optical features transition to elliptical.

Despite this, ALFALFA has uncovered a population of three "red and dead" dwarf ellipticals in the Virgo Cluster which still have detectable reservoirs of HI. These dwarf ellipticals are extremely gas-rich—as gas-rich as the cluster's star-forming dwarf irregulars (Hallenbeck et al. 2012). Where does this gas come from? We consider two possibilities. First, that the gas is recently acquired, and has not yet had time to form stars. Second, that the gas is primordial, and has been disrupted from being able to form stars during the current epoch.

We present deep optical (using CFHT and KPNO) and HI (Arecibo and VLA) observations of this sample to demonstrate that this gas is primordial. These observations show that all three galaxies have exponentially decreasing profiles characteristic of dwarf ellipticals and that their rotation velocities are extremely low. However, like more massive elliptical galaxies with HI, these dwarf galaxies show irregular optical morphology. For one target, VCC 190, we additionally observe an HI tail consistent with a recent interaction with the massive spiral galaxy NGC 4224.

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346.12 – Extending ALFALFA in the Direction of the Pisces-Perseus Supercluster with the Arecibo L-Band Wide Receiver

We have completed three "Harvesting ALFALFA" Arecibo observing programs in the direction of the Pisces-Perseus Supercluster (PPS) since ALFALFA observations were finished in 2012. The first was to perform follow-up observations on high signal-to-noise (S/N > 6.5) ALFALFA detections needing confirmation and low S/N sources lacking optical counterparts. A few more high S/N objects were observed in the second program along with targets visually selected from the Sloan Digital Sky Survey (SDSS). The third program included low S/N ALFALFA sources having optical counterparts with redshifts that were unknown or differed from the ALFALFA observations. It also included more galaxies selected from SDSS by eye and by Structured Query Language (SQL) searches with parameters intended to select galaxies at the distance of the PPS (~6,000 km/s). We used pointed basic Total-Power Position-Switched Observations in the 1340 – 1430 MHz ALFALFA frequency range. For sources of known redshift, we used the Wideband Arecibo Pulsar Processors (WAPP's) , while for sources of unknown redshift we utilized a hybrid/dual bandwidth Doppler tracking mode using the Arecibo Interim 50-MHz Correlator with 9-level sampling.
Results confirmed that a few high S/N ALFALFA sources are spurious as expected from the work of Saintonge (2007), low S/N ALFALA sources lacking an optical counterpart are all likely to be spurious, but low S/N sources with optical counterparts are generally reliable. Of the optically selected sources, about 80% were detected and tended to be near the distance of the PPS.
This work has been supported by NSF grant AST-1211005.

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Contributing team(s): Undergraduate ALFALFA Team

346.13 – Evolution of the BCG in Disturbed Galaxy Clusters

The present paradigm in cosmology tells us that large-scale structures grow hierarchically. This suggests that galaxy clusters grow by accreting mass and merging with other clusters, a process which should be detectable by the presence of substructure within a cluster. Using the Dressler-Shectman (DS) three-dimensional test for dynamical substructure, we determined which clusters showed evidence for disturbance from a set of 227 Abell clusters from Lauer et al. (2014) with at least 50 member galaxies and spectroscopic redshifts, z < 0.08. Our results show that 155 (68.2%) of the clusters showed evidence for substructure at ≥ 95% confidence, while 72 did not. Kolmogorov-Smirnov tests suggest that the two populations of clusters (those with and without detected substructure) are significantly different in their distributions of BCG luminosities (L_m), but not in their BCG stellar velocity dispersions (σ), their BCG spatial offsets from the x-ray centers of the clusters, their BCG velocity offsets from the mean cluster velocity, the logarithmic slopes of their BCG photometric curves of growth (α), their cluster velocity dispersions, or their luminosity differences between the BCG and the second-ranked galaxy in the cluster (M2). Similarly, no significant difference was found in the fitting of the L_m-α-σ metric plane for BCGs of clusters with substructure compared those in which there is not substructure. This is surprising since our hierarchical growth models suggest that some of these BCG/cluster properties would be affected by a disturbance of the cluster, indicating that our understanding of how BCGs evolve with their clusters is incomplete and we should explore other ways to probe the level of disturbance.

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346.14 – Accretion and Feedback from Supermassive Black Holes in Galaxy Clusters

A significant fraction of galaxy clusters, namely the cool-core clusters, exhibit a dip in their central temperature profiles, with radiative cooling times much shorter than the Hubble time. Unchecked, radiative cooling of this magnitude is expected to cause the accumulation of cold gas at the cluster center that leads to star formation rates 100-1000 times higher than those inferred by observations. This discrepancy suggests the existence of active heating mechanisms that counteract the overcooling in cluster centers. The dominant mechanism has now been widely recognized as the mechanical feedback from the radio-loud active galactic nuclei. However, recent observations find substantial amounts of cold gas in a number of cool-core clusters, as well as evidence that some clusters host quasars in their central dominant galaxies, raising concerns about the significance of radiative feedback in such systems. Motivated by these findings we use 3D radiation hydrodynamic simulations to explore the joint role of the radio- and quasar-mode feedback in the accretion and feedback cycle of supermassive black holes in cool-core clusters.

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346.15 – Star formation quenching and stellar mass in the cluster Abell 85

We report the discovery of a group of galaxies falling into the cluster Abell 85 showing a decrease in star formation limited to its dwarf galaxy population. We covered the cluster and its surroundings with a multi-wavelength survey from the UV to the far-IR using ground and space telescopes (including GALEX, Spitzer, and Herschel) and followed-up these observations with spectroscopic surveys with the WIYN/Hydra and VLT/VIMOS instruments. We were able to obtain spectra for 522 members down to r'=20, 30% of them showing H-alpha emission. We estimated the variation in star formation rate by using two different estimators based on continuum (UV) and line (H-alpha) emission. While massive infalling galaxies continue to produce stars during the infall, the star formation in dwarf galaxies appear to be quenched by the cluster environment. Considering the different time-scales of the two estimators, we can estimate that the quenching happens in a period of approximately 10 Myr.

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346.16 – The Co-Evolution of Galaxies, their ISM, and the ICM: The Hydrodynamics of Galaxy Transformation

Cluster of galaxies are hostile environments. Infalling cluster galaxies are stripped of their dark matter, stars, and hot and cold interstellar medium gas. The ISM, in addition to tidal and ram pressure stripping, can evaporate due to thermal conduction. Gas loss and the subsequent suppression of star formation is not straightforward: magnetic fields in the ISM and ICM shield galaxies and their stripped tails from shear instabilities and conduction, radiative cooling can inhibit gas loss, and feedback from stars and AGN can replenish the ISM. While there is observational evidence that these processes operate, a theoretical understanding of the physics controlling the energy cycle in cluster galaxies remains elusive. Additionally, galaxies have a significant impact on ICM evolution: orbiting galaxies stir up and stretch ICM magnetic field lines, inject turbulence into the ICM via their wakes and g-waves, and infuse metals into the ICM. Quantifying the balance between processes that remove, retain, and replenish the ISM, and the impact of galaxies on the ICM require specialized hydrodynamic simulations of the cluster environment and its galaxies. I will present results from some of these simulations that include ram pressure stripping of galaxies' hot ISM, the effect of magnetic fields on this process, and the effectiveness of isotropic and anisotropic thermal conduction in removing and retaining the ISM.

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347 – Evolution of Galaxies Poster Session

347.01 – Extraction of global 21-cm signal from simulated data for the Dark Ages Radio Explorer (DARE) using an MCMC pipeline

The Dark Ages Radio Explorer (DARE) is a mission concept proposed to NASA in which a crossed dipole antenna collects low frequency (40-120 MHz) radio measurements above the farside of the Moon to detect and characterize the global 21-cm signal from the early (z~35-11) Universe's neutral hydrogen. Simulated data for DARE includes: 1) the global signal modeled using the ares code, 2) spectrally smooth Galactic foregrounds with spatial structure taken from multiple radio foreground maps averaged over a large, well characterized beam, 3) systematics introduced in the data by antenna/receiver reflections, and 4) the Moon. This simulated data is fed into a signal extraction pipeline. As the signal is 4-5 orders of magnitude below the Galactic synchrotron contribution, it is best extracted from the data using Bayesian techniques which take full advantage of prior knowledge of the instrument and foregrounds. For the DARE pipeline, we use the affine-invariant MCMC algorithm implemented in the Python package, emcee. The pipeline also employs singular value decomposition to use known spectral features of the antenna and receiver to form a natural basis with which to fit instrumental systematics. Taking advantage of high-fidelity measurements of the antenna beam (to ~20 ppm) and precise calibration of the instrument, the pipeline extracts the global 21-cm signal with an average RMS error of 10-15 mK for multiple signal models.

Author(s): Keith A. Tauscher[2], Jack O. Burns[2], David Rapetti[2], Jordan Mirocha[1], Raul A. Monsalve[2]
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347.02 – Predicting the High Redshift Galaxy Population for JWST

The James Webb Space Telescope will be launched in Oct 2018 with the goal of observing galaxies in the redshift range of z = 10 - 15. As redshift increases, the age of the Universe decreases, allowing us to study objects formed only a few hundred million years after the Big Bang. This will provide a valuable opportunity to test and improve current galaxy formation theory by comparing predictions for mass, luminosity, and number density to the observed data. We have made testable predictions with the semi-analytical galaxy formation model Galacticus. The code uses Markov Chain Monte Carlo methods to determine viable sets of model parameters that match current astronomical data. The resulting constrained model was then set to match the specifications of the JWST Ultra Deep Field Imaging Survey. Predictions utilizing up to 100 viable parameter sets were calculated, allowing us to assess the uncertainty in current theoretical expectations. We predict that the planned UDF will be able to observe a significant number of objects past redshift z > 9 but nothing at redshift z > 11. In order to detect these faint objects at redshifts z = 11-15 we need to increase exposure time by at least a factor of 1.66.

Author(s): Zoey Flynn[1], Andrew Benson[2]
Institution(s): *1. Caltech, 2. Carnegie Observatories*

347.04 – A New Semi-Empirical Model of Reionization

I will present the results of our new analysis of the contribution of both galaxies and AGNs to the reionization of the intergalactic medium (IGM). The time evolution of reionization, and the ionizing sources, are poorly constrained primarily due to the lack of knowledge about the escape fraction of ionizing photons from star-forming galaxies. Using the results of detailed zoom-in hydrodynamical simulations, we parameterize the escape fraction as a function of halo mass and combine this with observations of the evolution of the galaxy luminosity function at high redshift. This fiducial model does not complete reionization by z=6. We thus run a MCMC analysis, using the observations of quasars and the electron scattering optical depth to the CMB to constrain a number of free parameters, including a scale factor applied to the simulation escape fraction results, a contribution from AGN, minimum halo mass for star formation, and the Lyman continuum photon production efficiency, finding that star-forming galaxies alone can fully reionize the universe by z~6 with an escape fraction of only ~5%, and that at least a 50% contribution from AGNs is required at z < 6. This model makes a number of important predictions for the number density and ionizing efficiency of galaxies at z > 8, and I will discuss these in the context of the design for a JWST extragalactic legacy survey.

Author(s): Steven L. Finkelstein3, Jan-Pieter Paardekooper[6], Peter Behroozi4, kristian finlator[1], Russell E. Ryan[2], Anson D'Aloisio5, Rachael C. Livermore3
Institution(s): *1. NMSU, 2. STScI, 3. The University of Texas at Austin, 4. UC Berkeley, 5. Univ of Washington, 6. University of Heidelberg*

347.05 – A Blind Search for Ly-α Emission from Galaxies at z = 6-8 with Deep HST Grism Spectra

This project aims to detect Ly-α emission lines from z = 6-8 galaxies to probe the ionization state of the intergalactic medium (IGM) during the epoch of reionization. We use extremely deep data from the Faint Infrared Grism Survey (FIGS; PI: Malhotra) which is currently the most sensitive G102 grism survey, targetting the high-redshift galaxies that were discovered in the CANDELS GOODS fields (Finkelstein et al. 2015). This dataset has already proven to be successful as one of these candidates, at redshift z=7.51, has been observed to have Ly-α emission detectable with the HST Grism (Tilvi et al 2016). The FIGS data uses five separate roll-angles of HST in an effort to reduce the overall contamination effects of nearby galaxies. We have created a method that accounts for and removes the contamination from surrounding galaxies, and also removes any residual continuum emission from each individual spectrum. We then utilize a MCMC routine to blindly search for 5σ emission lines in each individual spectrum. We compare the results for each galaxy across all roll angles and identify significant lines as those which are detected at the same wavelength in more than one roll angle. We have found several z > 7 candidates which, if confirmed, will increase the number of confirmed galaxies at this epoch by ~50%. The coarse spectral resolution of the G102 grism prevents us from measuring the expected asymmetric profile of the Ly-α emission line, so we have proposed for follow-up observations of our objects with ground based facilities.

Author(s): Rebecca L Larson3, Steven L. Finkelstein3, Norbert Pirzkal[2], Vithal Tilvi[1], Intae Jung3, Sangeeta Malhotra[1], James E. Rhoads[1]
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347.06 – Investigating the Initial Mass Function with Increased Redshift

The stellar initial mass function (IMF) is generally assumed to be universal but there are several factors that could alter it; one being that lower metallicities at higher redshift could lead to an increased production of higher mass stars. Understanding the IMF is crucial because inferred stellar population properties of galaxies from integrated photometry is heavily dependent on the assumed IMF. We present the initial findings of an investigation using the 3D-HST survey catalog to search for variations of the IMF for galaxies with redshift 0.7 < z < 1.5. We calculate the ratio of H-alpha luminosity to the UV luminosity, which probes the ratio of ionizing to non-ionizing UV light, which is dependent on the slope of the upper mass portion of the IMF. While the majority of our galaxies are consistent with having stars distributed according to a Saltpeter IMF (albeit with a range of star-formation histories resulting in significant scatter in the H-alpha/UV luminosity ratio), we do find eight galaxies with a luminosity ratio that is significantly higher than that expected for a Salpeter IMF. This increase in the expected amount of ionized photons could be caused by several factors that we will address, including but not limited to, Active Galactic Nuclei, varying star formation histories, or an increased production of high mass stars.

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347.07 – Searching for Extreme High Redshift Galaxies with HST Grism Spectroscopy

With ever increasing capability, we are now able to push galaxy evolution studies to extreme high redshift (z>6). At these early times, the first galaxies begin forming stars but some of their light is quickly absorbed by the neutral intergalactic medium. The result is that the La line of hydrogen is lost. But, with the recent upgrades to HST, we can now utilize the unique multiplexing capacity of slitless grism spectroscopy to explore large samples of candidate systems. By taking near-IR spectra for for every object in the field-of-view simultaneously, we can begin searching for galaxies with a favorable circumgalactic gas distribution where La emission may be obtained.

In this study we build on the work of 3D-HST to search for extreme high redshift galaxies (6<z<13) by using Bayesian techniques to quantify line detections. We systematically explore the spectra of some 100,000 photometric candidates over the five CANDELS fields for high-z emission lines using expanded prior redshift distributions compared to previous studies. We present preliminary results of 29 spectroscopic candidates selected for the first time as extreme high redshift galaxies. Follow-up of confirmed candidates will strengthen existing samples of distant galaxies and constrain properties of the early universe.

Author(s): John R Weaver[1], Michael Maseda[1]
Institution(s): *1. Leiden University*

347.08 – First Simultaneous Detection of Lyman-alpha Emission and Lyman Break from a Galaxy at Redshift 7.51 from Faint Infrared Grism Survey (FIGS)

Galaxies at high-redshifts provide a powerful tool to probe cosmic dawn, and therefore it is crucial to reliably identify these galaxies. Here, we present an unambiguous and first simultaneous detection of a Lyman-alpha line and a Lyman break from a galaxy (FIGS_GN1_1292) at z=7.51, observed in the Faint Infrared Grism Survey (FIGS: PI Mlahotra). FIGS is currently the most sensitive G102 grism survey, with 160-orbit depth equally distributed in four different fields in GOODS-N and GOODS-S. FIGS_GN1_1292 is detected independently in multiple position angles, and has a Lyman-alpha line flux of 1.06e-17 erg/s/cm^2, nearly a factor of four higher than in the archival MOSFIRE spectroscopic observations. This higher flux in the grism data is consistent with other recent observations implying that ground-based near-infrared spectroscopy may underestimate the total emission line fluxes, and if confirmed, can have strong implications for reionization studies that are based on ground-based Lyman-alpha measurements. The successful detection of continuum in such a high-redshift galaxy demonstrates the sensitivity of the FIGS survey, and the capability of grism spectroscopy to study the epoch of reionization using upcoming missions like the Wide Field Infrared Survey Telescope (WFIRST).

Author(s): Vithal Tilvi[1], Norbert Pirzkal[9], Sangeeta Malhotra[1], Steven L. Finkelstein[13], James E. Rhoads[1], Rogier A. Windhorst[1], Norman A. Grogin[9], Anton M. Koekemoer[9], Nadia L. Zakamska[3], Russell E. Ryan[9], Lise Christensen[11], Nimish P. Hathi[4], John Pharo[1], Bhavin Joshi[1], Huan Yang[1], Caryl Gronwall[7], Andrea Cimatti[10], J. Walsh[2], Robert W. O'Connell[12], Amber Straughn[6], Göran Östlin[8], Barry Rothberg[5], Rachael C. Livermore[13], Pascale Hibon[2], Jonathan P. Gardner[6]
Institution(s): *1. Arizona State University, 2. European Southern Observatory, 3. John Hopkins, 4. Laboratoire dAstrophysique de Marseille, 5. LBTO, 6. NASA, 7. Penn State, 8. Stockholm University, 9. STScI, 10. Universita di Bologna, 11. University of Copenhagen, 12. University of Virginia, 13. UT Austin*
Contributing team(s): FIGS Team

347.09 – Constraining CIII] Emission in a Statistic Sample of Five z = 5.7 Galaxies

Recent observations have suggested that the CIII]1907/1909 emission line could be an alternative diagnostic line for galaxies in reionization epoch. We use F128N narrowband filter on the Hubble Space Telescope's (HST) Wide Field Camera 3 (WFC3) to search for CIII] emission in a sample of five galaxies at z = 5.7 discovered by Subaru deep fields. Using the F128N narrowband imaging, together with the broadband imaging, we report a 2-sigma signal of CIII] flux of 3.39±1.81x10^(-18) erg/s/cm^(2) in J132416.13+274411.6, the brightest galaxy in our sample (z = 5.7, J_{AB} = 24.1). We do not detect the CIII] for the rest of 4 faint galaxies with J_{AB} ranging from 25 - 27. Using the stacked image, we put a 2-sigma upper limit of 1.66 A on the mean CIII] equivalent width for our sample of galaxies at z = 5.7. Further, we provide the continuum-subtracted narrowband images for each galaxy and we found a 2-sigma residual flux of 3.39±1.81x10^(-18) erg/s/cm^(2) for galaxy J132416.13+274411.6 and put a 2-sigma upper limit of 1.19x10^(-18) erg/s/cm^(2) for the other four faint galaxies (z = 5.7, J_{AB} ranging from 25 - 27). Our observations set an upper limit for CIII] emission at z = 5.7 and could be used as a guide for future observations in the reionization epoch.

Author(s): Jiani Ding4, Zheng Cai5, Xiaohui Fan4, Daniel Stark4, Fuyan Bian3, Linhua Jiang[2], Ian D. McGreer4, Brant E. Robertson5, Brian D. Siana[1]
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Contributing team(s): Space Telescope Science Institute

347.10 – The [CII]/[NII] far-infrared line ratio at z>5: extreme conditions for "normal" galaxies

Thanks to the Atacama Large (sub-)Millimeter Array (ALMA), observations of atomic far-infrared fine structure lines are a very productive way of measuring physical properties of the interstellar medium (ISM) in galaxies at high redshift, because they provide an unobscured view into the physical conditions of star formation. While the bright [CII] line has become a routine probe of the dynamical properties of the gas, its intensity needs to be compared to other lines in order to establish the physical origin of the emission. [NII] selectively traces the emission coming from the ionized fraction of the [CII]-emitting gas, offering insight into the phase structure of the ISM. Here we present ALMA measurements of [NII] 205 μm fine structure line emission from a representative sample of galaxies at z=5-6 spanning two orders of magnitude in star formation rate (SFR). Our results show at least two different regimes of ionized gas properties for galaxies in the first billion years of cosmic time, separated by their $L_{[CII]}/L_{[NII]}$ ratio. First, we find extremely low [NII] emission compared to [CII] from a "typical" Lyman Break Galaxy (LBG-1), likely due to low dust content and reminiscent of local dwarfs. Second, the dusty Lyman Break Galaxy HZ10 and the extreme starburst AzTEC-3 show ionized gas fractions typical of local star-forming galaxies and show hints of spatial variations in their [CII]/[NII] line ratio. These observations of far-infrared lines in “normal” galaxies at z>5 yield some of the first constraints on ISM models for young galaxies in the first billion years of cosmic time and shed light on the observed evolution of the dust and gas properties.

Author(s): Riccardo Pavesi[2], Dominik Riechers[2], Peter L. Capak[1], Chris Luke Carilli[4], Chelsea E. Sharon[3], Gordon J. Stacey[2], Alexander Karim[5], Nicholas Scoville[1], Vernesa Smolcic[6]
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347.11 – Discovery of Extreme [OIII]+Hβ Emission Line Galaxies Tracing an Overdensity at *z*~3.5

Using deep multi-wavelength photometry of galaxies with excess emission in the K_S-band from ZFOURGE, we build composite SEDs to analyze the continuum properties and equivalent widths of a population of Extreme [OIII]+Hβ Emission Line Galaxies at *z*~3.5.
In particular, we find 49 galaxies with a characteristic [OIII]+Hβ rest-frame equivalent width of ~300 Å, and another 216 galaxies with rest-frame equivalent widths of ~100 Å as measured from the composite SEDs.
These galaxies are analogous to the `green peas' found in the SDSS, and are thought to be undergoing their first burst of star formation due to their blue colors, young ages, and low dust attenuation values.
They also exhibit Lyman-α emission, strong nebular emission features, and compact sizes, consistent with the properties of the early star-forming galaxies possibly responsible for re-ionizing the Universe.
Many of these sources are clustered around *z*~3.5 and trace out an overdensity in CDFS, and we explore this very distant example of large scale structure.

Author(s): Ben Forrest[1], Kim-Vy Tran[1], Adam Broussard[1]
Institution(s): *1. Texas A&M University*
Contributing team(s): The ZFOURGE Collaboration

347.12 – Spatially Resolved Emission of a z~3 Damped Lyman Alpha Galaxy with Keck/OSIRIS IFU

The damped Lyman alpha (DLA) class of galaxies contains most of the neutral hydrogen gas over cosmic time. Few DLAs have been detected directly, which limits our knowledge of fundamental properties like size and mass. We present Keck/OSIRIS infrared integral field spectroscopy (IFU) observations of a DLA that was first detected in absorption toward a background quasar. Our observations use the Keck Laser Guide Star Adaptive Optics system to reduce the point-spread function of the quasar, making it possible to spatially resolve the DLA emission. We map this emission in O[III] 5007 Å. At redshift z~3, this DLA represents one of the highest redshift DLAs mapped with IFU spectroscopy. We present measurements of the star formation rate, metallicity, and gas mass of the galaxy.

This project was supported in part by the NSF REU grant AST-1358980 and by the Nantucket Maria Mitchell Association.

Author(s): Holly Christenson[2], Regina Jorgenson[1]
Institution(s): *1. Maria Mitchell Observatory, 2. Western Washington University*

347.13 – ZFOURGE: Exploring the Properties of ~1500 K_S-Selected Galaxies at 2.5 < z < 4 with Composite Spectra

We use deep multi-wavelength photometry from the FourStar Galaxy Evolution Survey (ZFOURGE) and public surveys to construct composite spectral energy distributions (SEDs) from ~1500 K_S-selected galaxies at 2.5 < z< 4. We identify seven star-forming composite SEDs that represent ~80% of the sample including galaxies with stellar masses down to $\log(M_*/M_\odot) = 9$. With rest-frame coverage of 0.08-7μm, we measure the UV flux, UV slope, rest-frame colors, and ratio of infrared to UV flux (IRX) by fitting to the composite SEDs. The IRX-β relation for the composite SEDs favors an SMC-like dust law. Rest-frame *UVJ* colors, specific star formation rate (sSFR), and UV flux are inversely correlated with stellar mass, stellar attenuation (A_V), and galaxy radius, i.e. composite SEDs with lower UV flux are composed of galaxies with higher stellar masses, redder colors, lower sSFR, more dust, and larger radii. The two bluest composite SEDs have very strong (Hβ+[OIII]) emission and essentially no dust, and their *UVJ* colors cannot be modeled by a simple stellar population. These extreme galaxies are small (radii ~1.2 kpc) and seem to be vigorously forming stars in their cores.

Author(s): Adam Broussard[1]
Institution(s): *1. Rutgers University*
Contributing team(s): ZFOURGE

347.14 – Investigating the Metallicity Evolution of Sub-damped Lyman alpha Systems

A clear understanding of the production and build up of metals across cosmic time is a key ingredient to any theory of galaxy formation and evolution. We present chemical abundance measurements for a sample of ~20 sub-damped Lyman alpha systems (subDLAs) detected in the absorption spectra of high redshift quasars taken by the Echellette Spectrograph and Imager (ESI) on the Keck II telescope. The sample contains absorbers with neutral hydrogen column densities of $10^{19.0}$ < N(HI) < $10^{20.3}$ cm^{-2} and redshifts of 2.90 < z < 4.50. Metal line column densities were measured using the apparent optical depth method while neutral hydrogen column densities were measured via Voigt profile fitting. We compare our measurements to those of DLAs and subDLAs from the literature to investigate the potential differences in metallicity evolution between these types of galaxies.

Author(s): Tarini Konchady[1], Regina Jorgenson[2]
Institution(s): *1. Johns Hopkins University, 2. Maria Mitchell Observatory*

347.15 – Constraining the Merging History of Massive Galaxies Since Redshift 3 Using Close Pairs. I. Major Pairs from Candels and the SDSS

Major galaxy-galaxy merging can play an important role in the history of massive galaxies (stellar masses > 2E10 Msun) over cosmic time. An important way to measure the impact of major merging is to study close pairs of galaxies stellar mass or flux ratios between 1 and 4. We improve on the best recent efforts by probing merging of lower mass galaxies, anchoring evolutionary trends from five Hubble Space Telescope Legacy fields in the Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey (CANDELS) to the nearby universe using Sloan Digital Sky Survey (SDSS) to measure the fraction of massive galaxies in such pairs during six epochs spanning 0<z<3. We perform comprehensive tests of the impact of pair selection techniques, demonstrating that individual selection items such as redshift proximity, mass or flux ratios, projected separations and corrections for random pairing play an important role, thus, the computed fractions are strongly dependent on the employed pair selection. For a range of projected separations (5-30 to 5-50 kpc), the mass-ratio fraction increases from 4-7% (z~0) to 9-16% (z = 1.0-1.5), then turns over and decreases to 5-10% at z=3. Yet, for flux ratio defined pairs we find higher fractions that continue to increase with redshift with no turnover. We estimate merger rates from the mass-ratio fractions using simple time scale assumptions. Despite good agreement with previous studies up to z~1-1.5, our merger rates are in tension with those predicted by simulations at z>1.5. This implies that major merging may not be as important at high redshifts as previously thought, merger timescales may not be fully understood, or we may be missing evidence of mergers at z~2-3 owing to CANDELS selections effects. Next, we will analyze pair fractions and merging timescales within realistic mocks of CANDELS from state of the art Semi-Analytic Model (SAM) to better understand and calibrate our empirical results.

Author(s): Kameswara Bharadwaj Mantha[21], Daniel H. McIntosh[21], Ryan Brennan[15], Joshua Cook[21], Dritan Kodra[23], Jeffrey Newman[23], Rachel S. Somerville[15], Guillermo Barro[18], Peter Behroozi[13], Christopher Conselice[22], Avishai Dekel[14], Sandra M. Faber[20], Henry Closson Ferguson[12], Steven L. Finkelstein[24], Adriano Fontana[5], Audrey Galametz[8], Pablo Perez-Gonzalez[16], Norman A. Grogin[12], Yicheng Guo[20], Nimish P. Hathi[1], Philip F. Hopkins[2], Jeyhan S. Kartaltepe[10], Dale Kocevski[3], Anton M. Koekemoer[12], David C. Koo[20], Seong-Kook Lee[11], Jennifer M. Lotz[12], Ray A. Lucas[12], Hooshang Nayyeri[19], Michael Peth[6], Janine Pforr[1], Joel R. Primack[20], Paola Santini[5], Brooke D Simmons[9], Mauro Stefanon[7], Amber Straughn[4], Gregory F. Snyder[12], Stijn Wuyts[17]
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347.16 – Flux sensitivity requirements for the detection of Lyman continuum radiation from star-forming galaxies below redshifts of 3

Flux estimates for Lyman continuum (LyC) escaping from star-forming galaxies, having characteristic luminosities $L^*_{1500}(1+z)$ derived from *GALEX* and the VIMOS-VLT Deep Survey, are presented as a function of redshift and escape fraction. These estimates serve to guide the design of instrumentation and observing strategies, be they spectroscopic or photometric, attempting to detect LyC escaping star-forming galaxies for redshifts z〈 3. Examples are given that relate the absolution escape fraction of ionizing photons, integrated over the extreme UV (EUV) bandpass, to the relative escape fraction observed just shortward of the ionization edge at 911.7Å, as a function of HI, HeI, and HeII column densities. Detection of LyC "drop-ins" in the rest-frame EUV will provide enhanced fidelity to determinations of the fraction of ionizing photons (f_e^{LyC}) that escape star-forming galaxies and contribute to the meta-galactic ionizing background.

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347.17 – Quantitative Morphology Measures in Galaxies: Ground-Truthing from Simulations

The process of galaxy assembly is a prevalent question in astronomy; there are a variety of potentially important effects, including baryonic accretion from the intergalactic medium, as well as major galaxy mergers. Recent years have ushered in the development of quantitative measures of morphology such as the Gini coefficient (G), the second-order moment of the brightest quintile of a galaxy's light (M_{20}), and the concentration (C), asymmetry (A), and clumpiness (S) of galaxies. To investigate the efficacy of these observational methods at identifying major mergers, we have run a series of very high resolution cosmological zoom simulations, and coupled these with 3D Monte Carlo dust radiative transfer. Our methodology is powerful in that it allows us to "observe" the simulation as an observer would, while maintaining detailed knowledge of the true merger history of the galaxy. In this presentation, we will present our main results from our analysis of these quantitative morphology measures, with a particular focus on high-redshift (z>2) systems.

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Institution(s): *1. Haverford College, 2. NCSA, 3. University of Florida, 4. University of the Western Cape*

347.18 – The 1D and 2D Hα Kinematics of Galaxies in ZFIRE at z ~ 2

We perform a kinematic analysis of star-forming galaxies at z ~ 2 in the COSMOS legacy field using near-infrared spectroscopy from Keck/MOSFIRE and F160W imaging from CANDELS as part of the ZFIRE survey. Our sample consists of galaxies from the overdense regions at z = 2.1 in COSMOS as well as field objects from 1.9 < z < 2.5. We measure Hα integrated velocity dispersions, and through modeling 2D exponential disks with arctangent velocity profiles, we measure rotational velocities and gas velocity dispersions. Our 1D kinematics show no statistically significant differences on the basis of environment, and we conclude that the kinematics of star-forming galaxies at z ~ 2 are not significantly different between the cluster and field. By testing our models against 2D simulations, we find we can recover our input kinematics to within 14% of the input values, allowing us to further constrain the debated evolution of the Tully-Fisher relation at z ~ 2.

Author(s): Leo Yvonne Alcorn[4], Kim-Vy Tran[4], Karl Glazebrook[3], Ivo Labbe[1], Caroline Straatman[2], Glenn Kacprzak[3]
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Contributing team(s): ZFIRE, ZFOURGE

347.19 – Discriminating among stellar population synthesis models of the TP-AGB phase in early quiescent galaxies

Galactic evolution at high redshifts is largely understood through stellar population synthesis (SPS) modeling of spectra and photometry integrated over all starlight of a galaxy. However, complex and poorly understood stellar phases like the unstable thermally-pulsating asymptotic giant branch (TP-AGB) phase make SPS modeling a difficult task. Recent models fail to agree on the TP-AGB contribution to the infrared luminosity, leading to significant discrepancy among the properties derived from modern SPS models when applied to early galaxies. Here we provide a thorough assessment of each of the most widely used SPS models by comparing their results and assessing their accuracy in modeling our unique dataset. We combine high-resolution spectroscopic observations from Keck/MOSFIRE with photometric data for 21 early quiescent galaxies with redshifts of z ~ 2. These galaxies are around the age of peak TP-AGB activity, between ~0.3 and 2 Gyr, and therefore provide an ideal test of the models. We find that models with a "light" TP-AGB contribution provide much better descriptions of our galaxies at ages of ~1 Gyr or less. This is true at high statistical significance and holds for models with or without dust reddening. However, contrary to previous studies, the model-dependent photometrically estimated ages are similar among the models, but they show only moderate agreement with the more model-independent spectroscopic ages derived from stellar absorption lines. The largest discrepancies are found for the Charlot & Bruzual (2007) models which show an artificial clustering of ages around 1 Gyr. The TP-AGB "light" models require more reddening, which can be independently tested by examining dust emission in the mid-infrared. The modeled fluxes are also mostly consistent with mid-infrared observations, with the exception of one model. Resolving these differences among the models will substantially strengthen our estimates of the properties of early quiescent galaxies.

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347.20 – Exploring the Role of Galaxy Morphology in the Mass-Metallicity-Star Formation Rate Relation

The Mass-Metallicity-Star Formation Rate (M-Z-SFR) fundamental relation reveals the underlying physics behind galaxy evolution: the mechanics of gas inflow, outflow, and the formation of stars are intimately connected. At higher redshift, we observe galaxies which are believed to be more actively accreting from the cosmic web, and as a result bright star-forming clumps are expected to form due to the increased gravitational instability of the

galactic medium. We investigate these “clumpy” galaxies in context of their location on the M-Z-SFR plane to search for evidence of metal-poor gas inflows as predicted by theoretical models, and to help us understand how galaxies form and change at a higher redshift (1.3 < z < 2.2). We use the CANDELS survey to examine the morphological structure of star forming regions utilizing the high resolution of space-based HST imaging. We create stamps in their rest-frame UV light to investigate recent star formation and visually classify the morphology of the galaxies. We also utilize stellar population fits of the photometric data to determine properties such as mass and star formation rate. From the grism data of the 3D-HST survey, we select 1861 galaxies based on the strong detection of the [OIII_5007] line, and determine metallicity through the line-diagnostic R_23 using [OIII_5007], [OII_3727] and H_beta. We improve these results through the stacking of spectra to remove a sample bias of requiring strong detections on weak emission lines. Using mass, star formation rate, and metallicity we compare the location of clumpy galaxies on the fundamental plane to investigate possible diminished metallicity and heightened star formation rate compared to the remainder of the sample. This will enable us to better understand the theoretical underpinnings of gas accretion and galaxy evolution at high redshift.

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347.22 – Reconstruction of Galaxy Star Formation Histories through SED Fitting: The Dense Basis Approach

The standard assumption of a simplified parametric form for galaxy Star Formation Histories (SFHs) during Spectral Energy Distribution (SED) fitting biases estimations of physical quantities (Stellar Mass, SFR, age) and underestimates their true uncertainties. Here, we describe the Dense Basis formalism, which uses an atlas of well-motivated basis SFHs to provide robust reconstructions of galaxy SFHs and provides estimates of previously inaccessible quantities like the number of star formation episodes in a galaxy's past. We train and validate the method using a sample of realistic SFHs at z=1 drawn from current Semi Analytic Models and Hydrodynamical simulations, as well as SFHs generated using a stochastic prescription. We then apply the method on ~1100 CANDELS galaxies at 1〈z〈1.5,compare existing results with SpeedyMC, an MCMC code, and provide new results, including the fraction of galaxies with multiple major episodes of star formation. The Dense Basis formalism offers a general method for a large class of problems and can be expected to have broad data-science applications, including the reconstruction of past events from single-epoch observations, and its scalability allows it to be applied to the high S/N SEDs for the N~O(10^8) galaxies from the upcoming generation of surveys including LSST, HETDEX and J-PAS.

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347.23 – Modeling the Internal Kinematics (Rotation and Dispersion) of Distant Galaxies (z ~ 1.0) Using Multi-PA Keck DEIMOS Slit Spectra

The stark difference between the chaotic internal motion of distant galaxies and the ordered rotation of typical local spiral galaxies suggests that disordered galaxies at high redshifts (i.e., early times in the Universe's history) gradually settle into well ordered disk morphologies with ordered rotation. We have used slit spectra obtained with Keck DEIMOS at four different position angles for 133 distant objects (z ~ 1.0) in the GOODS-N field. The emission lines in the 2D spectra of the galaxies were used to calculate the redshift/velocity at each spatial location. For each slit row, the distribution of flux over velocity was modeled as a Gaussian curve from which we obtained the radial velocity and spread of radial velocity. Rotation curves and velocity dispersions for each galaxy at each slit angle were plotted at these values. We qualitatively classified galaxies as regularly rotating, merging, face-on, or unable to be determined by examining overlays of the rotation curves from the four slit angles. We found that regular rotating galaxies tended to have peak velocity dispersion at the center while mergers had fairly constant velocity dispersions. Face-on galaxies had chaotic and inconsistent velocity dispersions between different slit angles. Regularly rotation galaxies represented 45% of our sample and mergers represented 27%. The relative percentage of galaxies that were either regularly rotating or mergers roughly matched those of the literature. This research was supported by NASA and the National Science Foundation. Most of this work was carried out by high school students working under the auspices of the Science Internship Program at UC Santa Cruz.

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347.24 – Cosmic Web of Galaxies in the COMOS Field

We use a mass complete sample of galaxies with accurate photometric redshifts in the COSMOS field to estimate the density field and to extract the components of the cosmic web. The comic web extraction algorithm relies on the signs and the ratio of eigenvalues of the Hessian matrix and is enable to integrate the density field into clusters, filaments and the field. We show that at z < 0.8, the median star-formation rate in the cosmic web gradually declines from the field to clusters and this decline is especially sharp for satellite galaxies (~1 dex vs. ~0.4 dex for centrals). However, at z > 0.8, the trend flattens out. For star-forming galaxies only, the median star-formation rate declines by ~ 0.3-0.4 dex from the field to clusters for both satellites and centrals, only at z < 0.5. We argue that for satellite galaxies, the main role of the cosmic web environment is to control their star-forming/quiescent fraction, whereas for centrals, it is mainly to control their overall star-formation rate. Given these, we suggest that most satellite galaxies experience a rapid quenching mechanism as they fall from the field into clusters through the channel of filaments, whereas for central galaxies, it is mostly due to a slow quenching process. Our preliminary results highlight the importance of the large-scale cosmic web on the evolution of galaxies.

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Contributing team(s): The COSMOS science team

347.25 – Constraining Metallicity and Age for Massive Quiescent Galaxies in a Redshift Range of 1

Using HST/WFC3 grism spectroscopy from the CANDELS Lyman-alpha Emission at Reionization (CLEAR) survey, we constrain the metallicities and ages of massive quiescent galaxies, at z ~ 1.5. CLEAR provides deep spectroscopy (12 HST orbits per pointing) with the WFC3/G102 grism over the wavelength range ~ 7,500 < λ < 12,000 Å, at a spectral resolution of R ~ 200, within the GOODS-N and GOODS-S Deep regions of CANDELS. These data cover important age and metallicity sensitive spectral features for galaxies at 1 < z < 2, including the redshifted Ca HK lines, 4000 Å break, Balmer-series lines, and Hg+G features. We stack the G102 spectra of a stellar-mass limited sample of 34 quiescent galaxies, with $\log(M_*/M_\odot) > 10$ and 1 < z < 2, and fit the spectra using two sets of stellar population synthesis models, BC03 (Bruzual & Charlot 2003) and FSPS (Flexible Stellar Population Synthesis, Conroy & Gunn 2010). From these fits, we construct probability distribution functions of age and metallicity for these galaxies, separated into two mass bins, $10 < \log(M_*/M_\odot) < 10.9$ and $\log(M_*/M_\odot) > 10.9$. The model fits favor higher metallicity for the more massive quiescent galaxies, with $Z/Z_\odot \sim 1$, with some systematics possibly leading from differences in the stellar population models. Therefore, there is no evidence for significant evolution in metallicity for the most massive quiescent galaxies since z ~ 1.5. The model fits to the lower mass quiescent galaxies favor lower metallicites, $Z/Z_\odot \sim 0.4$, with an offset of ~ 0.3 dex from the present-day relation (e.g., Galazzi et al. 2005). For quiescent galaxies in this mass range, $10.0 < \log(M_*/M_\odot) < 10.9$, this requires evolution in metallicity, either as a result of continued chemical enrichment of current galaxies, or the formation of additional quiescent galaxies (presumably quenching of star-forming galaxies at z > 1), or a combination of the two.

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347.26 – Evolution in Solitude - Field Galaxies from Half the Age of the Universe to the Present

We analyze the stellar populations and evolutionary history of bulge-dominated ($n_{ser} \geq 1.5$) field galaxies at redshifts up to z≈1 as part of the Gemini/HST Galaxy Cluster Project (GCP). High signal-to-noise optical spectroscopy from Gemini Observatory and imaging from Hubble Space Telescope is used to analyze a total of 44 field galaxies, focusing on 30 passive (EW[OII] ≤ 5Å) field galaxies. Our results indicate that the size-mass and size-velocity dispersion relations for the passive field galaxies show no significant evolution between z≈1 and the present. The passive field galaxies contain younger stellar populations than cluster galaxies at similar redshifts, with a formation redshift z_{form} = 1.2-1.4 compared to z_{form} = 1.8 for the cluster galaxies. We establish the Fundamental Plane and study the M/L ratios, both indicating that the formation redshift for the passive field galaxies is mass dependent. The zero point differences of the scaling relations for the M/L ratios agree with the formation redshift of z_{form} = 1.2-1.4 found from the line indices and are consistent with the passive evolution model.

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347.27 – Thick Disks and Galaxy Morphology in the Hubble Space Telescope Frontier Fields

Thick disk evolution was studied by identifying and analyzing 149 edge-on galaxies in the Hubble Space Telescope Frontier Fields Abell 2744 Parallel and MACS J0416.1-2403 Parallel. Visual inspection and radial profiles were used to classify the galaxies into four categories: clumpy, spiral, transition, and spheroidal. Spirals were only found at z < 1.5; other types were observed out to z=4. Vertical profiles, corrected for the point spread function, were fit to a sech^2 function to determine their scale heights in B_{435}, V_{606} and I_{814} passbands. Scale heights ranged from 500 to 1500 pc, scaling with galaxy mass. The ratio of average scale height to radius in the I_{814} band was found to have about the same distribution function for all types. About 90% of the galaxies had a V-I color index ~ 0.3 mag redder at one scale height than in the midplane, indicating that age increases with height.

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347.28 – The Stability Of Disk Barred Galaxies Over the Past 7 Billion Years

A recently released model of interacting disk galaxies provides a hypothesis for the origins of off center bars in disks. No systematic search for offset bars in the early universe has yet been undertaken. The Galaxy Zoo project has produced data regarding the large-scale bars of many galaxies. Using this data alongside images collected by the Hubble Space Telescope and other sources, we have examined 5190 galaxies for signatures of off-centered bars. Less than 5 percent of the sample shows clear signs of an offset bar. We describe their overall properties of this sub-sample and compare the properties of galaxies with offset bars to those with centered bars. We assess the feasibility of the proposed model and place these galaxies in the context of the overall evolution of galaxies.

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347.29 – Broadband and Narrowband Search for z < 1 Analogs of High Redshift Star Forming Galaxies

Studies of high redshift (z > 6) galaxies rely on extreme broadband colors from Spitzer/IRAC to select samples of low-mass star forming galaxies. These broadband excess searches are biased towards galaxies with the strongest emission lines, and the extent to which existing studies miss fainter galaxies with lower star formation rates remains unknown. Using both broadband (BB) and narrowband (NB) imaging from the HyperSuprimeCam (HSC) and SuprimeCam (SC) on the Subaru Telescope, we have performed a search for z < 1 strong emission line galaxies, which are analogs of the high redshift population. The search was performed over roughly 4 square degrees centered on the COSMOS field, and the narrowband filters allow us to probe fainter emission lines than the broadband searches. We carried out spectral followup of our BB excess and NB excess samples using WIYN/Hydra to measure redshifts and line ratios in order to understand the biases in the different selection techniques. We also investigate the rest frame UV properties of our sample using data from GALEX. This study demonstrates the effectiveness of using broadband colors to select intermediate redshift emission line galaxies.

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347.30 – Characterizing and Cataloguing Star-Forming Galaxies in Preparation for the LADUMA Survey

This poster presents the results of an effort to process, characterize, and catalog the optical spectra of ~ 1,500 star-forming galaxies, located in the Extended Chandra Deep Field South (ECDFS), which will be used in stacking experiments by the Looking At the Distant Universe with the MeerKAT Array (LADUMA) deep HI survey. The LADUMA HI data will be used to study the evolution of the Tully-Fisher relation, cosmic neutral gas density, and other intrinsic properties of galaxies as a function of redshift. The stacking component of this research will rely on large catalogs of star-forming galaxies in the ECDFS, categorized according to star-formation rate (SFR), metallicity, stellar color excess, and redshift. We used optical spectra obtained with the Anglo-Australian Telescope, for which we have developed an automated pipeline to calculate extinction-corrected line fluxes, SFRs, and various metallicity diagnostics. The pipeline ultimately provides a visualization of the objects and their intrinsic properties as related to redshift for future analysis by the LADUMA team.

This work has been supported by NSF grant PHY-1560077.

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347.31 – Gas dynamical imaging and dust properties of the strongly-lensed quasar host galaxy

RXJ1131-1231 at z~0.65

Studies over the last two decades have revealed that the comoving star formation rate (SFR) and the black hole accretion rate densities have been steeply declining since z~2. Tracing the evolution of the cold molecular gas which fuels star formation and black hole accretion in galaxies at intermediate redshift (0.5<z<1) is therefore essential to obtain a coherent picture connecting high-z galaxies with their present-day descendants. We present CO J=2-1 and 3-2 line observations in the quadruply-lensed quasar RXJ1131-1231 at z~0.65 obtained using the Plateau de Bure Interferometer (PdBI) and the Combined Array for Research in Millimeter-wave Astronomy (CARMA), making this the first resolved CO study at intermediate redshift. We perform dynamical lens modeling of the CO emission in the visibility-plane using our code UVMCMCFIT (github.com/astro313/uvmcmcfit), finding that the asymmetry in its double-horned line profile is a result of differential lensing, with a magnification factor varying from ~3 to ~9 across different kinematic components. We recover an intrinsically symmetric line profile and a source-plane velocity gradient that suggest the presence of an extended, ~6kpc radius gas disk with a dynamical mass of ~$8\times10^{10}M_\odot$, a gas mass of ~$1.5\times10^{10}M_\odot$, and a gas mass fraction of ~19% in RXJ1131-1231. The modest gas fraction is consistent with the observed trend of decreasing molecular gas content in star-forming galaxies since z~2. Based on our spectral energy distribution (SED) modeling, we find a lensing-corrected stellar mass of ~$3\times10^{10}M_\odot$ and a SFR of ~120 $M_\odot\ yr^{-1}$, a rate comparable to those of local mergers and high-z disk galaxies. The CO source size, gas depletion timescale and star formation efficiency of RXJ1131-1231 suggest that its star formation is driven by global gravitational instabilities rather than merger interactions. We also find a black hole-to-bulge mass ratio of >0.27%, which is higher than those of local galaxies, suggesting that its black hole mass is largely in place while its stellar bulge is still assembling. Our results thus support the emerging picture that quasars grow faster and/or earlier than their host galaxies at earlier epochs.

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347.32 – Prediction of the Statistical Robustness of the Measurement of Neutral Hydrogen Mass Functions in the COSMOS H i Large Extragalactic Survey (CHILES)

Hydrogen is the fuel for star formation, but relatively little is known about the role of cold gas in galaxy evolution. The COSMOS H I Large Extragalactic Survey (CHILES) is an on-going deep H I survey being conducted with the Karl G. Jansky Very Large Array, probing a 0.5 degree region within the COSMOS field in the 21cm line of neutral hydrogen. CHILES is the first survey to observe H I in emission from z=0 to z~0.5, which corresponds to a look-back time of ~ 5 Gyr. This allows us to observe the content, morphology and kinematics of H I in relation to stellar disks, and how it may have evolved over this period. Here, we present a simulation of the galaxy detections that could be made by the survey, based on multi-wavelength data from the COSMOS dataset in the VLA field of view.

We use the simulated data to calculate the Neutral Hydrogen Mass Function (HIMF), which describes the space density of galaxies as a function of their H I mass. The HIMF has been studied in the local universe, but seeing how it changes in redshift and environment can constrain current models of galaxy formation. We show the robustness of the HIMF we are capable of deriving for the entire survey and as a function of redshift and environment.

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Contributing team(s): CHILES team

347.33 – The AGN Luminosity Fraction in Galaxy Mergers

Galaxy mergers are key events in galaxy evolution, generally triggering massive starbursts and AGNs. However, in these chaotic systems, it is not yet known what fraction each of these two mechanisms contributes to the total luminosity. Here we measure and model spectral energy distributions (SEDs) using the Code for Investigating Galaxy Emission (CIGALE) in up to 33 broad bands from the UV to the far-IR for 23 IR-luminous galaxies to estimate the fraction of the bolometric IR luminosity that can be attributed to the AGN. The galaxies are split nearly evenly into two subsamples: late-stage mergers, found in the IRAS Revised Bright Galaxy Sample or Faint Source Catalog, and early-stage mergers found in the Spitzer Interacting Galaxy Sample. We find that the AGN contribution to the total IR luminosity varies greatly from system to system, from 0% up to ~90%, but is substantially greater in the later-stage and brighter mergers. This is consistent with what is known about galaxy evolution and the triggering of AGNs.

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347.34 – Correlating The Star Formation Histories Of MaNGA Galaxies With Their Past AGN Activity

We investigate active galactic nuclei (AGN) as a primary mechanism affecting star formation in MaNGA galaxies. Using the Pipe3D code, we modeled the stellar population from MaNGA spectra and derived the star formation histories of 53 AGN host galaxies. We seek to compare the star formation histories of the host galaxies of AGN with the ages of their radio lobes to better understand the role of AGN feedback in the star formation histories of MaNGA galaxies. MaNGA (Mapping Nearby Galaxies at APO) is one of the three core programs in the fourth generation Sloan Digital Sky Survey(SDSS). MaNGA will investigate the internal kinematics of nearly 10,000 local galaxies through dithered observations using fiber integral field units (IFUs) that vary in diameter from 12" (19 fibers) to 32" (127 fibers). In this poster, we present initial results on the star formation histories of MaNGA AGN host galaxies. This work was supported by the SDSS Research Experience for Undergraduates program, which is funded by a grant from Sloan Foundation to the Astrophysical Research Consortium.

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347.35 – Incidence of WISE-Selected Obscured AGNs in Major Mergers and Interactions from the SDSS

We use the Wide-field Infrared Survey Explorer (WISE) and the Sloan Digital Sky Survey (SDSS) to confirm a connection between dust-obscured active galactic nuclei (AGNs) and galaxy merging. Using a new, volume-limited (z≤0.08) catalog of visually-selected major mergers and galaxy-galaxy interactions from the SDSS, with stellar masses above 2×10^10 M⊙, we find that major mergers (interactions) are 5--17 (3--5) times more likely to have red [3.4]-[4.6] colors associated with dust-obscured or `dusty' AGNs, compared to non-merging galaxies with similar masses. Using published fiber spectral diagnostics, we map the [3.4]-[4.6] versus [4.6]-[12] colors of different emission-line galaxies and find one-quarter of Seyferts have colors indicative of a dusty AGN. We find that AGNs are five times more likely to be obscured when hosted by a merging galaxy, half of AGNs hosted by a merger are dusty, and we find no enhanced frequency of optical AGNs in merging over non-merging galaxies. We conclude that undetected AGNs missed at shorter wavelengths are at the heart of the ongoing AGN-merger connection debate. The vast majority of mergers hosting dusty AGNs are star-forming and located at the centers of Mhalo<10^13 M⊙ groups. Assuming plausibly short duration dusty-AGN phases, we speculate that a large fraction of gas-rich mergers experience a brief obscured AGN phase, in agreement with the strong connection between central star formation and black hole growth seen in merger simulations. We will use the WISE-selected AGNs (and AGNs selected by other methods) to perform SED analysis of mergers and interactions and dissect the SEDs to disentangle AGN and SF activity.

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347.36 – Kinematics of Galaxy Mergers in The FIRE Simulation

The morphology of galaxies is a field of science still under current investigation. Today, galaxy merger simulations provide us with crucial information that plays an important role in describing the morphology of today and future galaxies. Using the Calar Alto Legacy Integral Field Area (CALIFA) survey, Barrera-Ballesteros et al. find morpho-kinematic misalignments in the stellar and ionized gas's line of sight velocity when comparing the axis of symmetry to the axis of rotation (2015). Similarly, using the Feedback in Realistic Environment (FIRE) simulation we are able to measure stellar and ionized gas's line of sight velocities of various galaxy mergers. The aim of this work is to determine if the observed morpho-kinematic misalignments between the axis of symmetry and axis of rotation appears in our simulations. The cause of such morpho-kinematic misalignments is yet unresolved, but by exploring various galaxy merger simulations with different properties on FIRE we plan to find a plausible explanation. This unexplained phenomenon raises awareness in determining whether current simulations match current observations and offer a better insight in understanding the morphology of galaxies.

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347.37 – Galaxy merger time-scales in the Illustris Simulation

In this project we are investigate merger time-scales, define as the time delays from dark matter halo viral crossing to galaxy-galaxy coalescence. Our project uses merger history trees drawn from the Illustris Simulation, a cosmological hydrodynamic run that follows the formation and evolution of galaxies across cosmic time. Preliminary results indicate that merger time-scales are not sensitive to stellar mass or mass ratio, in stark contrast to what has been found earlier with cosmological dark-matter-only simulations. Work towards understanding the source of this disagreement is currently in progress.

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347.38 – Properties of Pseudo-bulges and Classical Bulges Identified Among SDSS Galaxies

We have used publicly-available SDSS photometry and structural parameters to classify nearby galaxies($z<0.05$) into four bulge-related groups, i.e., those galaxies with : 1) no bulges; 2) pseudo-bulges; 3) classical bulges; and 4) nearly pure bulges, i. e., elliptical-like. We adopt the stellar-mass surface-density within the inner 1 kpc (Σ_1) radius as a key parameter. A sample of 1000 galaxies with previously-classified bulge-types by Gadotti (2009) is used to identify the regions within the Σ_1 vs integrated, stellar-mass plane of galaxies to which each bulge group belongs. In this plane, galaxies with classical bulges appear to overlap the region of elliptical galaxies, while those with pseudo-bulges or no bulges lie at lower Σ_1 at a given stellar mass. In contrast to some previous results, our main finding is that the properties of pseudo-bulge and classical-bulge groups have distributions that appear mostly blended or overlapping, i.e., continuous, rather being distinct, i.e., bimodal.

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347.39 – The HI Content of Galaxies as a Function of Local Density and Large-Scale Environment

We examine the HI content of galaxies as a function of environment, based on a catalogue of 41527 galaxies that are part of the 70% complete Arecibo Legacy Fast-ALFA (ALFALFA) survey. We use nearest-neighbor methods to characterize local environment, and a modified version of the algorithm developed for the Galaxy and Mass Assembly (GAMA) survey to classify large-scale environment as group, filament, tendril, or void. We compare the HI content in these environments using statistics that include both HI detections and the upper limits on detections from ALFALFA. The large size of the sample allows to statistically compare the HI content in different environments for early-type galaxies as well as late-type galaxies. This work is supported by NSF grants AST-1211005 and AST-1637339, the Skidmore Faculty-Student Summer Research program, and the Schupf Scholars program.

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Contributing team(s): ALFALFA Team

347.40 – HI data reduction for the Arecibo Pisces-Perseus Supercluster Survey

The Undergraduate ALFALFA team is currently focusing on the analysis of the Pisces-Perseus Supercluster to test current supercluster formation models. The primary goal of our research is to reduce L-band HI data from the Arecibo telescope. To reduce the data we use IDL programs written by our collaborators to reduce the data and find potential sources whose mass can be estimated by the baryonic Tully-Fisher relation, which relates the luminosity to the rotational velocity profile of spiral galaxies. Thus far we have reduced data and estimated HI masses for several galaxies in the supercluster region.

We will give examples of data reduction and preliminary results for both the fall 2015 and 2016 observing seasons. We will also describe the data reduction process and the process of learning the associated software, and the use of virtual observatory tools such as the SDSS databases, Aladin, TOPCAT and others.

This research was supported by the NSF grant AST-1211005.

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Contributing team(s): Undergraduate ALFALFA Team

347.41 – The Local [CII] Emission Line Luminosity Function

I present, for the first time, the local [CII]158 μm emission line luminosity function measured using a sample of more than 500 galaxies from the RBGS. [CII] luminosities are measured from the Herschel PACS observations of the LIRGs in the GOALS survey and estimated for the rest of the sample based on the far-IR luminosity and color. The sample covers 91.3% of the sky and is complete at $S_{60\mu m} > 5.24$ Jy. We calculated the completeness as a function of [CII] line luminosity and distance, based on the far-IR color and flux densities. The [CII] luminosity function is constrained in the range $\sim 10^{7-9} \ L_{\odot}$ from both the 1/Vmax and the STY maximum likelihood methods. The shape of our derived [CII] emission line luminosity function agrees well with the IR luminosity function. For the CO(1-0) and

[CII] luminosity functions to agree, we propose a varying ratio of [CII]/CO(1-0) as a function of CO luminosity, with larger ratios for fainter CO luminosities. Limited [CII] high redshift observations as well as estimates based on the IR and UV luminosity functions, are suggestive of an evolution in the [CII] luminosity function similar to the evolution trend of the cosmic star formation rate density. ALMA with full capability will be able to confirm this prediction.

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347.42 – Haro 11: Where is the Lyman Continuum Source?

Haro 11 is the best known source of Lyman continuum (LyC) emission in the local universe and is thought to be an analog of the early galaxies that drove cosmic reionization. The source of LyC emission within Haro 11 has not yet been identified, since the LyC detection is unresolved. To map the optically thin regions in this galaxy, we apply our technique of ionization parameter mapping, which uses continuum-subtracted, HST WFC3 and ACS narrowband images of [O III] and [O II] emission to construct ratio maps. These allow us to identify regions of the galaxy that are likely to be optically thin. Due to the importance of continuum subtraction for this technique, we also develop a new method for scaling the continuum images based on the mode of the pixel distribution. We find that a region extending from Haro 11 Knot A appears to be optically thin. Other regions of the galaxy have also been suggested as potential LyC sources, based on the presence of a ULX (Knot B) and Ly-alpha emission (Knot C). Our work now adds Knot A as a third candidate LyC source in this complex merger system. (This work was supported by NASA grant HST-GO-13702)

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347.43 – Ram Pressure Stripping of Galaxy JO201

Despite the discovery of the morphology-density relation more than 30 years ago, the process driving the evolution of spiral galaxies into S0s in clusters is still widely debated. Ram pressure stripping--the removal of a galaxy's interstellar medium by the pressure of the intracluster medium through which it orbits--may help explain galactic evolution and quenching in clusters. MUSE (Multi Unit Spectroscopic Explorer) observational data of galaxy JO201 in cluster Abell 85 reveal it to be a jellyfish galaxy--one with an H-alpha emitting gas tail on only one side. We model the possible orbits for this galaxy, constrained by the cluster mass profile, line of sight velocity, and projected distance from the cluster center. Using Enzo, an adaptive mesh refinement hydrodynamics code, we simulate effects of ram pressure on this galaxy for a range of possible orbits. We present comparisons of both the morphology and velocity structure of our simulated galaxy to the observations of H-alpha emission.

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347.44 – Ram Pressure Stripping: Observations Meet Simulations

Ram pressure stripping occurs when a galaxy falls into the potential well of a cluster, removing gas and dust as the galaxy travels through the intracluster medium. This interaction leads to filamentary gas tails stretching behind the galaxy and plays an important role in galaxy evolution. Previously, these “jellyfish” galaxies had only been observed in nearby clusters, but recently, higher redshift ($z > 0.3$) examples have been found from HST data imaging.

Recent work has shown that cosmic rays injected by supernovae can cause galactic disks to thicken due to cosmic ray pressure. We run three-dimensional magneto-hydrodynamical simulations of ram pressure stripping including cosmic rays to compare to previous models. We study how the efficiency of the ram pressure stripping of the gas, and the morphology of the filamentary tails, depend on the magnitude of the cosmic ray pressure support. We generate mock X-ray images and radio polarization data. Simultaneously, we perform an exhaustive search of the HST archive to increase the sample of jellyfish galaxies and compare selected cases to simulations.

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347.45 – Turbulence and Star Formation in Interacting Galaxies

We investigate the turbulent gas motion in the tidal bridges and tails of colliding galaxies to see if there is a relation between this phenomenon and star formation within these galaxies. Previous studies have shown that the higher-order statistical moments, i.e. skewness and kurtosis, of the neutral hydrogen (HI) gas are linked to their turbulent motion in a galaxy. Such turbulences are considered to be potentially crucial in enhancing star formation at regions where the gas density is low, for example, the outer disk of a spiral galaxy, a dwarf galaxy, and tidal tails in an interacting system. Here we present these studies on a sample of colliding galaxy systems in detail. We create skewness and kurtosis maps representing the distribution of turbulent gas in these galaxies as a whole system and of the individual regions we are interested in. These maps also inform us as to whether the gas motion in these regions is sub-sonic or super-sonic. In order to investigate the relation between the turbulent gas motion and the star formation in low-density regions such as tidal tails, we compare these maps to far-ultraviolet images taken by GALEX space telescope.

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347.46 – A Search for Triggered Star Formation in the Compact Group of Galaxies NGC 5851, NGC 5852 and CGCG 077-007

Galaxy interactions provide ideal conditions for triggering star formation, and impact galaxy evolution and the structure of the universe. The aim of this research is to study the key factors during galaxy interactions that influence star formation events by studying close pairs of galaxies to find the relationship between interaction properties (e.g. relative velocities and distances, mass ratios, orientation, and merger stage) and star formation rate (SFR). We present our analysis on one compact group of star-forming galaxies CGCG 077-007, NGC 5851, and their quiescent companion NGC 5852. Within this group we investigate the conditions where galaxy interactions cause higher SFR or supermassive black hole accretion (i.e. AGN activity), which might rather quench SFR. Areas of increased star formation are classified by the identification of the most UV bright regions within the galaxies. We find these areas by taking the Swift UVOT W2 filter and subtracting from it the Sloan Digital Sky Survey (SDSS) z-band image in order to remove the underlying stellar population. The regions identified by this process allow us to conduct a multi-wavelength study of stellar populations within this compact group. We use Spectral Energy Distribution models to fit ultraviolet to mid-infrared photometry from Swift UVOT, SDSS, 2MASS and WISE and measure global star formation histories for the galaxies and for the identified star forming regions within the galaxies. In the future we will include analysis of Swift XRT data to place constraints on AGN activity, and relate to the star formation history. This group serves as a pilot study and we will apply these methods to a sample of 30 galaxy groups and close pairs in order to investigate the relationship between galaxy interactions, SFR, and AGN activity and gain deeper insight into how mergers drive galaxy evolution.

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Contributing team(s): NASA / GSFC X-ray Galaxies Group

347.47 – The prevalence of dwarf galaxy compact groups over cosmic time

Galaxy interactions are critical to the evolution of the universe, influencing everything from star formation to the structure of the known universe. By studying galaxy interactions through computer simulations, we are instantaneously able to observe processes that normally take billions of years. “Compact groups” are extremely dense assemblies of at least 3 but typically no more than 10 galaxies that are interacting gravitationally. These groups yield much information about galaxy interactions and mergers in dense environments but are difficult to observe at high redshifts. Compact groups of only dwarf galaxies probe a regime of galaxy evolution that has been hypothesized to be common in the early universe. Here we investigate the populations of such dwarf galaxy compact groups in the Millennium II simulation. Millennium II is a massive n-body simulation of cold dark matter particles on a time scale equivalent to the known universe; allowing us to access to high redshift galaxies and the ability to track their descendants. Our preliminary findings indicate that these dwarf galaxy compact groups do exist in the Millennium II simulation. In the simulation, there is a non-inconsequential number of dwarf compact groups with an evolutionary track that mirrors the more massive compact groups with a peak in groups around a redshift of 2.

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347.48 – The Radial Flow Speed of the Neutral Hydrogen in the Oval Distortion of NGC 4736

Radial flows are difficult to measure in the presence of elliptical flows. This is because the model describing the observed velocity field when both kinds of flows are present is degenerate in the unknown parameters. In this poster we show that the degeneracy can be overcome if the pattern speed and position angle of the elliptical flows are known. The method is demonstrated for NGC 4736 using 3.6 micrometer and neutral hydrogen data. We find a mean inward radial flow speed of 5.6 +/- 1.7 km/s in the region of the oval distortion.

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347.49 – Faraday rotation measure synthesis of UGC 10288

Faraday rotation measure synthesis is a powerful tool that has been employed in the past decade when studying line-of-sight magnetic fields of galactic and extragalactic sources. Rotation measures, which are sensitive to the strength and direction of fields in an intervening medium between the source and observer, were classically determined by assuming a single, uniform Faraday-rotating medium. Rotation measure synthesis, on the other hand, is a more robust method that allows for probing a more complicated scenario. We will outline results from a study of magnetic field structure in the disk and halo of edge-on galaxy UGC 10288, using 6 cm and 20 cm observations from CHANG-ES (Continuum Halos in Nearby Galaxies – an EVLA Survey). The presence of a strongly polarized complex background source situated perpendicular to the foreground disk allows for an investigation of the disk-halo magnetic fields of UGC 10288. In particular, we present evidence of magnetic field reversals above the plane of the disk. This finding is not easily explained solely by the prevailing α-Ω dynamo mechanism. Rather, a field reversal may be indicative of different parities of the poloidal field components for the individual disk and halo mechanisms.

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347.50 – Study of Remote Globular Cluster Satellites of M87

We present a sample of “orphan” globular clusters (GCs) with previously unknown parent galaxies, which we determine to be remote satellites of M87, a massive elliptical galaxy at the center of the Virgo Cluster of Galaxies. Because GCs were formed in the early universe along with their original parent galaxies, which were cannibalized by massive galaxies such as M87, they share similar age and chemical properties. In this study, we first confirm that M87 is the adoptive parent galaxy of our orphan GCs using photometric and spectroscopic data to analyze spatial and velocity distributions. Next, we increase the signal-to-noise ratio of our samples’ spectra through a process known as coaddition. We utilize spectroscopic absorption lines to determine the age and metallicity of our orphan GCs through comparison to stellar population synthesis models, which we then relate to the GCs’ original parent galaxies using a mass-metallicity relation. Our finding that remote GCs of M87 likely developed in galaxies with ~10^{10} solar masses implies that M87’s outer halo is formed of relatively massive galaxies, serving as important parameters for developing theories about the formation and evolution of massive galaxies.

This research was funded in part by NASA/STScI and the National Science Foundation. Most of this work was carried out by high school students working under the auspices of the Science Internship Program at UC Santa Cruz.

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347.51 – Tracing the Angular Dependence of the CGM

The circumgalactic media (CGM) is enriched with metals through a process called the baryon cycle, which may play a significant role in the regulation of star formation. While the relationship between the CGM’s baryonic makeup and impact parameter is well documented, the relationship between the baryonic distribution of the CGM and the azimuthal angle out of the plane of the galaxy remains an open question. We investigated the angular distribution of baryons in the CGM by creating mock-absorption line spectra for a high-resolution simulation of a Milky Way-like galaxy at redshift zero. By comparison with data from the Cosmic Origins Spectrograph-Halos survey, we determined that our equivalent widths of HI, MgII, CIII, SiII, and SiIII are consistent with observations. Using our data, we found that low ionization state material is more prevalent at low azimuthal angles and that high ionization state material is more prevalent at high angles within the virial radius. We attributed this increased ionization to higher temperatures at high angles. We also found that the highest metallicity levels appear at high and low azimuthal angles, with lower metallicities at middle angles. This evidence supports the recycled accretion model of CGM baryon flow.

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347.52 – Effects of Mechanical and Radiative Supernova Feedback on Subhalo Evolution

Using cosmological hydrodynamical simulations, we investigate the effects supernova feedback has on populations of subhalos at current redshift. A group of halos was run through two simulations, each with different feedback models. One had thermal feedback, and the other had mechanical and radiative feedback. We used a friend-of-friend halo finder on the output of these simulations to explore the stellar and dark matter subhalos created. The number of stellar subhalos created by the mechanical feedback simulation was significantly less than the number created by the thermal feedback model, especially at low mass. Thus, the mechanical feedback model created a number of stellar subhalos more consistent with observations. The mechanical feedback model also showed a presence of dark matter subhalos that lacked stellar particles, or dark subhalos. The results of this analysis can give insight to the Missing Satellite Problem.

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347.53 – Comparing the effects of supernovae feedback models on the interstellar medium

Stellar feedback affects the state of the interstellar medium and plays an important role in the formation of galaxies. However, different ways of modeling that feedback lead to different galaxy morphologies even when using the same initial conditions. We investigated the differences between two models of supernovae feedback, blastwave feedback and superbubble feedback, using a smoothed particle hydrodynamics code to simulate the formation of an isolated galaxy. The two feedback models were compared across three different models of the ISM: primordial cooling, metal-line cooling, and metal-line cooling in addition to molecular hydrogen. The simulations run with metal-line cooling indicate that superbubble feedback creates a greater amount of high-density gas than blastwave feedback does while also regulating star formation more efficiently. Galaxies produced with metal-line cooling or H_2 physics created cold, dense gas, and the increased cooling efficiency was also linked to more pronounced spiral structure.

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347.54 – Recent Advances and Coming Attractions in the NASA/IPAC Extragalactic Database

We review highlights of recent advances and developments underway at the NASA/IPAC Extragalactic Database (NED). Extensive updates have been made to the infrastructure and processes essential for scaling NED for the next steps in its evolution. A major overhaul of the data integration pipeline provides greater modularity and parallelization to increase the rate of source cross-matching and data integration. The new pipeline was used recently to fold in data for nearly 300,000 sources published in over 900 recent journal articles, as well as fundamental parameters for 42 million sources in the Spitzer Enhanced Imaging Products Source List. The latter has added over 360 million photometric measurements at 3.6, 4.5, 5.8. 8.0 (IRAC) and 24 microns (MIPS) to the spectral energy distributions of affected objects in NED. The recent discovery of super-luminous spiral galaxies (Ogle et al. 2016) exemplifies the opportunities for science discovery and data mining available directly from NED's unique data synthesis, spanning the spectrum from gamma ray through radio frequencies. The number of references in NED has surpassed 103,000. In the coming year, cross-identifications of sources in the 2MASS Point Source Catalog and in the AllWISE Source Catalog with prior objects in the database (including GALEX) will increase the holdings to over a billion distinct objects, providing a rich resource for multi-wavelength analysis. Information about a recent surge in growth of redshift-independent distances in NED is presented at this meeting by Steer et al. (2017). Website updates include a 'simple search' to perform common queries in a single entry field, an interface to query the image repository with options to sort and filter the initial results, connectivity to the IRSA Finder Chart service, as well as a program interface to query images using the international virtual observatory Simple Image Access protocol. Graphical characterizations of NED content and completeness are being further developed. A brief summary of new science functionality under development is also given. NED is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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347.55 – Spectral Analysis, Synthesis, & Energy Distributions of Nearby E+A Galaxies Using SDSS-IV MaNGA

Utilizing data from the Mapping Nearby Galaxies at APO (MaNGA) Survey (MaNGA Product Launch-4, or MPL-4), of the latest generation of the Sloan Digital Sky Survey (SDSS-IV), we identified nine post-starburst (E+A) systems that lie within the Green Valley transition zone. We identify the E+A galaxies by their SDSS single fiber spectrum and u-r color, then confirmed their classification as post-starburst by coding/plotting methods and spectral synthesis codes (FIREFLY and PIPE3D), as well as with their Spectral Energy Distributions (SEDs) from 0.15 μm to 22 μm, using GALEX, *SDSS*, 2MASS, and WISE data. We produced maps of gaussian-fitted fluxes, equivalent widths, stellar velocities, metallicities and age. We also produced spectral line ratio diagrams to classify regions of stellar populations of the galaxies. We found that our sample of E+As retain their post-starburst properties across the entire galaxy, not just at their center. We detected matching a trend line in the ultraviolet and optical bands, consistent with the expected SEDs for an E+A galaxy, and also through the J, H and Ks bands, except for one object. We classified one of the nine galaxies as a luminous infrared galaxy, unusual for a post-starburst object. Our group seeks to further study stellar population properties, spectral energy distributions and quenching properties in E+A galaxies, and investigate their role in galaxy evolution as a whole. This work was supported by the Alfred P. Sloan Foundation via the SDSS-IV Faculty and Student Team (FAST) initiative, ARC Agreement #SSP483 to the CUNY College of Staten Island. This work was also supported by grants to The American Museum of Natural History, and the CUNY College of Staten Island through from National Science Foundation.

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Contributing team(s): SDSS Collaboration

347.56 – A Study of E+A Galaxies Through SDSS-MaNGA Integral Field Spectroscopy

We outline the selection process and analysis of sixteen E+A galaxies observed by the Mapping Nearby Galaxies at the Apache Point Observatory (MaNGA) survey as a part of the fourth generation of the Sloan Digital Sky Survey (SDSS-IV). We present their Integral field spectroscopy and analyze their spatial distribution of stellar ages, metallicities and other stellar population properties. We can potentially study the variation in these properties as a function of redshift. This work was supported by the Alfred P. Sloan Foundation via the SDSS-IV Faculty and Student Team (FAST) initiative, ARC Agreement #SSP483 to the CUNY College of Staten Island. This work was also supported by grants to The American Museum of Natural History, and the CUNY College of Staten Island through The National Science Foundation.

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347.57 – Gas motions within high-velocity cloud Complex A reveal that it is dissolving into the Galactic Halo

A massive gas cloud, known as Complex A, is headed towards our Galaxy. This high-velocity cloud is made up of 2 million solar masses of neutral and ionized hydrogen. This cloud is traveling through the Galactic halo, which causes a headwind that damages the cloud. Light escaping the Milky Way's disk also hits the cloud and ionizes it. Using 21-cm radio observations from the Green

Bank Telescope, we studied the motions of the gas. We found that diffuse gas is lagging behind the denser parts of the cloud. These motions suggest that gas is being stripped off the cloud and that it is dissolving into the Galactic halo. This disruptive process means that less gas will safely reach the disk of Milky Way and therefore the cloud will provide less gas for making future stars.

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348 – Next Generation VLA Poster Session

348.01 – Preliminary Antenna Concept for the ngVLA

The preliminary concept for a Next Generation Very Large Array (ngVLA) calls for an interferometric array having an effective collecting area and spatial resolution that are both 10 times better than that of the current VLA and operating over a frequency range of 1.2-116 GHz. Given the large number of antennas needed to meet the collecting area goal, the ngVLA antenna concept must strike a balance between competing science requirements and the programmatic targets for the array's life cycle cost.

Antenna diameters currently under consideration for the ngVLA are in the range of 12-25 m, with a nominal 18-m diameter aperture used for the conceptual design. Currently, the optimization for operations and construction cost suggests that a smaller number of larger apertures is preferable.

The surface accuracy goal for the antennas is 185 µm rms (λ/16 @ 100 GHz) for the primary and subreflector combined under optimal environmental conditions. The subreflector will be optimized for performance above 10 GHz, with some degradation in aperture efficiency accepted at lower frequencies.

For high dynamic range imaging, particularly at the low end of the ngVLA's frequency range, the optimum optical configuration is likely an offset geometry. An unblocked aperture will minimize scattering, spillover, and sidelobe pickup. Both performance and maintenance requirements favor a receiver feedarm on the low side of the reflector.

High pointing accuracy will also be necessary to provide the imaging dynamic range required of the system. With an unblocked aperture, variations in the antenna gain pattern are expected to be dominated by pointing errors. Preliminary requirements are for an absolute pointing accuracy of 40" RMS, with referenced pointing of 3" RMS (FWHM/10 at 10 GHz and 120 GHz, respectively, for an 18-m diameter dish).

The antenna mount is expected to be a typical altitude-azimuth design. Both pedestal bearing and rail-based azimuth drives are under consideration. If fast-switching is required for phase calibration, the antenna mechanical and servo design will need to be optimized for rapid acceleration and low settling time.

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348.02 – Antenna Optics and Receiver Concept for the Next Generation Very Large Array

The Next Generation Very Large Array (ngVLA) is envisioned to be an interferometric array with 10 times the effective collecting area and 10 times higher spatial resolution than the current VLA, operating over a frequency range of 1.2-116 GHz. Achieving these goals will require about 300 antennas of nominally 18m diameter on baselines of 300km. Options for the optical configuration of the antennas and possible receiver configurations to cover the ngVLA frequency range are presented.

The options for the antenna optics take into account performance, cost, receiver accessibility for maintenance purposes, and receiver distribution in the focal plane. Both on-axis and off-axis configurations are considered. The off-axis design has the advantages of higher gain, low near-in sidelobes, lower antenna temperature, and reduced standing waves. The main advantage of the on-axis configuration is its lower cost. The trade-off between subreflector opening angle and feed size is presented. The performance of different dual-offset reflector geometries is summarized.

The ngVLA receivers will be cryogenically-cooled with cryostats integrating multiple receiver bands for reduced maintenance and operating costs. The total number of bands required depends on their fractional bandwidth: maximizing this reduces the band count and number of cryostats, but with a penalty in sensitivity. For the higher frequencies, waveguide-bandwidth receivers are proposed to cover 11-50 GHz and 70-116 GHz in four separate bands, possibly integrated into a single cryostat. Corrugated conical feeds will be used, providing good aperture efficiency and symmetric, uniform beam shape. For 1.2-11 GHz, waveguide-bandwidth receivers are not practical due to the large number of receiver/feed combinations needed to cover the ~9:1 frequency range. Also, the large size of the feeds and polarizers mandates individual cryostats for each band. A possible compromise is two 3:1-bandwidth receivers with smooth-walled, ambient-temperature conical feeds, wideband coaxial LNAs, and cooled OMTs. Aperture efficiency and cross-polarization performance will be degraded, but with the advantage of significant operational cost savings due to the smaller number of cryostats.

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348.03 – Low Cost 1.2 to 116 GHz Receivers for the ngVLA

The next-generation VLA (ngVLA) is a major new radio telescope that is being considered for implementation is the southwest US in the 2020 decade. The general parameters which have been discussed in science and technology workshops in the past 18 months are an array with 10 times the sensitivity and resolution of the current JVLA and operating in the 1.2 to 116 GHz range which is the approximate frequency gap between the SKA and ALMA. This can be implemented with 256 x 18m antennas at fixed locations within a 300km maximum baseline.

A major requirement for this instrument is affordable capital and operating cost. This poster addresses a receiver design to minimize these costs. A goal is an operating cost no larger than the current JVLA. An important parameter in the operating cost both for electric power and maintenance is the number of cryogenic coolers and vacuum dewars. The JVLA has 8 such systems on 27 telescopes and our goal is 1 cryogenic dewar on each of the 256 telescopes to give approximately the same total number of cryogenic systems.

Key questions are the number and frequency range of the receivers packaged as one system. Much work has been done in the past several years on wideband antenna feeds and low noise amplifiers and the important question is the sensitivity as measured by effective area divided by system noise compared to this figure of merit for narrow band receivers. We consider that the 70-116 GHz range will be covered by one conventional bandwidth receiver, the 50 to 70 GHz range range will be skipped due to atmospheric oxygen absorption, and 1.2 to 50 GHz will be covered by 3 to 5 receivers depending upon performance studies and science needs.

This poster presents constraints on the reflector shaped Gregorian optics to allow the feeds to be completely cooled in one package, possible layout of the cryogenic dewar, cooling power requirements, and a current estimate of performance.

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348.04 – Antenna Electronics Concept for the Next-Generation Very Large Array

The National Radio Astronomy Observatory (NRAO), in collaboration with its international partners, completed two major projects over the past decade: the sensitivity upgrade for the Karl Jansky Very Large Array (VLA) and the construction of the Atacama Large Millimeter/Sub-Millimeter Array (ALMA). The NRAO is now considering the scientific potential and technical feasibility of a next-generation VLA (ngVLA) with an emphasis on thermal imaging at milli-arcsecond resolution. The preliminary goals for the ngVLA are to increase both the system sensitivity and angular resolution of the VLA tenfold and to cover a frequency range of 1.2-116 GHz.

A number of key technical challenges have been identified for the project. These include cost-effective antenna manufacturing (in the hundreds), suitable wide-band feed and receiver designs, broad-band data transmission, and large-N correlators. Minimizing the overall operations cost is also a fundamental design requirement.

The designs of the antenna electronics, reference distribution system, and data transmission system are anticipated to be major construction and operations cost drivers for the facility. The electronics must achieve a high level of performance, while maintaining low operation and maintenance costs and a high level of reliability. Additionally, due to the uncertainty in the feasibility of wideband receivers, advancements in digitizer technology, and budget constraints, the hardware system architecture should be scalable to the number of receiver bands and the speed and resolution of available digitizers.

Here, we present the projected performance requirements of the ngVLA, a proposed block diagram for the instrument's electronics systems, parameter tradeoffs within the system specifications, and areas of technical risk where technical advances may be required for successful production and installation.

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348.05 – Implementation Status of a Ultra-Wideband Receiver Package for the next-generation Very Large Array

The next-generation Very Large Array (ngVLA) is a concept for a radio astronomical interferometric array operating in the frequency range 1.2 GHz to 116 GHz and designed to provide substantial improvements in sensitivity, angular resolution, and frequency coverage above the current Very Large Array (VLA). As notional design goals, it would have a continuous frequency coverage of 1.2 GHz to 48 GHz and be 10 times more sensitive than the VLA (and 25 times more sensitive than a 34 m diameter antenna of the Deep Space Network [DSN]). One of the key goals for the ngVLA is to reduce the operating costs without sacrificing performance. We are designing an ultra-wideband receiver package designed to operate across the 8 to 48 GHz frequency range, which can be contrasted to the current VLA, which covers this frequency range with five receiver packages. Reducing the number of receiving systems required to cover the full frequency range would reduce operating costs, and the objective of this work is to develop a prototype integrated feed-receiver package with a sensitivity performance comparable to current narrower band systems on radio telescopes and the DSN, but with a design that meets the requirement of low long-term operational costs.

The ultra-wideband receiver package consists of a feed horn, low-noise amplifier (LNA), and down-converters to analog intermediate frequencies. Key features of this design are a quad-ridge feed horn with dielectric loading and a cryogenic receiver with a noise temperature of no more than 30 K at the low end of the band. We will report on the status of this receiver package development including the feed design and LNA implementation. We will present simulation studies of the feed horn including the insertion of dielectric components for improved illumination efficiencies across the band of interest. In addition, we will show experimental results of low-noise 35nm InP HEMT amplifier testing performed across the 8–50 GHz frequency range.

Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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348.06 – Computing Architecture for the ngVLA

Computing challenges for the Next Generation Very Large Array (ngVLA) are not always the ones that first come to mind. Current design concepts have visibility data rates which allow the permanent storage of the raw visibility data, and although challenging, the calibration and imaging processing for the ngVLA is not beyond the capabilities of existing systems (let alone those that will exist when ngVLA construction is completed).

Design goals include a system that supports a wide range of PI-driven projects, end to end data management, and the production of science ready data products. This should be accomplished while minimizing the operating costs of an array consisting of hundreds of elements distributed over an area of nearly 100,000 km^2.

We discuss a proposed architecture of the computing system, design constraints for a detailed design, and some possible design choices and their implications.

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348.07 – Core Strength: Investigating Two Possible Configurations of the NGVLA

The Next Generation VLA (NGVLA) aims to provide a revolutionary increase in cm-wavelength collecting area and sensitivity, while at the same time providing excellent image fidelity over a wide range of spatial scales. Most radio interferometers feature movable antennas, facilitating reconfiguration of the telescope for different science goals. In order to reduce costs, current designs of the NGVLA assume most or all of the antennas have fixed locations. The choice of array configuration is thus of key importance to address the diverse range of science cases the community wishes to pursue. One important trade-off is long baselines (for resolution) vs short baselines (for accurate imaging of resolved structures).

We consider the performance of a 300 element array of 18-meter antennas extending to 150km radius with with two different core-concentrations: 20% vs. 40% of the antennas in a 0.6km radius core. In neither case is the naturally weighted beam suited to high fidelity imaging at full resolution. We consider two performance metrics: (i) the noise penalty due to visibility weighting that is required to achieve both high angular resolution and high fidelity imaging, relative to natural weighting; and (ii) the mapping speed for large scale structures of the compact core. Initial analysis suggests that the (Jy/bm) noise penalty to achieve both high angular resolution and a reasonably behaved PSF is a factor 1.9 and 2.4, for the 20% and 40% core, respectively. In terms of core mapping speed, the 40% core ngVLA configuration has a mapping speed a factor 2.8 faster than the most compact ALMA configuration (ALMA-out01), and a factor 13 times faster than the ALMA-out09 configuration. The 1" resolution of ALMA-out09 at 90 GHz has been deemed critical for studying the ISM of nearby galaxies (Leroy et al 2016, ngVLA memo. 6); in terms of ALMA Cycle 4 configurations, these two reference ALMA configurations are closest to C40-1 and C40-4. The same factors for the 20% core configuration are 0.6 and 4.2, respectively.

Finally we investigate what total power (single dish) data would be required to complement the (NGVLA) interferometric data using these configurations with high fidelity imaging of very large scale structures.

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348.08 – Science with a Next-Generation VLA

Inspired by dramatic discoveries from the Jansky VLA and ALMA, a plan has been initiated to pursue a future large area radio interferometer that will open new discovery space from proto-planetary disks to distant galaxies. Building on the superb cm observing conditions and existing infrastructure of the VLA site, the current vision of ngVLA is an interferometric array with more than 10 times the effective collecting area and 10 times higher spatial resolution than the current VLA and the Atacama Large Millimeter Array (ALMA) that will operate at frequencies spanning ~1.2-116GHz. The ngVLA is optimized for observations at wavelengths between the exquisite performance of ALMA at submm wavelengths, and the future SKA-1 at few centimeter and longer wavelengths, thus lending itself to be highly complementary with these facilities. As such, the ngVLA will open a new window on the universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcecond resolution, as well as deliver unprecedented broad band continuum polarimetric imaging of non-thermal processes. The ngVLA will be the only facility in the world that can tackle a broad range of outstanding scientific questions in modern astronomy by simultaneously delivering the capability to: directly image planet formation in the terrestrial-zone; map dust-obscured star formation and the cosmic baryon cycle down to pc-scales out to the Virgo cluster; take a cosmic census of the molecular gas which fuels star formation back to first light and cosmic reionization; and carry out novel techniques for exploring temporal phenomena from milliseconds to years. In this poster we highlight a number of the tranformative science cases that are driving the design of the ngVLA.

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Contributing team(s): ngVLA Science Working Groups

348.09 – Imaging Cold Gas to 1 kpc scales in high-redshift galaxies with the ngVLA

The next generation Very Large Array (ngVLA) will revolutionize our understanding of the distant Universe via the detection of cold molecular gas in the first galaxies. Its impact on studies of galaxy characterization via detailed gas dynamics will provide crucial insight on dominant physical drivers for star-formation in high redshift galaxies, including the exchange of gas from scales of the circumgalactic medium down to resolved clouds on mass scales of ~10^5 M_sun. In this study, we employ a series of high-resolution, cosmological, hydrodynamic zoom simulations from the MUFASA simulation suite and a CASA simulator to generate mock ngVLA observations. Based on a direct comparison between the inferred results from our mock observations and the cosmological simulations, we investigate the capabilities of ngVLA to constrain the mode of star formation, dynamical mass, and molecular gas kinematics in individual high-redshift galaxies using cold gas tracers like CO(1-0) and CO(2-1). Using the Despotic radiative transfer code that encompasses simultaneous thermal and statistical equilibrium in calculating the molecular and atomic level populations, we generate parallel mock observations of high-J transitions of CO and C+ from ALMA for comparison. The factor of 100 times improvement in mapping speed for the ngVLA beyond the Jansky VLA and the proposed ALMA Band 1 will make these detailed, high-resolution imaging and kinematic studies routine at z=2 and beyond.

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348.10 – Tracing the Baryon Cycle within Nearby Galaxies with a next-generation VLA

The evolution of galaxies over cosmic time is shaped by the cycling of baryons through these systems, namely the inflow of atomic gas, the formation of molecular structures, the birth of stars, and the expulsion of gas due to associated feedback processes. The best way to study this cycle in detail are observations of nearby galaxies. These systems provide a complete picture of baryon cycling over a wide range of astrophysical conditions. In the next decade, higher resolution/sensitivity observations of such galaxies will fundamentally improve our knowledge of galaxy formation and evolution, allowing us to better interpret higher redshift observations of sources that were rapidly evolving at epochs soon after the Big Bang. In particular, the centimeter-to-millimeter part of the spectrum provides critical diagnostics for each of the key baryon cycling processes and access to almost all phases of gas in galaxies: cool and cold gas (via emission and absorption lines), ionized gas (via free-free continuum and recombination lines), cosmic rays and hot gas (via synchrotron emission and the Sunyaev-Zeldovich effect). This poster highlights a number of key science problems in this area whose solutions require a next-generation radio-mm interferometer such as the next-generation VLA.

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348.11 – Next Generation Very Large Array: The Cradle of Life

This paper discusses compelling science cases for a future long-baseline interferometer operating at millimeter and centimeter wavelengths, like the proposed Next Generation Vary Large Array (ngVLA). We report on the activities of the Cradle of Life science working group, which focused on the formation of low- and high-mass stars, the formation of planets and evolution of protoplanetary disks, the physical and compositional study of Solar System bodies, and the possible detection of radio signals from extraterrestrial civilizations. We propose 19 scientific projects based on the current specification of the ngVLA. Five of them are highlighted as possible Key Science Projects: (1) Resolving the density structure and dynamics of the youngest HII regions and high-mass protostellar jets, (2) Unveiling binary/multiple protostars at higher resolution, (3) Mapping planet formation regions in nearby disks on scales down to 1 AU, (4) Studying the formation of complex molecules, and (5) Deep atmospheric mapping of giant planets in the Solar System. For each of these projects, we discuss the scientific importance and feasibility. The results presented here should be considered as the beginning of a more in-depth analysis of the science enabled by such a facility, and are by no means complete or exhaustive.

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Contributing team(s): ngVLA Cradle of Life

348.12 – The Cold Gas History of the Universe as seen by the ngVLA

The Next Generation Very Large Array (ngVLA) will fundamentally advance our understanding of the formation processes that lead to the assembly of galaxies throughout cosmic history. The combination of large bandwidth with unprecedented sensitivity to the critical low-level CO lines over virtually the entire redshift range will open up the opportunity to conduct large-scale, deep cold molecular gas surveys, mapping the fuel for star formation in galaxies over substantial cosmic volumes. Informed by the first efforts with the Karl G. Jansky Very Large Array (COLDz survey) and the Atacama Large (sub)Millimeter Array (ASPECS survey), we here present initial predictions and possible survey strategies for such "molecular deep field" observations with the ngVLA. These investigations will provide a detailed measurement of the volume density of molecular gas in galaxies as a function of redshift, the "cold gas history of the universe". This will crucially complement studies of the neutral gas, star formation and stellar mass histories with large low-frequency arrays, the Large UV/Optical/Infrared Surveyor, and the Origins Space Telescope, providing the means to obtain a comprehensive picture of galaxy evolution through cosmic times.

Author(s): Dominik A. Riechers[3], Chris Luke Carilli[8], Caitlin Casey[10], Elisabete da Cunha[1], Jacqueline Hodge[6], Rob Ivison[4], Eric J. Murphy[8], Desika Narayanan[5], Mark T. Sargent[9], Nicholas Scoville[2], Fabian Walter[7]
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348.13 – Time Domain Science and Fundamental Physics with the Next-generation Very Large Array

The Next-generation Very Large Array (ngVLA) is a design concept for a future large-area radio telescope under development by the NRAO and interested members of the scientific community. The approximate ngVLA specifications call for a frequency range of ~1--116 GHz, ten times the effective collecting area and moderately increased field of view versus the current VLA, and an array configuration consisting of a dense (~km-scale) array core with some baselines extending out to hundreds of km. This instrument will enable new discoveries in many diverse areas of research relevant to modern astronomy; our group has explored the impact the ngVLA will have in time domain astronomy and fundamental physics.

Here we present several key science topics considered as part of this work. These include: Searching for and timing radio pulsars at the galactic center -- the frequency coverage and sensitivity of the ngVLA will allow detection of highly-scattered pulsars near Sgr A*. Monitoring these sources will permit unprecedented tests of general relativity. Detecting and characterizing explosive transient sources -- electromagnetic observations of gravitational-wave sources provide complementary information to the GW signals themselves. Observations across the wide frequency range spanned by the ngVLA are critical for energy calorimetry of these events. Finally, with sufficient long-baseline coverage, novel astrometric approaches to cosmology become possible, by watching the expansion of the universe in real time through correlated proper motions of many extragalactic radio sources.

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400 – Lancelot M. Berkeley Prize: Exploring for Galaxies in the First Billion Years with Hubble and Spitzer - Pathfinding for JWST, Garth Illingworth (UC Santa Cruz)

400.01 – Exploring for Galaxies in the First Billion Years with Hubble and Spitzer - Pathfinding for JWST

Hubble has revolutionized the field of distant galaxies through its deep imaging surveys, starting with the Hubble Deep Field (HDF) in 1995. That first deep survey revealed galaxies at redshift z~1-3 that provided insights into the development of the Hubble sequence. Each new HST instrument has explored new regimes, through the peak of star formation at z~2-3, just 2-3 billion years after the Big Bang, to our first datasets at a billion years at z~6, and then earlier to z~11. HST's survey capabilities were enhanced by 40X with ACS, and then similarly with the WFC3/IR, which opened up the first billion years to an unforeseen degree. I will discuss what we have learned from the remarkable HST and Spitzer imaging surveys (HUDF, GOODS, HUDF09/12 and CANDELS), as well as surveys of clusters like the Hubble Frontier Fields (HFF). Lensing clusters provide extraordinary opportunities for characterizing the faintest earliest galaxies, but also present extraordinary challenges. Together these surveys have resulted in the measurement of the volume density of galaxies in the first billion years down to astonishingly faint levels. The role of faint galaxies in reionizing the universe is still much-discussed, but there is no doubt that such galaxies contribute greatly to the UV ionizing flux, as shown by deep luminosity function studies. Together Hubble and Spitzer have also established the stellar-mass buildup over 97% of cosmic history. Yet some of the greatest surprises have come from the discovery of very luminous galaxies at z~8-11, around 400-650 million years after the Big Bang. Spectroscopic followup by Keck of some of these very rare, bright galaxies has confirmed redshifts from z~7 to z~9, and revealed, surprisingly, strong Lyα emission near the peak of reionization when the HI fraction in the IGM is high. The recent confirmation of a z=11.1 galaxy, just 400 million years after the Big Bang, by a combination of Hubble and Spitzer data, moved Hubble into JWST territory, far beyond what we ever expected Hubble could do. Twenty years of astonishing progress with Hubble and Spitzer leave me looking to JWST to provide even more remarkable exploration of the realm of the first galaxies.

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Contributing team(s): HUDF09, HLF

401 – Extrasolar Planets: Characterization & Theory VI

401.01 – HAT-P-26b: A Neptune-mass Exoplanet with Primordial Solar Heavy Element Abundance

A trend in giant planet mass and atmospheric heavy elemental abundance was first noted last century from observations of planets in our own solar system. These four data points from Jupiter, Saturn, Uranus, and Neptune have served as a corner stone of planet formation theory. Here we add another point in the mass-metallicity trend from a detailed observational study of the extrasolar planet HAT-P-26b, which inhabits the critical mass regime near Neptune and Uranus. Neptune-sized worlds are among the most common planets in our galaxy and frequently exist in orbital periods very different from that of our own solar system ice giants. Atmospheric studies are the principal window into these worlds, and thereby into their formation and evolution, beyond those of our own solar system. Using the Hubble Space Telescope and Spitzer, from the optical to the infrared, we conducted a detailed atmospheric study of the Neptune-mass exoplanet HAT-P-26b over 0.5 to 4.5 μm. We detect prominent H2O absorption at 1.4 μm to 525 ppm in the atmospheric transmission spectrum. We determine that HAT-P-26b's atmosphere is not rich in heavy elements (≈1.8×solar), which goes distinctly against the solar system mass-metallicity trend. This likely indicates that HAT-P-26b's atmosphere is primordial and obtained its gaseous envelope late in its disk lifetime with little contamination from metal-rich planetesimals.

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401.02 – Characterizing K2 Exoplanets with NIR Transit Photometry from the 3.5m WIYN Telescope

The NASA K2 mission has discovered over 400 transiting exoplanets as of October 2016 and continues to produce new discoveries on a regular basis. Expected to launch in late 2017, the Transiting Exoplanet Survey Satellite (TESS) will continue the era of exoplanet discovery by performing an all-sky search for transiting exoplanets. Given the ever increasing number of known exoplanets, it is critical that we optimize follow-up observations now in order to characterize the many interesting systems discovered by these missions. For example, K2 is finding (and TESS will find even more) small, super-Earth-size planets around cool, nearby stars. I will present results from our program for near-infrared (NIR) transit photometry of K2 exoplanet candidates conducted using the 3.5m WIYN telescope at Kitt Peak National Observatory. NIR transit photometry with the high spatial resolution WHIRC imager installed on the WIYN telescope allows us to confirm the transit host, to verify that the transit is achromatic, and to constrain the planet radius by minimizing effects of stellar limb darkening. Furthermore, the high-precision and high-cadence photometry from WIYN+WHIRC allows us to track and constrain the transit ephemeris, which is crucial for future follow-up efforts with other facilities like the upcoming James Webb Space Telescope (JWST). Ultimately, this program will vet K2 exoplanet candidates and identify prime targets for detailed characterization with JWST. This program complements K2 follow-up being done with the Spitzer Space Telescope and demonstrates the capabilities of a ground-based facility that can be used to characterize small planets from K2 and TESS for years to come.

This work was supported by the NASA-NSF Exoplanet Observational Research (NN-EXPLORE) program.

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401.03D – *Kepler* Planet Masses and Eccentricities from Transit Timing Variations

The *Kepler* mission's census of transiting exoplanets has shown that planets between one and four times the radius of Earth with short orbital periods are extremely common. Given their small sizes, the properties of these planets can be difficult or impossible to constrain via radial velocity observations. Mutual gravitational interactions in multi-planet systems induce variations in the arrival times of planets' transits. These variations can used to probe planets' masses and eccentricities, which in turn constrain their compositions and formation histories. I will discuss the results of our analysis of the transit timing variations (TTVs) of 145 *Kepler* planets from 55 multi-planet systems. Bulk densities inferred from TTVs imply that many of these planets are covered in gaseous envelopes ranging from a few percent to ~20% of their total mass. Eccentricities in these systems are small but in a many instances definitively non-zero. These results support theoretical predictions for super-Earth/sub-Neptune planets accreting their envelopes from a depleting proto-planetary disk.

Author(s): Sam Hadden[1], Yoram Lithwick[1]
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401.04 – Mitigating bias in testing the origins of warm Jupiters via constraints on transit duration variations

Warm Jupiters are a mysterious class of giant planet in ~10-100 day orbits whose origins are debated. Many have intermediate eccentricities too high to have been excited by planet-disk interactions or planet-planet scattering following in situ formation or disk migration but too low for the warm Jupiter to be currently undergoing high eccentricity tidal migration. Nearby planets on mutually inclined orbits can cause modulated eccentricity oscillations that periodically drive these warm Jupiters to eccentricities large enough for tidal migration. For transiting warm Jupiters, we can place constraints on the presence of such nearby, mutually inclined perturbers from detection of or limits on transit duration variations. The transit duration variation is caused by precession of the warm Jupiter's longitude of ascending node that changes the impact parameter from transit to transit. I show that such changes are commonly of the magnitude to be detectable in the Kepler data. However, I demonstrate that allowing the impact parameter to vary from transit to transit while keeping the planet-star separation constant biases the change in impact parameter to larger values and also results in underestimated uncertainties in the planet's eccentricity via the photoeccentric effect. I present an approach for mitigating this bias when assessing constraints on transit duration variations for individual systems and statistically for the entire population of warm Jupiters to test theories for their origins.

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401.05 – What Determines the Presence of a Thermal Inversion in Hot Jupiters?

Stratospheric temperature inversions in the atmospheres of giant exoplanets, once expected to be fairly common in hot Jupiters, have proven to be extremely elusive. Even though many planets have day side temperatures above the TiO/VO condensation point, TiO/VO-driven thermal inversions seem to be rare. Recent observations, however, have given some of the first clear detections of thermal inversions in two very hot giant exoplanets' atmospheres. We report on observations of two additional systems in the same temperature range, which again suggest that the presence of an inversion is not solely driven by atmospheric temperature. Our hypothesis for why this is so would explain the lack of an inversion in our two targets, as well as in cooler hot Jupiters, and would support some theoretical predictions for the processes governing TiO/VO inversions.

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401.06 – Atmosphere-magma ocean modeling of GJ 1132 b

GJ 1132 b is a nearby Earth-sized exoplanet transiting an M dwarf, and is amongst the most highly characterizable small exoplanets currently known. Using a coupled atmosphere-magma ocean model, we determine that GJ 1132 b must have begun with more than 5 wt% initial water in order to still retain a water-based atmosphere. We also determine the amount of O_2 that can build up in the atmosphere as a result of hydrogen dissociation and loss. We find that the magma ocean absorbs at most ~ 10% of the O_2 produced, whereas more than 90% is lost to space through hydrodynamic drag. The results of the model depend strongly on the initial water abundance and the XUV model. The most common outcome for GJ 1132 b from our simulations is a tenuous atmosphere dominated by O_2, although for very large initial water abundances, atmospheres with several thousands of bars of O_2 are possible. A substantial steam envelope would indicate either the existence of an earlier H_2 envelope or low XUV flux over the system's lifetime. A steam atmosphere would also imply the continued existence of a magma ocean on GJ 1132 b. Preliminary modeling with the addition of CO_2 gas will be presented.

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402 – AGN, QSO, Blazars: X-rays & Gamma Rays

402.01 – Scientific Drivers for X-Ray Polarimetry Observations of Active Galactic Nuclei

Although photons cannot escape the gravitational field of a black hole, we can observe the emission from matter spiraling into the black hole forming an accretion disk. X-ray observations are particularly suited to explore the inner structure of the accretion flows onto astrophysical stellar mass and supermassive black holes. In this talk, I will present results from general relativistic ray tracing simulations demonstrating the scientific promise of spectropolarimetric observations of AGNs. Combining timing, spectral, and polarimetric information will allow us to reveal the physical properties of accretion disks and their coronas. I will discuss the potential of X-ray observations for distinguishing between different corona models based on simulations of coronas with different physical properties and in the presence of different sources of seed photons including thermal, cyclotron, and synchrotron seed photons.

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402.02 – A Long Look at NGC 3783 with Chandra/HETG and NuSTAR

We have obtained a simultaneous observation of the Seyfert 1 AGN NGC 3783 with Chandra/HETG (160 ks) and NuSTAR (80 ks). The primary purpose of this deep observing campaign is to address the highly disparate measurements of supermassive black hole spin in this source reported in the literature. The high signal-to-noise, broadband X-ray spectra enabled by a simultaneous Chandra and NuSTAR pointing allow us to definitively deconvolve the primary continuum, absorption and reprocessed emission components in NGC 3783 for the first time. We then isolate the signatures of relativistic reflection from the inner disk and measure the spin of the black hole with previously unachievable accuracy. Here we report on our spectral modeling results and also discuss the implications of this work for our understanding of the physics at work in the corona, the nature of the soft X-ray excess, and the structure of the absorbing gas at present in this bright, nearby AGN.

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402.03 – *Chandra* Observations of the Sextuply Imaged Quasar SDSS J2222+2745

While there are ~100 examples of background quasars strongly lensed by galaxies, there are only a few examples of background quasars strongly lensed by clusters. These systems are both rare and important because they can provide unique constraints on the internal structure of clusters through measurements of the frequency of occurrence and modeling the mass distributions. These constraints, along with statistics of image multiplicity can provide a strong test of the ΛCDM paradigm.

SDSS J2222+2745 was discovered by Dahle et al. (2013), and three images (A–C) of the quasar are immediately obvious in the SDSS image, with a fourth image (D) also evident. Through follow-up imaging and spectroscopy, Dahle et al. found evidence for two additional images (E and F), which are not evident in the SDSS image since they are overwhelmed by the light from the red elliptical galaxies in the center of the system. While there are no direct predictions of the occurrence of six-imaged cluster-lensed quasars in the literature, the predicted occurrence of *any* type of cluster-lensed quasar is very rare and depends sensitively on cosmological parameters such as the matter density Ω_M and the matter power spectrum σ_8.

We report on our *Chandra* observation of SDSS J2222+2745, which clearly shows all six images of the quasar. We present the lensing model based on our *Chandra* observation and discuss the effects of stellar microlensing on the observed flux ratios in the X-ray and optical bands.

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Institution(s): *1. MIT, 2. Trinity University*

402.04D – X-Ray Modeling of the Intrinsic Absorption in NGC 4151

We have investigated the relationship between the long term X-ray spectral variability in the Seyfert 1.5 galaxy NGC 4151 and its intrinsic absorption, by comparing our 2014 simultaneous ultraviolet/X-Ray observations taken with *Hubble* STIS Echelle and *Chandra* HETGS with archival observations from *Chandra*, *XMM-Newton* and *Suzaku*. The observations were divided into "high" and "low" states, with the low states showing strong and unabsorbed extended emission at energies below 2 keV. Our X-ray model consists of a broken powerlaw, neutral reflection and the two dominant absorption components identified by Kraemer et al (2005), X-High and D+Ea, which are present in all epochs. The model fittings suggest that the absorbers are very stable, with the principal changes in the intrinsic absorption resulting from variations in the ionization state of the gas in response to the variable strength of the ionizing continuum. However, the low states show evidence of larger column densities in one or both of the absorbers. Among plausible explanations for the column increase, we discuss the possibility of an expanding/contracting X-ray corona. X-High is consistent with being part of a magnetohydrodynamic (MHD) wind, while D+Ea is possibly radiatively driven, which suggests that at a sufficiently large radial distance there could be a break point between MHD-dominated and radiatively driven outflows. Preliminary results on the analysis of the AGN mass outflow rates and kinematics of the ionized gas in the extended emission region of NGC 4151 will also be presented.

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402.05 – The BAT AGN Spectroscopic Survey (BASS)

We present the Swift BAT AGN Spectroscopic Survey (BASS) and discus the first four papers. The catalog represents an unprecedented census of hard-X-ray selected AGN in the local universe, with ~90% of sources at z<0.2. Starting from an all-sky catalog of AGN detected based on their 14-195 keV flux from the 70-month Swift/BAT catalog, we analyze a total of 1279 optical spectra, taken from twelve dierent telescopes, for a total of 642 spectra of unique AGN. We present the absorption and emission line measurements as well as black hole masses and accretion rates for the majority of obscured and un-obscured AGN (473), representing more than a factor of 10 increase from past studies. Consistent with previous surveys, we find an increase in the fraction of un-obscured (type 1) AGN, as measured from broad Hbeta and Halpha, with increasing 14-195 keV and 2-10 keV luminosity. We find the FWHM of the emission lines to show broad agreement with the X-ray obscuration measurements. Compared to narrow line AGN in the SDSS, the X-ray selected AGN in our sample with emission lines have a larger fraction of dustier galaxies suggesting these types of galaxies are missed in optical AGN surveys using emission line diagnostics. Additionally, we discuss follow-on efforts to study the variation of [OIII] to Xray measurements, a new method to measure accretion rates from using line ratios, a sample of 100 AGN observed with NIR spectroscopy, and an effort to measure the accretion rates and obscuration with merger stage in a subsample of mergers.

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Contributing team(s): BASS Team, Swift BAT Team

402.06 – Gamma-ray blazars within the first two billion years

MeV blazars, with a high-energy peak in the MeV band, are the most powerful persistent sources in the Universe, exhibiting larger-than-average jet powers, accretion luminosities, and black hole masses. Their detection above redshift 3 has the power to constrain the formation mechanism of heavy black holes. Here we report the first detection with the Fermi Large Area Telescope of gamma-ray emitting blazars beyond redshift 3. The newly detected objects have black-hole masses in excess of 1 billion solar masses and very prominent disk and gamma-ray emission. We will discuss the new finding within the context of blazar evolution and the disk-jet connection in powerful jetted AGN.

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Contributing team(s): Fermi-LAT Collaboration

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403 – Extrasolar Planets Detection: Radial Velocity II

403.01 – The Dharma Planet Survey of Low-mass and Habitable Rocky Planets around Nearby Solar-type Stars

The Dharma Planet Survey (DPS) aims to monitor ~150 nearby very bright FGK dwarfs (most of them brighter than V=7) during 2016-2019 using the TOU optical very high resolution spectrograph (R~100,000, 380-900nm) at the dedicated 50-inch Robotic Telescope on Mt. Lemmon. Operated in high vacuum (<0.01mTorr) with precisely controlled temperature (~1 mK), TOU has delivered ~ 0.5 m/s (RMS) long-term instrument stability, which is a factor of two times more stable than any of existing Doppler instruments to our best knowledge. DPS aims at reaching better than 0.5 m/s (a goal of 0.2 m/s) Doppler measurement precision for bright survey targets. With very high RV precision and high cadence (~100 observations per target randomly spread over 450 days), a large number of rocky planets, including possible habitable ones, are expected to be detected. The discovery of a Neptune mass planet and early survey results will be announced.

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403.02 – Light Curves as Predictors of Good Radial Velocity Planet Search Targets in New Stellar Domains

As Kepler and K2 have collectively found thousands of exoplanet candidates, their discoveries have strained ground-based radial velocity (RV) follow-up resources, which are unable to simultaneously keep up with the pace of transit discoveries by measuring masses for all of the candidates and maintain vigorous RV searches for planets that do not transit their parent star. The burden to the RV community is expected to worsen with the upcoming TESS mission, even as new RV instruments are slated to come online in the coming years. Observations that can enable the RV community to prioritize targets on the basis of their stellar RV variability in advance and, ideally, independently of the RV instruments themselves, can therefore permit us to reserve our RV resources for the stars most likely to yield the highest payoff. We show that the light curves from space-based transit surveys may not only be used as predictors of good RV search targets for the stars predominantly targeted by the exoplanet community but also for stars usually avoided by both RV and transit surveys due to their high intrinsic levels of stellar variability. We also briefly present recommendations to the RV planet search community on how to improve prospects for finding Earth analogs from the recent workshop at the Aspen Center for Physics, “Approaching the Stellar Astrophysical Limits of Exoplanet Detection: Getting to 10cm/s.”

Author(s): Fabienne A. Bastien[2], Jason Wright[2], Steinn Sigurdsson[2], Xavier Dumusque3, Jacob K. Luhn[2], Andrew Howard[1]
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403.03D – Multiplexing Precision Radial Velocities with the Michigan/Magellan Fiber System: Searching for Hot Jupiters in Southern Open Star Clusters

The Michigan/Magellan Fiber System enables multiplexed, precision radial velocity surveys of open star clusters for warm- and hot-Jupiter exoplanetary companions while simultaneously allowing detailed study of stellar properties to V~17. To create this capability, we developed a novel mechanism to improve its maximum resolving power from ~20,000 to ~60,000 along with an automated control system that enables users to rapidly reconfigure M2FS for different scientific programs. We report the results of a survey of 126 photometric FGK members of the young (141 Myr), nearby (346 pc) open star cluster NGC 2516 and 100 photometric FGK members plus 25 candidate members of the young (72 Myr), nearby (491 pc) open cluster NGC 2422 (M 47). Our results show M2FS can achieve RV precisions in the 20–60 m/s range for up to 128 stars simultaneously while our median RV precision of 80 m/s on individual epochs, which span a temporal baseline of 1.1 yrs, enables us to investigate membership and stellar binarity and search for sub-stellar companions. We also report the methods developed to make precise spectroscopic measurements of T_{eff} (±30 K), [Fe/H] and [α/Fe] (±0.02 dex), and v_r sin(i) (±0.3 km/s). We determine membership probabilities and RV variability probabilities for our sample along with candidate companion orbital periods for a select subset of stars. We identify 81 RV members in NGC 2516, 27 spectroscopic binaries (17 previously identified as photometric binaries), and 16 other stars that show significant RV variability after accounting for average stellar jitter found to be at the 74 m/s level. In NGC 2422 we identify 57 members, 11 spectroscopic binaries, and 3 other stars that show significant RV variability after accounting for an average jitter of 138 m/s. We use Monte Carlo simulations to verify our stellar jitter measurements, determine the proportion of exoplanets and stellar companions to which we are sensitive, and estimate companion mass limits for our targets. We also report mean cluster metallicity, velocity, and velocity dispersion based on our member targets and identify 58 non-member stars as velocity variables – 24 of which have RV amplitudes that imply stellar or brown-dwarf mass companions.

Author(s): John Ira Bailey[3], Mario L. Mateo[4], Russel J. White[2], Jeffrey D. Crane[1], Stephen A. Shectman[1]
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Contributing team(s): M2FS Instrument Team

403.04 – Halpha as a Diagnostic of FGKM Stellar Atmospheres

The detection of exoplanets via radial velocity (RV) has become increasingly dependent on a deep understanding of the behavior of stellar atmospheres. Periodic variations due to stellar activity, rotation, and/or pulsation can be, and have been, confused with signals of orbiting planets, but are also diagnostic of fundamental properties of stars, like age or interior structure. Studying such variation diagnostics across a wide sample of stars is thus important to tease out different dependencies, including planet-induced RV variations, particularly for small planets. I will present, for the first time, measures of the stellar activity as reckoned from the Halpha Balmer line of hydrogen at 6563A in ~43,000 HIRES spectra of ~1500 FGKM stars being monitored for planets, many for over ten years. The motivation to use an additional activity index, besides the S value, comes from the low flux of M dwarf stars in the Ca H&K wavelength region; these stars are the most promising candidates for habitable planets. However, I will show that the variation in Halpha flux is also diagnostic of higher mass star properties, proving its utility across a wide SpT space for both RV planet detection and stellar atmosphere characterization.

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Contributing team(s): Carnegie/California Planet Search Team

403.05D – Illuminating the Origins of Planets with Solar Twins

It is now well established that stellar photospheric compositions can act as a fossil record of the protostellar environments in which planets form. Stellar spectroscopy of planet-hosting stars is therefore a valuable source of information about chemical conditions for planet formation. However, the difficulty of resolving planet-scale abundance differences in the photospheres of stars requires a unique approach. I will present recent results from a five-year-long radial velocity planet survey and complementary stellar spectroscopy focusing on solar twins. By restricting our sample to a set of "twin" stars, we demonstrate that we can resolve changes in stellar compositions on the scale of only a few Earth masses, potentially offering a new observational window into planet formation signatures. The techniques developed through our solar twin program will become increasingly valuable as we enter the TESS era of bright, spectroscopy-friendly planet host stars.

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403.06 – Precise Radial Velocity First Light Observations With iSHELL

We present our first light observations with the new iSHELL spectrograph at the NASA Infrared Telescope facility. iShell replaces the 25 year old CSHELL with improvements in spectral grasp (~40x), resolution (70,000 versus 46,000), throughput, optics, and detector characteristics. With CSHELL, we obtained a radial velocity precision of 3 m/s on a bright red giant and we identified several radial velocity variable M dwarfs for future follow up. Our goal with iSHELL is to characterize the precise radial velocity performance of the methane isotopologue absorption gas cell in the calibration unit. We observe bright nearby radial velocity standards to better understand the instrument and data reduction techniques. We have updated our CSHELL analysis code to handle multiple orders and the increased number of pixels. It is feasible that we will obtain a radial velocity precision of < 3 m/s, sufficient to detect terrestrial planets in the habitable zone of nearby M dwarfs. We will also follow up radial velocity variables we have discovered, along with transiting exoplanets orbiting M dwarfs identified with the K2 and TESS missions.

Author(s): Bryson Lee Cale[6], Peter Plavchan[6], America Nishimoto[6], Angelle M. Tanner[5], Jonathan Gagne[1], Peter Gao[7], Elise Furlan[13], Russel J. White[2], Bernie Walp[7], Kaspar von Braun[4], Carolyn Brinkworth[14], John A. Johnson[3], Guillem Anglada-Escudé[10], Todd J. Henry[2], Joseph Catanzarite[12], Stephen R. Kane[11], Charles Beichman Charles.A.Beichman@jpl.nasa.gov[8], David R. Ciardi[8], J. Kent Wallace[9], Bertrand Mennesson[9], Gautam Vasisht[9]
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403.07 – Planets around nearby M dwarfs

Our current view of exoplanets is one derived primarily from Solar-like stars with a strong focus on understanding our Solar System. Our knowledge about the properties of exoplanets around the dominant stellar population by number, the so called low-mass stars or M dwarfs is much more cursory. Based on combining radial velocities of nearby M dwarfs obtained with HARPS, UVES and HIRES datea we find many new M dwarf planets. By computing the estimated detection probability function the occurrence rate of planets less than 10 Earth masses around nearby M dwarfs is found to be around two planet per star. The mass of radial velocity M dwarf planets is relatively much lower than the expected mass dependency based on stellar mass and thus it is inferred that planet formation efficiency around low mass stars is relatively impaired. Techniques to overcome the practical issue of obtaining good quality radial velocity data for M dwarfs are considered: (1) the wavelength sensitivity of radial velocity signals, (2) the combination of radial velocity data from different experiments for robust detection of small amplitude signals and (3) optimum selection of targets.

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Contributing team(s): Tuomi, M., Anglada-Escude, G., Feng, F., Butler, R.P., Vogt, S.

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404 – Galaxy Clusters II

404.01 – Strong Lens Models for Massive Galaxy Clusters in the Reionization Lensing Cluster Survey

We present strong lensing models for five galaxy clusters from the Planck SZ cluster catalog as a part of the Reionization Lensing Cluster Survey (RELICS), a program that seeks to constrain the galaxy luminosity function past z~9 by conducting a wide field survey of massive galaxy clusters with HST (GO-14096, PI: Coe). The strong gravitational lensing effects of these clusters significantly magnify background galaxies, which enhances our ability to discover the large numbers of high redshift galaxies at z~9-12 needed to create a representative sample. We use strong lensing models for these clusters to study their mass distribution and magnification, which allows us to quantify the lensing effect on the background galaxies. These models can then be utilized in the RELICS survey in order to identify high redshift galaxy candidates that may be lensed by the clusters. The intrinsic properties of these galaxy candidates can be derived by removing the lensing effect as predicted by our models, which will meet the science goals of the RELICS survey. We use HST WFC3 and ACS imaging to create lensing models for the clusters RXC J0142.9+4438, ACO-2537, ACO-2163, RXCJ2211.7-0349, and ACT-CLJ0102-49151.

Author(s): Catherine Cerny9, Keren Sharon9, Dan A. Coe4, Rachel Paterno-Mahler9, Christine Jones3, Nicole G. Czakon1, Keiichi Umetsu1, Daniel Stark6, Larry D. Bradley4, Michele Trenti8, Traci Johnson9, Marusa Bradac7, William Dawson2, Steven A. Rodney5, Louis-Gregory Strolger4
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Contributing team(s): RELICS Team

404.02 – Mass Distrubtion from Strong Gravitational Lensing of Merging Cluster Abell 2146

The merging cluster Abell 2146 consists of two galaxy clusters that have recently collided close to the plane of the sky. In images from *Chandra X-ray Observatory* there are two distinct shock fronts in the intracluster medium. An unusual feature of one of the clusters is that the peak in the X-ray is leading the brightest cluster galaxy. The dark matter component is coincident with the brightest cluster galaxy (BCG). Shortly after first core passage one would typically expect the dark matter and BCG to lead the X-ray emitting plasma, however, that is not the case with Abell 2146. Strong lensing features were identified on images taken by the *Hubble Space Telescope*. These features were used as constraints on a lens model that maps the matter distribution of the system. We focus on the cluster Abell 2146-A to determine the dark matter centroid near BCG-A and the peak in the X-ray. The results from the strong lensing model indicate the X-ray cool core leads both the dark matter centroid and BCG-A. The dark matter centroid and BCG-A are separated by ≈ 2 kpc. The X-ray peak and dark matter centroid are separated by ≈ 30 kpc.

Author(s): Joseph E. Coleman2, Lindsay J King2, Masamune Oguri3, Helen Russell1
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404.03 – Discovery of Electron Re-Acceleration at Galaxy Cluster Shocks

In a growing number of galaxy clusters elongated Mpc-size radio sources, so-called radio relics, have been found. These relics trace relativistic electrons in the intracluster medium accelerated by collisionless shocks, generated by cluster-cluster merger events. However, cluster merger shocks typically have low Mach numbers and it is therefore unclear how these weak shocks are able to accelerate particles so efficiently, as inferred from the radio luminosity of these relics. A proposed solution to resolve this apparent discrepancy is that cluster shocks re-accelerate a population of fossil relativistic electrons, instead of thermal electrons.

Here we present deep radio and Chandra X-ray observations of the merging cluster A3411-3412. This cluster is known to host a complex-shaped Mpc-size radio relic. In our new GMRT and VLA radio images of the cluster, we find a direct connection between the radio relic and a cluster radio galaxy. From the radio galaxy's nucleus, a tail of radio emission "feeds" into the radio relic located about 90 kpc to its south. At the location of the relic, we find evidence for an X-ray surface brightness edge, consistent with the presence of a weak shock. Therefore, these observations show evidence that fossil relativistic electrons from active galactic nuclei are re-accelerated by weak cluster shocks.

Our study indicates that in order to understand the non-thermal component of the intracluster medium, the presence and distribution of radio galaxies needs to be taken into account, in addition to particle acceleration at shocks. Observations at low radio frequencies, in particular with LOFAR, will be key to unveiling the connections between radio relics and radio AGN, because low-frequency observations are sensitive to synchrotron emission from older fossil radio plasma.

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404.04 – The Fraction of Cool-Core Clusters in X-ray vs. SZ samples using Chandra Observations

We derive and compare the fraction of cool-core clusters in the Planck early Sunyaev-Zel'dovich (ESZ) sample of detected clusters with z ≤ 0.35 and in a flux-limited X-ray sample with z ≤ 0.30, using Chandra observations. We use three metrics to identify the presence of a cool-core: 1) the concentration parameter: the ratio of the integrated surface brightness within 0.15 r_500 to that within r_500 (where r_500 is the radius within which the average density is 500 times the critical value), 2) the cuspiness of the gas density profile: the negative of the logarithmic derivative of the gas density with respect to the radius measured at 0.04 r_500, and 3) the central density, measured at a radius of 10 kpc. We find that the sample of X-ray selected clusters contains a significantly larger fraction of cool-core clusters compared to the sample of SZ selected clusters (62% vs. 30% using the concentration parameter as a metric for cool-cores). Qualitatively, for our X-ray sample, the cool-core clusters are more luminous at fixed mass. Hence, our X-ray flux-limited sample, compared to the approximately mass-limited SZ sample, is over-represented with cool-core clusters. We describe a simple quantitative model that successfully predicts the observed difference based on the selection bias.

Author(s): Felipe Andrade-Santos1, Christine Jones1, William R. Forman1, Lorenzo Lovisari1
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Contributing team(s): Chandra-Planck Collaboration

404.05 – Cool Core Disruption in Abell 1763

We present the analysis of a 20 ksec Chandra archival observation of the massive galaxy cluster Abell 1763. A model-subtracted image highlighting excess cluster emission reveals a large spiral structure winding outward from the core to a radius of ~950 kpc. We measure the gas of the inner spiral to have significantly lower entropy than non-spiral regions at the same radius. This is consistent with the structure resulting from merger-induced motion of the cluster's cool core, a phenomenon seen in many systems. Atypical of spiral-hosting clusters, an intact cool core is not detected. Its absence suggests the system has experienced significant disruption since the initial dynamical encounter that set the sloshing core in motion. Along the major axis of the elongated ICM distribution we detect thermal features consistent with the merger event most likely responsible for cool core disruption. The merger-induced transition towards non-cool core status will be discussed. The interaction between the powerful ($P_{1.4}$ ~ 10^{26} W Hz^{-1}) cluster-center WAT radio source and its ICM environment will also be discussed.

Author(s): Edmund Douglass3, Elizabeth L. Blanton1, Tracy E. Clarke5, Scott W. Randall4, Louise O. V. Edwards2, Ziad Sabry3
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404.07 – Are SZ and X-ray experiments detecting the same population of galaxy clusters?

Galaxy clusters are a powerful tool to constrain cosmological parameters.
An accurate knowledge of the scaling relations between X-ray

observables and cluster mass is a crucial step because it enables us to compare theoretical predictions with the real data and with cosmological models.
Most of the cosmological studies assume that clusters are in equilibrium but if equilibrium relations are applied to merging clusters their masses can be over- or underestimated leading to a systematic bias.
We will show how the cluster properties and morphologies differ for X-ray and SZ selected samples. In particular we will show that the Planck clusters are in general more disturbed than X-ray selected clusters. We derive scaling relations separately for relaxed and disturbed systems. Galaxy clusters with less morphological substructures tend to have shallower scaling relations and smaller scatter.

Author(s): Lorenzo Lovisari[1], Christine Jones[1], Felipe Andrade-Santos[1], William R. Forman[1]
Institution(s): *1. Smithsonian Astrophysical Observatory*

404.08 – Subsonic evolution of the radio bubbles in the nearby massive early-type galaxy NGC 4472: uplift, buoyancy, and heating

We present results from a deep (380 ks) Chandra observation of the hot gas in the nearby massive early-type galaxy NGC 4472. X-ray cavities were previously reported coincident with the radio lobes (Biller *et al.* 2004). In our deeper observation, we confirm the presence of the cavities and detect rims of enhanced emission surrounding the bubbles. The temperature of the gas in these rims is less than that of the ambient medium, demonstrating that they cold, low entropy material that has been drawn up from the group center by the buoyant rise of the bubbles and not shocks from supersonic inflation of the lobes. Interestingly, the gravitational energy required to lift these lobes from the group center is a significant fraction of the bubble enthalpy. This suggests that uplift by AGN bubbles may play an important role in some cases in offsetting the radiative cooling at cluster and group centers. This uplift also provides an efficient means of transporting enriched material from the group center to large radii.

Author(s): Ralph P. Kraft[1], Marie-Lou Gendron Marsolais[2], Akos Bogdan[1], Yuanyuan Su[1], William R. Forman[1], Julie Hlavacek-Larrondo[2], Christine Jones[1], Paul Nulsen[1], Scott W. Randall[1], Elke Roediger3
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404.09 – X-ray Scaling Relations of SPT Selected Galaxy Clusters Observed with XMM-Newton

We will present results of X-ray observations of a sample of 68 South Pole Telescope selected galaxy clusters observed with XMM-Newton. Using X-ray follow-up observations with XMM-Newton, we estimate the temperature, luminosity, and mass of the intracluster medium within R500 for each cluster. From these, we constrain the Mg-Tx, Lx-Tx, and Yx-Mgas scaling relations for a sample of massive clusters at 0.1<z<1.5. I will present the results from this analysis and compare the properties of the SPT sample to those of X-ray-selected samples in the literature

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405 – NASA's 2020 Decadal Studies: An Update

NASA has started preparations to identify the next strategic mission to follow JWST and WFIRST. A community-driven process has indicated that the most likely candidate mission concepts will be a Far-IR (FIR) Surveyor, a Habitable Exoplanet Imager (HabEx), a Large UV, Optical, and IR (LUVOIR) Surveyor, and an X-ray Surveyor. In order to define the mission Concepts for consideration and prioritization by the 2020 Decadal, NASA has assembled four Study and Technology Definition Teams (STDTs) drawing membership from the astrophysics community. STDTs' work has been progressing steadily during the last 9 months, with telecons and face-to-face meetings. This session will report the progress achieved so far as well as providing an opportunity to the astrophysics community at large to give feedback.

405.01 – Origins Space Telescope

The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its spectrographs will enable 3D surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at firsurveyor_info@lists.ipac.caltech.edu. I will summarize the OST STDT, mission design and instruments, key science drivers, and the study plan over the next two years.

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Contributing team(s): Origins Space Telescope Study Team

405.02 – The Habitable Exoplanet (HabEx) Imaging Mission: Preliminary Science Drivers and Technical Requirements

HabEx is one of four candidate flagship missions being studied in detail by NASA, to be submitted for consideration to the 2020 Decadal Survey in Astronomy and Astrophysics for possible launch in the 2030s. It will be optimized for direct imaging and spectroscopy of potentially habitable exoplanets, and will also enable a wide range of general astrophysics science. HabEx aims to fully characterize planetary systems around nearby solar-type stars for the first time, including rocky planets, possible water worlds, gas giants, ice giants, and faint circumstellar debris disks. In particular, it will explore our nearest neighbors and search for signs of habitability and biosignatures in the atmospheres of rocky planets in the habitable zones of their parent stars. Such high spatial resolution, high contrast observations require a large (roughly greater than 3.5m), stable, and diffraction-limited optical space telescope. Such a telescope also opens up unique capabilities for studying the formation and evolution of stars and galaxies. We present some preliminary science objectives identified for HabEx by our Science and Technology Definition Team (STDT), together with a first look at the key challenges and design trades ahead.

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Contributing team(s): Habitable Exoplanet Imaging Mission Science and Technology Definition Team

405.03 – Feryal Ozel: Revealing the Invisible Universe with the Lynx Mission

405.04 – The Large Ultraviolet/Optical/Infrared Surveyor (LUVOIR)

LUVOIR is one of four potential large mission concepts for which the NASA Astrophysics Division has commissioned studies by Science and Technology Definition Teams (STDTs) drawn from the astronomical community. LUVOIR will have an 8 to16-m segmented primary mirror and operate at the Sun-Earth L2 point. It will be designed to support a broad range of astrophysics and exoplanet studies. The notional initial complement of instruments will include 1) a high-performance optical/NIR coronagraph with imaging and spectroscopic capability, 2) a UV imager and spectrograph with high spectral resolution and multi-object capability, 3) a high-definition wide-field optical/NIR camera, and 4) a multi-resolution optical/NIR spectrograph. LUVOIR will be designed for extreme stability to support unprecedented spatial resolution and coronagraphy. It is intended to be a long-lifetime facility that is both serviceable and upgradable. This is the first report by the LUVOIR STDT to the community on the top-level architectures we are studying, including preliminary capabilities of a mission with those parameters. The STDT seeks feedback from the astronomical community for key science investigations that can be undertaken with the notional instrument suite and to identify desirable capabilities that will enable additional key science.

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Contributing team(s): LUVOIR Science and Technology Definition Team

406 – Cosmology III

406.01 – The Distribution of Dark and Luminous Matter in the Galaxy Cluster Merger Abell 2146

Abell 2146 (z = 0.232) consists of two galaxy clusters undergoing a major merger, presenting two large shock fronts on *Chandra* X-ray Observatory maps. These observations are consistent with a collision close to the plane of the sky, caught soon after first core passage. Here we outline the weak gravitational lensing analysis of the total mass in the system, using the distorted shapes of distant galaxies seen with *Hubble Space Telescope*. The highest peak in the mass reconstruction is centred on the brightest cluster galaxy in Abell 2146-A. The mass associated with Abell 2146-B is more extended. The best-fitting mass model with two components has a mass ratio of ~3:1 for the two clusters. From the weak lensing analysis, Abell 2146-A is the primary halo component, and the origin of the apparent discrepancy with the X-ray analysis where Abell 2146-B is the primary halo will be discussed.

Author(s): Lindsay King[4], Douglas Clowe[2], Joseph E. Coleman[4], Helen Russell[6], Rebecca Santana[2], Jacob White[5], Rebecca Canning[3], Nicole Deering[4], Andrew C Fabian[6], Brandyn Lee[4], Baojiu Li[1], Brian R. McNamara[7]
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406.02 – The impact of baryonic matter on gravitational lensing by galaxy clusters

Since the bulk of the matter comprising galaxy clusters exists in the form of dark matter, gravitational N-body simulations have historically been an effective way to investigate large scale structure formation and the astrophysics of galaxy clusters. However, upcoming telescopes such as the Large Synoptic Survey Telescope are expected to have lower systematic errors than older generations, reducing measurement uncertainties and requiring that astrophysicists better quantify the impact of baryonic matter on the cluster lensing signal. Here we outline the effects of baryonic processes on cluster density profiles and on weak lensing mass and concentration estimates. Our analysis is done using clusters grown in the suite of cosmological hydrodynamical simulations known as cosmo-OWLS.

Author(s): Brandyn E Lee[3], Lindsay King[3], Douglas Applegate[2], Ian McCarthy[1]
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406.03 – A Study of the Gamma-Ray Burst Fundamental Plane

A class of long gamma-ray bursts (GRBs) with a plateau phase in their X-ray afterglows obeys a three dimensional (3D) relation (Dainotti et al. 2016), between the rest-frame time at the end of the plateau, T_a, its corresponding X-ray luminosity, L_{a}, and the peak luminosity in the prompt emission, L_{peak}, which is an extension of the two dimensional Dainotti relation. This 3D relation identifies a GRB fundamental plane whose existence we confirmed. We extended the original analysis with X-ray data from July 2014 to July 2016 achieving a total sample of 183 {\it Swift} GRBs with afterglow plateaus and known redshifts. We added the most recent GRBs to the previous `gold sample' (now including 45 GRBs) and obtained an intrinsic scatter compatible within one σ with the previous result. We compared several GRB categories, such as short with extended emission, X-ray Flashes, GRBs associated with SNe, a sample of only long duration GRBs (132), selected from the total sample by excluding GRBs of the previous categories, and the gold sample, composed only by GRBs with light curves with good data coverage and relatively flat plateaus. We evaluated the relation planes for each of the mentioned categories and showed that they are not statistically different from the plane derived from the gold sample and that the fundamental plane derived from the gold sample has an intrinsic scatter smaller than any plane derived from the other sample categories. We compared the jet opening angles tabulated in literature with the angles derived using the $E_{iso}-E_{gamma}$ relation of the method in Pescalli et al. (2015) and calculated the relation plane for a sample of long GRBs accounting for the different jet opening angles. We observed that this correction does not significantly reduce the scatter. In an extended analysis, we found that the fundamental plane is independent from several prompt and afterglow parameters, such as the jet opening angle, θ_{jet}, the prompt emission duration, T_{90}, the peak energy, E_{peak}, and the temporal decay index after the plateau emission, α.

Author(s): Maria Dainotti[4], Christian Gilbertson[5], Sergey Postnikov[1], Shigehiro Nagataki[3], Richard Willingale[2]
Institution(s): *1. Indiana, 2. Leicester, 3. RIKEN, 4. Stanford University, 5. Virginia Tech*

406.04D – RR Lyrae period luminosity relations with Spitzer

RR Lyrae variable stars have long been known to be valuable distance indicators, but only recently has a well defined period luminosity relationship been utilized at infrared wavelengths. In my thesis, I am combining Spitzer Space Telescope data of RR Lyrae stars obtained as part of the Carnegie RR Lyrae Program with ground based NIR data to characterize the period-luminosity-metallicity (PLZ) relation and provide an independent Population II calibration of the cosmic distance scale. I will discuss the ongoing efforts to calibrate this relation using objects such as M4 and NGC 6441 and how the first data release from the Gaia mission impacts our findings. I will also compare my preliminary empirical relations to theoretical PLZ relations derived from stellar pulsation models.

Author(s): Jillian R Neeley[1], Massimo Marengo[1]
Institution(s): *1. Iowa State University*
Contributing team(s): CRRP team

406.05 – Co-evolution of Central Direct Collapse Black Holes and Stellar Populations in the Early Universe

The formation and growth of supermassive black holes (SMBHs) in the centers of galaxies and their role in shaping the evolution of galaxies and their stellar populations is a central topic for cosmology. In order to understand the co-evolution between the SMBHs and the host galaxy dynamics in the early universe we perform cosmological radiation hydrodynamics simulations. These simulations include the unique implementation of the interactions between X-rays and the non-zero metallicity gas. This is particularly important since, as shown by observations, the ambient gas around active galactic nuclei is already enriched by metals at high redshifts. I will present the results from our latest simulations on how X-ray irradiation from an accreting direct collapse seed black hole affects the distribution and evolution of stellar populations in the host galaxy and their possible observational implications.

Author(s): Aycin Aykutalp[1], John Wise[1]
Institution(s): *1. Georgia Institute of Technology*

406.07 – The WFIRST Supernova Survey

WFRIST is expected to launch in the mid 2020s. As part of its main mission, it will conduct a survey to measure the Universe's cosmic expansion history with supernovae. I will present the first simulations of this survey. The simulations take into account our current knowledge of the hardware, realistic properties of the supernovae, and our understanding of the relevant systematic uncertainties. I will compare the ultimate dark enegery figures of merit derived from the simulations and discuss future plans. These data will be extremely useful for other science; other transient science and studies of the resulting deep static images will particularly benefit.

Author(s): Ryan J. Foley[2], Rebekah Hounsell[2], Daniel Scolnic[1]
Institution(s): *1. U Chicago/KICP, 2. UC Santa Cruz*
Contributing team(s): WFIRST Supernova Science Investigation Team

406.08 – Multi-Messenger Time-Domain Astronomy with the Fermi Gamma-ray Burst Monitor

With exciting new detections of gravitational waves by LIGO and astrophysical neutrinos by IceCube and ANTARES, the era of multi-messenger time-domain astronomy has arrived. The Fermi Gamma-ray Burst Monitor (GBM) continuously observes the entire sky that is not occulted by the Earth in gamma-rays from 8 keV - 40 MeV with 2 microsecond temporal resolution, with regular data downlinks every few hours. This wealth of near-realtime all-sky data has lead to the development of continuous data searches for gamma-ray events, such as Gamma-Ray Bursts (GRBs), in coincidence with astrophysical neutrinos and gravitational wave events. Additionally, GBM has the ability to localize triggered and untriggered transient events to a few-degree accuracy, rapidly disseminate the alerts and localization sky maps within tens of seconds, and there have been several successful follow-up attempts by wide-field optical telescopes, such as the Palomar Transient Factory, to catch the fading optical afterglow of GBM-triggered GRBs. We discuss the current applications and importance of Fermi GBM in leading multi-messenger time-domain astronomy in the gamma-ray regime.

Author(s): Valerie Connaughton[1], Adam Goldstein[1]
Institution(s): *1. USRA*
Contributing team(s): Fermi GBM - LIGO group

407 – GW-Stellar Mass BH

407.01D – Temporal Constraints on the Size of Gamma-ray Burst Progenitors and Implications for Gravitational Wave Follow-up

Uncovering the intrinsic variability of Gamma-ray bursts (GRBs), the most energetic explosions since the Big Bang, constrains the size of the GRB emission region, and ejecta velocity, in turn providing hints on the nature of GRBs and their progenitors.
We develop a novel method which ties together wavelet and structure-function analyses to measure, for the first time, the actual minimum variability timescale, Δt_{min}, of GRB light curves. Implementing our technique to the largest sample of GRBs collected by *Swift* and *Fermi* instruments, reveals that only less than 10% of GRBs exhibit evidence for variability on timescales below 2 ms. Investigation on various energy bands of *Fermi*/GBM (spanning 8 keV–1 MeV) shows that the tightest constraints on progenitor radii derive from timescales obtained from the hardest energy channel of light curves (299 –1000 keV). Our derivations for the minimum Lorentz factor, Γ_{min}, and the minimum emission radius, $R = 2\,c\,\Gamma_{min}^2\,\Delta t_{min} / (1+z)$, find $\Gamma \geq 400$ which imply typical emission radii $R \approx 1\times10^{14}$ cm for long-duration GRBs and $R \approx 3\times10^{13}$ cm for short-duration GRBs (sGRBs). This information is served in an online, publicly-accessible table which is automatically updated upon a new GRB trigger event.
Given the possible linkage between sGRBs and Compact Binary Coalescence events, the practical approach to finally detect the Electromagnetic counterparts of *LIGO* triggers is to focus our follow-up resources on sGRBs. Our sGRB selection methodology, a direct measure of the emission region size, along with the implemented vetting algorithm of extracted transient candidates found by an image subtraction code could optimize efficiently *LIGO* follow-up with the *Ground-based Telescopes*.

Author(s): V. Zach Golkhou[1], Nathaniel Butler[1], Owen Littlejohns[1]
Institution(s): *1. ASU*

407.02 – Detectability of GW150914-like events by gravitational microlensing

The recent discovery of gravitational waves from stellar-mass binary black holes (BBHs) provided direct evidence of the existence of these systems. These BBHs would have gravitational microlensing signatures that are, due to their large masses and small separations, distinct from single-lens signals. We apply Bayesian statistics to examine the distinguishability of BBH microlensing events from single-lens events under ideal observing conditions, using modern photometric and astrometric capabilities. Given one year of ideal observations, a source star at the Galactic center, a GW150914-like BBH lens (total mass 65 $M_{\odot}$, mass ratio 0.8) at half that distance, and an impact parameter of 0.4 Einstein radii, we find that BBH separations down to 0.00634 Einstein radii are detectable, which is < 0.00716 Einstein radii, the limit at which the BBH would merge within the age of the universe. We encourage analyses of LSST data to search for similar modulation in all long-duration events, providing a new channel for the discovery of short-period BBHs in our Galaxy.

Author(s): Daniel Eilbott[1], Alexander Riley[1], Jonathan Cohn[1], Michael H. Kesden[1], Lindsay J King[1]
Institution(s): *1. The University of Texas at Dallas*

407.03 – Electromagnetic counterparts to Gravitational Wave events with the Fermi Large Area Telescope

At least a fraction of Gravitational Wave (GW) progenitors is expected to emit an electromagnetic (EM) signal in the form of a short gamma-ray burst (sGRB). The discovery of such a transient EM counterpart is challenging because the LIGO/VIRGO localization region is much larger (several hundreds of square degrees) than the field of view of X-ray, optical and radio telescopes. The Fermi Large Area Telescope (LAT) has a wide field of view (~ 2.4 sr), and detects ~2-3 sGRBs per year above 100 MeV. It can detect them not only during the short prompt phase but also during their long-lasting high-energy afterglow phase. If other wide-field high-energy instruments such as Fermi-GBM, Swift-BAT or INTEGRAL-ISGRI cannot detect or localize with enough precision an EM counterpart during the prompt phase, the LAT can potentially pinpoint it with < 10 arcmin accuracy during the afterglow phase. This routinely happens in the case of gamma-ray bursts. Moreover, the LAT covers the entire localization region within hours of any GW triggers during normal operations, allowing upper bounds to be evaluated. This has been demonstrated in the case of the three known GW events (GW150914, LVT151012, and GW151226). Over the coming years, as LIGO and Virgo approach design sensitivity and will soon be able to detect these mergers, LAT will continue to provide a unique capability to potentially localize and characterize gravitational wave events.

Author(s): Giacomo Vianello3, Nicola Omodei3, Judith L. Racusin[1], Julie E. McEnery[1], James Chiang[2], Sara Buson[1]
Institution(s): *1. NASA/GSFC, 2. SLAC, 3. Stanford University*
Contributing team(s): Fermi LAT collaboration

407.04 – Learning about Black-Hole Formation from Gravitational Waves

The first observing run of the Advanced Laser Interferometer Gravitational-wave Observatory (LIGO) discovered gravitational waves from two binary black-hole mergers. Although astrophysical black holes are simple objects fully characterized by their masses and spins, key features of binary black-hole formation such as mass transfer, natal kicks, and common-envelope evolution can misalign black-hole spins with the orbital angular momentum of the binary. These misaligned spins will precess as gravitational-wave emission causes the black holes to inspiral to separations at which the waves are detectable by observatories like LIGO. Spin precession modulates the amplitude and frequency of the gravitational waves observed by LIGO, allowing it to not only test general relativity but also reveal the secrets of black-hole formation. This talk will briefly describe those elements of binary black-hole formation responsible for initial spin misalignments, how spin precession and radiation reaction in general relativity determine how spins evolve from formation until the black holes enter LIGO's sensitivity band, and how spin-induced gravitational-wave modulation in band can be used as a diagnostic of black-hole formation.

Author(s): Michael H. Kesden[1]
Institution(s): *1. University of Texas at Dallas*

407.05 – LBT in the era of electromagnetic follow-up of gravitational sources

The era of gravitational astronomy has started on September 14, 2015 with the first detection of gravitational waves (GW) by the aLIGO and AdVirgo collaboration.A wealth of additional information on the GW source nature would be provided by its electromagnetic (EM) counterpart, expected to be faint and/or rapidly fading. Wide-field survey telescopes will play a crucial role in the detection of the EM counterpart candidates. Long-term photometry and spectroscopy of detected transients with sensitive telescopes will further characterize each candidate, ultimately confirming the true EM counterpart. Indeed, LBT with its large size, instruments sensitivity and unique "binocular" configuration (i.e. acquire photometry and spectroscopy and/or one optical and one NIR band simultaneously) can play a crucial role in the identification of the EM counterpart of the GW signal. The Italian GRAwitational Wave INAF TeAm (GRAWITA) is participating in a collaborative world wide effort to detect the EM counterparts of GW events. Since May 2015,the team is working to make possible a prompt observational campaign to GW alert and follow-up activity with multiwavelength observing facilities, and in collaboration with ground and space based high energies facilities.

Author(s): Andrea Rossi[1]
Institution(s): *1. INAF/IASFBO*

407.06 – Discriminating Formation Channels of Binary Black Hole Systems with Advanced LIGO

The field of gravitational-wave astronomy has been initiated by the recent observations of binary black hole mergers. These observations illuminate objects that are inaccessible with electromagnetic telescopes, and open inquiries as to how binary black hole systems form and merge. Two possible formation channels proposed for such systems are isolated binary evolution in the galactic field and dynamical formation in star clusters. Currently, the coarse localization of these gravitational-wave events cannot indicate the environment in which the binary formed, and simulations find that the mass distributions and merger rates of the aforementioned formation channels do not have an appreciable difference. However, the component spins of the black holes have the potential to unveil the formation history of the system. In this talk, I will discuss how to match measurements of the black hole component spin alignment with the spin distributions produced by population synthesis simulations of the galactic field and star clusters. Using this framework, we will link black hole spin measurements to the formation channel of a merger, thus leading to a more detailed picture of their environments and origins.

Author(s): Michael Zevin[1], Carl L. Rodriguez[1], Chris Pankow[1], Vassiliki Kalogera[1], Frederic A. Rasio[1]
Institution(s): *1. Northwestern*

407.07D – Constraining Microwave Emission from Extensive Air Showers via the MIDAS Experiment

Ultra high energy cosmic rays (UHECRs) are accelerated by the most energetic processes in the universe. Upon entering Earth's atmosphere they produce particle showers known as extensive air showers (EASs). Observatories like the Pierre Auger Observatory sample the particles and light produced by the EASs through large particle detector arrays or nitrogen fluorescence detectors to ascertain the fundamental properties of UHECRs. The large sample of high quality data provided by the Pierre Auger Observatory can be attributed to the hybrid technique which utilizes the two aforementioned techniques simultaneously; however, the limitation of only being able to observe nitrogen fluorescence from EASs on clear moonless nights yields a limited 10% duty cycle for the hybrid technique. One proposal for providing high quality data at increased statistics is the observation of isotropic microwave emission from EASs, as such emission would be observed with a 100% duty cycle. Measurements of microwave emission from laboratory air plasmas conducted by Gorham et al. (2008) produced promising results indicating that the microwave emission should be observable using inexpensive detectors. The Microwave Detection of Air Showers (MIDAS) experiment was built at the University of Chicago to characterize the isotropic microwave emission from EASs and has collected 359 days of observational data at the location of the Pierre Auger experiment. We have performed a time coincidence analysis between this data and data from Pierre Auger and we report a null result. This result places stringent limits on microwave emission from EASs and demonstrates that the laboratory measurements of Gorham et al. (2008) are not applicable to EASs, thus diminishing the feasibility of using isotropic microwave emission to detect EASs.

Author(s): Matthew Richardson[1], Paolo Privitera[2]
Institution(s): *1. Planetary Science Institute, 2. University of Chicago*

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408 – The Coolest Stars & Brown Dwarfs

408.01 – Precision Spectral Variability of L Dwarfs from the Ground

L dwarf photospheres (1500 K < T < 2500 K) contain mineral and metal condensates, which appear to organize into cloud structures as inferred from observed periodic photometric variations with amplitudes of <1%-30%. Studying the vertical structure, composition, and long-term evolution of these clouds necessitates precision spectroscopic monitoring, until recently limited to space-based facilities. Building on techniques developed for ground-based exoplanet transit spectroscopy, we present a method for precision spectral monitoring of L dwarfs with nearby visual companions. Using IRTF/SpeX, we demonstrate <0.5% spectral variability precision across the 0.9-2.4 micron band, and present results for two known L5 dwarf variables, J0835-0819 and J1821+1414, both of which show evidence of 3D cloud structure similar to that seen in space-based observations. We describe a survey of 30 systems which would sample the full L dwarf sequence and allow characterization of temperature, surface gravity, metallicity, rotation period and orientation effects on cloud structure, composition and evolution.

This research is supported by funding from the National Science Foundation under award No. AST-1517177, and the National Aeronautics and Space Administration under Grant No. NNX15AI75G.

Author(s): Adam J. Burgasser[2], Everett Schlawin3, Johanna K. Teske[1], Theodora Karalidi3, John Gizis4
Institution(s): *1. Carnegie Institute of Washington, 2. UC San Diego, 3. University of Arizona Steward Observatory, 4. University of Delaware*

408.02D – A Survey of Peculiar L and T Dwarfs in a Cross-Correlation of the SDSS, 2MASS and WISE Databases

Brown dwarf atmospheres are complex, hosting a wide variety of molecule and condensate species. With the goal of understanding how surface gravities, metallicities and other unusual cloud properties affect the atmospheric characteristics of ultracool objects, we have carried out a large program to identify peculiar brown dwarfs in the SDSS, 2MASS and WISE catalogs based on their optical and infrared colors. From this program we have uncovered a number of unusually red and blue brown dwarfs along with several candidate binaries. One of the most notable outcomes is the discovery of one of the brightest young, planetary-mass brown dwarfs known to date: 2MASS J11193254-1137466. With this systematic search for peculiar brown dwarfs, we have been able to shed light on the full range of atmospheric properties of L and T dwarfs and aim to constrain the population properties and evolutionary paths of substellar objects.

Author(s): Kendra Kellogg[1], Stanimir A. Metchev[1]
Institution(s): *1. Western University*

408.03D – Atmospheric Properties of T Dwarfs Inferred from Model Fits at Low Spectral Resolution as Exoplanet Atmosphere Analogs

Exoplanet direct detections are reaching the temperature regime of cool brown dwarfs, motivating further understanding of the coolest substellar atmospheres. These objects, T and Y dwarfs, are numerous and isolated in the field, thus making them easier to study in detail than objects in companion systems. Brown dwarf spectral types are derived from spectral morphology and generally appear to correspond with decreasing mass and effective temperature (Teff). However, spectral subclasses of the colder objects do not share this monotonic temperature correlation, indicating that secondary parameters (gravity, metallicity, dust) significantly influence spectral morphology. These secondary atmospheric parameters can provide insight into age and formation mechanism. We seek to disentangle the fundamental parameters that underlie the spectral morphology of T dwarfs, the coolest fully populated spectral class of brown dwarfs, using comparisons to atmospheric models. We investigate the relationship between spectral type and Teff from the best fit model parameters for a sample of 152 T dwarfs with low resolution (R~75-100) near-infrared SpeX Prism spectra. We use synthetic spectra from four model grids (Saumon & Marley 2008, Morley+ 2012, Saumon+ 2012, and BT Settl 2013) and a Markov-Chain Monte Carlo (MCMC) analysis to determine robust best fit parameters with uncertainties. To evaluate the consistency of each model grid, we perform our analysis on the full spectrum and on narrower wavelength ranges where directly detected exoplanets are typically characterized. We provide foundational assessments of the factors that affect T dwarf spectral morphology to prescribe the best approach to interpreting spectra of cool substellar objects. Using T dwarfs as exoplanet analogs, we create spectral templates from observed spectra for comparison to cool companion spectra of high contrast imaged objects. Our analysis of these proof-of-concept cases provide the backbone for interpreting spectra for some of the benchmark companion objects found with today's exoplanet imagers. Our analysis is the most extensive T dwarf model comparison to date, thereby laying the foundation for interpretation of cool brown dwarf and exoplanet spectra.

Author(s): Paige A. Godfrey[1]
Institution(s): *1. The Graduate Center at the City University of New York*

408.04 – Variable and Polarized Radio Emission from a T6 Brown Dwarf

Route & Wolszczan (2016) recently detected five radio bursts from the T6 brown dwarf WISEP J112254.7+255021.5 and used the timing of these events to propose that this object rotates with an ultra-short period of ~17.3 minutes. We conducted follow-up observations with the Very Large Array and Gemini-North but found no evidence for this periodicity. We do, however, observe variable, highly circularly polarized radio emission possibly with a period of 116 minutes, although our observation lasted only 162 minutes and so more data are needed to confirm it. Our proposed periodicity is typical of other radio-active ultracool dwarfs. The handedness of the circular polarization alternates with time and there is no evidence for any unpolarized emission component, the first time such a phenomenology has been observed in radio studies of very low-mass stars and brown dwarfs. We suggest that the object's magnetic dipole axis may be highly misaligned relative to its rotation axis.

Author(s): Peter K. G. Williams[1], John Gizis[2], Edo Berger[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. University of Delaware*

408.05 – Parallaxes for 21 late-T and Y dwarfs in the Spitzer Parallax Program

We present parallaxes and proper motions for 21 late-type T and Y dwarfs in the Spitzer Parallax Program (PI: Kirkpatrick). The Spitzer Parallax Program targets all T6 and later dwarfs within the nearest 20pc to produce a volume-limited sample of the coldest brown dwarfs in the solar neighborhood. Measuring distances to the coldest brown dwarfs is an essential step towards completing the census of objects in the solar neighborhood and will aid in our understanding of the low-mass end of the field mass function. We used images from Spitzer's IRAC channel 2 taken at maximum parallax factor over multiple epochs to determine astrometric fits to each object. Centroiding was performed using APEX/MOPEX with a custom warm-mission Point Response Function and 5th order distortion correction, provided by the Spitzer Science Center. We present first-time distance measurements for 6 newly identified late-T and Y dwarfs in our sample and further constrain distances to 15 others. Our high-quality distance measurements allow us to improve the spectral type vs. absolute magnitude and color vs. absolute magnitude relations for these ultracool dwarfs and further highlight a peculiar Y dwarf outlier.

Author(s): Emily Martin[6], J. Davy Kirkpatrick[2], Charles A. Beichman3, Richard L Smart4, Patrick Lowrance[2], James G. Ingalls[2], Michael Cushing5, Edward L. Wright[6], Jacqueline K. Faherty[1], Christopher R. Gelino[2], Ian S. McLean[6], Sarah E. Logsdon[6], Christopher G. Tinney7
Institution(s): *1. Carnegie Institute of Washington, 2. IPAC, 3. NExSci, 4. OATO, 5. U Toledo, 6. UCLA, 7. University of New South Wales*

408.06D – Constraining Substellar Magnetic Dynamos using Auroral Radio Emission

An important outstanding problem in dynamo theory is understanding how magnetic fields are generated and sustained in fully convective stellar objects. A number of models for possible dynamo mechanisms in this regime have been proposed but constraining data on magnetic field strengths and topologies across a wide range of mass, age, rotation rate, and temperature are sorely lacking, particularly in the brown dwarf regime. Detections of highly circularly polarized pulsed radio emission provide our only window into magnetic field measurements for objects in the ultracool brown dwarf regime. However, these detections are very rare; previous radio surveys encompassing ~60 L6 or later targets have yielded only one detection.

We have developed a selection strategy for biasing survey targets based on possible optical and infrared tracers of auroral activity. Using our selection strategy, we previously observed six late L and T dwarfs with the Jansky Very Large Array (VLA) and detected the presence of highly circularly polarized radio emission for five targets. Our initial detections at 4-8 GHz provided the most robust constraints on dynamo theory in this regime, confirming magnetic fields >2.5 kG. To further develop our understanding of magnetic fields in the ultracool brown dwarf mass regime bridging planets and stars, we present constraints on surface magnetic field strengths for two Y-dwarfs as well as higher frequency observations of the previously detected L/T dwarfs corresponding ~3.6 kG fields. By carefully comparing magnetic field measurements derived from auroral radio emission to measurements derived from Zeeman broadening and Zeeman Doppler imaging, we provide tentative evidence that the dynamo operating in this mass regime may be inconsistent with predicted values from currently in vogue models.

This suggests that parameters beyond convective flux may influence magnetic field generation in brown dwarfs.

Author(s): Melodie Kao[1], Gregg Hallinan[1], J. Sebastian Pineda[1], Ivanna Escala[1], Adam J. Burgasser[2], David J. Stevenson[1]
Institution(s): *1. California Institute of Technology, 2. University of California San Diego*

409 – Statistical, Mathematical & Computational Methods for Astronomy (ASTRO): SAMSI 2016-17

Statistical and Applied Mathematical Sciences Institute (SAMSI), a National Science Foundation funded institute in Research Triangle Park, NC, is organizing a year-long research (Aug 2016- May 2017) program on Statistical, Mathematical and Computational Methods for Astronomy (ASTRO). This program will bring together astronomers, computer scientists, applied mathematicians and statisticians. The main aims are: to foster cross¬disciplinary activities; to accelerate the adoption of modern statistical and mathematical tools into modern astronomy; and to develop new tools needed for important astronomical research problems. This is timely given the flood of data into astronomy from ground- and space-based missions at multiple wavelengths. Interpretation of the resulting complex data require diverse statistical and mathematical methods. Mapping appropriate methods when confronting large datasets is crucial. Astronomical themes identified by SAMSI include cosmology, exoplanets, gravitational waves and synoptic surveys. Each of the astronomical sub-fields could benefit from improved time series analysis, hierarchical modeling, uncertainty quantification, reduced order modeling and inference with misspecified models and will be addressed. The SAMSI program is working on establishing some working groups viz. I: Uncertainty Quantification and Reduced Order Modeling in Gravitation, Astrophysics, and Cosmology, II: Synoptic Time Domain Surveys, III: Time Series Analysis for Exoplanets & Gravitational Waves: Beyond Stationary Gaussian Processes, IV: Population Modeling & Signal Separation for Exoplanets & Gravitational Waves, V: Statistics, computation, and modeling in cosmology. Collaborating scientists spend extended periods (weeks to a semester) of time at SAMSI and meet regularly via webex/telecon throughout the year.

409.01 – Overview of the SAMSI year-long program on Statistical, Mathematical and Computational Methods for Astronomy

A year-long research (Aug 2016- May 2017) program on `*Statistical, Mathematical and Computational Methods for Astronomy (ASTRO)*' is well under way at **Statistical and Applied Mathematical Sciences Institute (SAMSI),** a National Science Foundation research institute in Research Triangle Park, NC. This program has brought together astronomers, computer scientists, applied mathematicians and statisticians. The main aims of this program are: to foster cross-disciplinary activities; to accelerate the adoption of modern statistical and mathematical tools into modern astronomy; and to develop new tools needed for important astronomical research problems. The program provides multiple avenues for cross-disciplinary interactions, including several workshops, long-term visitors, and regular teleconferences, so participants can continue collaborations, even if they can only spend limited time in residence at SAMSI. The main program is organized around five working groups:
i) Uncertainty Quantification and Astrophysical Emulation;
ii) Synoptic Time Domain Surveys;
iii) Multivariate and Irregularly Sampled Time Series;
iv) Astrophysical Populations;
v) Statistics, computation, and modeling in cosmology.

A brief description of each of the work under way by these groups will be given. Overlaps among various working groups will also be highlighted. How the wider astronomy community can both participate and benefit from the activities, will be briefly mentioned.

Author(s): G. Jogesh Babu[1]
Institution(s): *1. Penn State University*

409.02 – Statistical Methods for Characterizing Variability in Stellar Spectra

Recent years have seen a proliferation in the number of exoplanets discovered. One technique for uncovering exoplanets relies on the detection of subtle shifts in the stellar spectra due to the Doppler effect caused by an orbiting object. However, stellar activity can cause distortions in the spectra that mimic the imprint of an orbiting exoplanet. The collection of stellar spectra potentially contains more information than is traditionally used for estimating its radial velocity curve. I will discuss some statistical methods that can be used for characterizing the sources of variability in the spectra. Statistical assessment of stellar spectra is a focus of the Statistical and Applied Mathematical Sciences Institute (SAMSI)'s yearlong program on Statistical, Mathematical and Computational Methods for Astronomy's Working Group IV (Astrophysical Populations).

Author(s): Jessi Cisewski[1]
Institution(s): *1. Yale University*
Contributing team(s): Yale Astrostatistics

409.03 – Statistics, Computation, and Modeling in Cosmology

Current and future ground and space based missions are designed to not only detect, but map out with increasing precision, details of the universe in its infancy to the present-day. As a result we are faced with the challenge of analyzing and interpreting observations from a wide variety of instruments to form a coherent view of the universe. Finding solutions to a broad range of challenging inference problems in cosmology is one of the goals of the “Statistics, Computation, and Modeling in Cosmology” workings groups, formed as part of the year long program on ‘Statistical, Mathematical, and Computational Methods for Astronomy’, hosted by the Statistical and Applied Mathematical Sciences Institute (SAMSI), a National Science Foundation funded institute. Two application areas have emerged for focused development in the cosmology working group involving advanced algorithmic implementations of exact Bayesian inference for the Cosmic Microwave Background, and statistical modeling of galaxy formation. The former includes study and development of advanced Markov Chain Monte Carlo algorithms designed to confront challenging inference problems including inference for spatial Gaussian random fields in the presence of sources of galactic emission (an example of a source separation problem). Extending these methods to future redshift survey data probing the nonlinear regime of large scale structure formation is also included in the working group activities. In addition, the working group is also focused on the study of ‘Galacticus’, a galaxy formation model applied to dark matter-only cosmological N-body simulations operating on time-dependent halo merger trees. The working group is interested in calibrating the Galacticus model to match statistics of galaxy survey observations; specifically stellar mass functions, luminosity functions, and color-color diagrams. The group will use subsampling approaches and fractional factorial designs to statistically and computationally efficiently explore the Galacticus parameter space. The group will also use the Galacticus simulations to study the relationship between the topological and physical structure of the halo merger trees and the properties of the resulting galaxies.

Author(s): Jeff Jewell[1], Joe Guiness[2]
Institution(s): *1. NASA JPL, 2. North Carolina State University*
Contributing team(s): SAMSI 2016 Working Group in Cosmology

409.04 – Statistical and Mathematical Methods for Synoptic Time Domain Surveys

Recent advances in detector technology, electronics, data storage, and computation have enabled astronomers to collect larger and larger datasets, and moreover, pose interesting questions to answer with those data. The complexity of the data allows data science techniques to be used. These have to be grounded in sound techniques. Identify interesting mathematical and statistical challenges and working on their solutions is one of the aims of the year-long ‘Statistical, Mathematical and Computational Methods for Astronomy (ASTRO)’ program of SAMSI. Of the many working groups that have been formed, one is on Synoptic Time Domain Surveys. Within this we have various subgroups discussing topics such as Designing Statistical Features for Optimal Classification, Scheduling Observations, Incorporating Unstructured Information, Detecting Outliers, Lightcurve Decomposition and Interpolation, Domain Adaptation, and also Designing a Data Challenge. We will briefly highlight some of the work going on in these subgroups along with their interconnections, and the plans for the near future. We will also highlight the overlaps with the other SAMSI working groups and also indicate how the wider astronomy community can both participate and benefit from the activities.

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Contributing team(s): SAMSI Synoptic Surveys Time Domain Working Group

410 – Supernovae & Remnants

410.01 – Type Iax Supernovae

In recent years we have learned that not all white dwarf supernovae are normal type Ia supernovae (SN Ia). The largest class of "peculiar" white dwarf supernovae are type Iax supernovae (SN Iax), with prototypes like SN 2002cx and SN 2005hk. We will describe recent Hubble Space Telescope observations of the SN Iax 2012Z, the only white dwarf supernova with a pre-explosion detection of a progenitor system. Surprisingly, our understanding of the progenitors and explosions of SN Iax may actually be more certain than our understanding for normal SN Ia.

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Institution(s): *1. Las Cumbres Observatory Global Telescope, 2. Rutgers University, 3. University of California Santa Cruz*

410.02 – Near-infrared absolute magnitudes of Type Ia Supernovae

Type Ia Supernovae light curves (SN Ia) in the near infrared (NIR) exhibit low dispersion in their peak luminosities and are less vulnerable to extinction by interstellar dust in their host galaxies. The increasing number of high quality NIR SNe Ia light curves, including the recent CfAIR2 sample obtained with PAIRITEL, provides updated evidence for their utility as standard candles for cosmology. Using NIR YJHKs light curves of ~150 nearby SNe Ia from the CfAIR2 and CSP samples, and from the literature, we determine the mean value and dispersion of the absolute magnitude in the range between -10 to 50 rest-frame days after the maximum luminosity in B band. We present the mean light-curve templates and Hubble diagram for YJHKs bands. This work contributes to a firm local anchor for supernova cosmology studies in the NIR which will help to reduce the systematic uncertainties due to host galaxy dust present in optical-only studies. This research is supported by NSF grants AST-156854, AST-1211196, Fundacion Mexico en Harvard, and CONACyT.

Author(s): Arturo Avelino[1], Andrew S. Friedman[2], Kaisey Mandel[1], Robert Kirshner[1], Peter Challis[1]
Institution(s): *1. Harvard University, 2. MIT*

410.03D – Interstellar-medium Mapping in M82 and Circumstellar Environment Constraints through Light Echoes Around Supernova 2014J

We present multiple-epoch measurements of the size and surface brightness of the light echoes from supernova (SN) 2014J in the nearby starburst galaxy M82. Hubble Space Telescope (HST) ACS/WFC images were taken ~277 and ~416 days after B-band maximum in the filters F475W, F606W, and F775W. Linear polarimetry of the SN 2014J has also been acquired. The images reveal the temporal evolution of at least two major light-echo components. The first one exhibits a filled ring structure with position-angle-dependent intensity. This radially extended, diffuse echo indicates the presence of an inhomogeneous interstellar dust cloud ranging from ~100 pc to ~500 pc in the foreground of the SN. The second echo component appears as an unresolved luminous quarter-circle arc centered on the SN. The wavelength dependence of scattering measured in different dust components suggests that the dust producing the luminous arc favors smaller grain sizes, while that causing the diffuse light echo may have sizes similar to those of the Milky Way dust. Smaller grains can produce an optical depth consistent with that along the supernova-Earth line of sight measured by previous studies around maximum light. Therefore, it is possible that the dust slab, from which the luminous arc arises, is also responsible for most of the extinction towards SN 2014J. The optical depths produced by the diffuse Milky Way-like dust in the scattering matters are lower than that produced by the dust slab. Apart from the resolved light echoes, the polarization of the SN 2014J point source measured at day 277 shows conspicuous deviations from other epochs and this can be identified as due to at least 10^{-6} M_{sun} of dust located at a distance of ~5×10^{17} cm away from the SN. The presence of this CS dust may set strong constraints on the progenitor system that led to the explosion of SN 2014J.

Author(s): Yi Yang[1], Lifan Wang[1]
Institution(s): *1. Texas A&M University*

410.04 – The Three-Dimensional Motions of the Ejecta of Tycho's Supernova Remnant

We present the first three-dimensional measurements of the velocity of various ejecta knots in Tycho's supernova remnant, the remains of SN 1572, known to be a Type Ia explosion. When the ejecta knots pass through the reverse shock, they become heated to X-ray emitting temperatures, and Chandra's unmatched spatial resolution combined with the small age of this remnant allows us to watch it expand on measurable timescales. By combining a new epoch of 2015 Chandra X-ray observations with a previous 2003 epoch, we have a 12-year baseline over which we can measure proper motions from nearly 60 "tufts" of Si-rich ejecta, giving us the velocity in the plane of the sky. For the line of sight velocity, we use two different methods: a non-equilibrium ionization model fit to the strong Si and S lines in the 1.2-2.8 keV regime, and a fit consisting of a series of Gaussian lines. These methods give consistent results, and allow us to determine the red or blue shift of each of the knots, and thus, the third dimension of the velocity vector. Assuming a distance of 3.5 kpc, we find total velocities that range from roughly 2400 to 6600 km/s, with mean and median values of 4429 and 4450 km/s, respectively. In the plane of the sky, we find several regions where the ejecta knots have overtaken the forward shock. These regions have proper motions in excess of 6000 km/s. Some Type Ia supernova explosion models predict a velocity asymmetry in the ejecta, where the ejecta on one side of the remnant is moving faster than another side. We find no such velocity asymmetries in Tycho, and discuss our findings in light of various explosion models. Our previous work has shown an asymmetry in the velocity of the forward shock, with speeds in the southwest being significantly higher than those in the northeast. We have attributed this to a measured density gradient in the ISM, and not an asymmetry in the explosion. We compare our measurements with hydrodynamic simulations to show how the forward shock and ejecta expand in such an environment.

Author(s): Brian J. Williams[2], Nina Coyle5, Hiroya Yamaguchi[2], Joseph M. DePasquale[1], John W. Hewitt[6], John M. Blondin3, Kazimierz J. Borkowski3, Parviz Ghavamian[4], Robert Petre[2], Stephen P. Reynolds3
Institution(s): *1. Harvard-Smithsonian CfA, 2. NASA Goddard, 3. North Carolina State University, 4. Towson University, 5. University of Chicago, 6. University of North Florida*

410.05 – A new set of supernova remnant distances for

the inner Galaxy

We derive new distances for supernova remnants using 1420 MHz continuum and HI observations from the VGPS survey, supplemented with
CO line survey observations. The new distances yield a wide spread in the sigma-D relation, confirming previous studies that hint that the sigma-D relation is not useful for deriving distances. We assess the incompleteness of detection of radio supernova remnants, and compare
to the well-measured stellar population measurements in the Galaxy to infer a new value for the supernova rate. We also assess the evolutionary states of the individual supernova remnants.

Author(s): Denis A. Leahy[1], Sujith Ranasinghe[1]
Institution(s): *1. Univ. of Calgary*

410.06 – The Unprecedented Metamorphosis of Supernova 2014C: New Insights from New Observations by HST and Gemini

Recent observations of major eruptions preluding supernova explosions within one year of core collapse have challenged long held notions of stellar evolution. These eruptions are not easily explained by our current understanding of the physical mechanisms that drive mass loss in evolved massive stars, and may have significant ramifications for fields of research that depend on the predictions of stellar evolution models. Our group recently discovered a remarkable event — SN 2014C — in the nearby spiral galaxy NGC 7331 (D ~ 15.8 Mpc) whose classification underwent a metamorphosis from a hydrogen-poor type Ib explosion to a hydrogen-rich type IIn. The transformation was the result of a rarely observed delayed interaction between a stripped-envelope supernova and a massive shell of circumstellar material located ~5×10^{16} cm from the explosion site. Here we present new observations of SN 2014C obtained with the Hubble Space Telescope and the Gemini-N telescope that are part of a larger multi-wavelength Chandra/NuSTAR/VLA/SMA monitoring campaign. Our late-time ultraviolet/optical/near-infrared spectroscopy probes the composition, density, temperature, and speed of the emitting gas, and our high-resolution ultraviolet/optical images map out the nearby stellar environment. We find that the mass loss experienced by the progenitor system was strongly asymmetric, and that it was potentially driven by interaction between the progenitor star and a close binary companion. Our work supports the view that delays of ~1000 yr between eruptive mass loss and core collapse are possible in massive stars that have been stripped of their hydrogen envelopes.

Author(s): Dan Milisavljevic[1], Daniel Patnaude[1], Raffaella Margutti[3], Atish Kamble[1], John C. Raymond[1], Michael Bietenholz[6], Jerod Parrent[1], Robert Kirshner[1], Peter Challis[1], Claes Fransson[4], Wen-fai Fong[5], Ashley Zauderer[2]
Institution(s): *1. Harvard-Smithsonian, CfA, 2. New York University, 3. Northwestern University, 4. Stockholm University, 5. University of Arizona, 6. York University*

410.07 – Critical Resolution and Physical Dependenices of Supernovae: Stars in Heat and Under Pressure

For over five decades, the mechanism of explosion in core-collapse supernova continues to remain one of the last untoppled bastions in astrophysics, presenting both a technical and physical problem.

Motivated by advances in computation and nuclear physics and the resilience of the core-collapse problem, collaborators Adam Burrows (Princeton), Joshua Dolence (LANL), and Aaron Skinner (LNL) have developed FORNAX - a highly parallelizable multidimensional supernova simulation code featuring an explicit hydrodynamic and radiation-transfer solver.

We present the results (Vartanyan et. al 2016, Burrows et. al 2016, both in preparation) of a sequence of two-dimensional axisymmetric simulations of core-collapse supernovae using FORNAX, probing both progenitor mass dependence and the effect of physical inputs in explosiveness in our study on the revival of the stalled shock via the neutrino heating mechanism. We also performed a resolution study, testing spatial and energy group resolutions as well as compilation flags. We illustrate that, when the protoneutron star bounded by a stalled shock is close to the critical explosion condition (Burrows & Goshy 1993), small changes of order 10% in neutrino energies and luminosities can result in explosion, and that these effects couple nonlinearly.

We show that many-body medium effects due to neutrino-nucleon scattering as well as inelastic neutrino-nucleon and neutrino-electron scattering are strongly favorable to earlier and more vigorous explosions by depositing energy in the gain region. Additionally, we probe the effects of a ray-by-ray+ transport solver (which does not include transverse velocity terms) employed by many groups and confirm that it artificially accelerates explosion (see also Skinner et. al 2016).

In the coming year, we are gearing up for the first set of 3D simulations yet performed in the context of core-collapse supernovae employing 20 energy groups, and one of the most complete nuclear physics modules in the field with the ambitious goal of simulating supernova remants like Cas A. The current environment for core-collapse supernova provides for invigorating optimism that a robust explosion mechanism is within reach on graduate student lifetimes.

Author(s): David Vartanyan[1], Adam Seth Burrows[1]
Institution(s): *1. Princeton University*

410.08 – The Role of Waves in the Explosion Mechanism of Core-Collapse Supernovae

The core-collapse supernova (CCSN) explosion mechanism is not well understood. For garden variety CCSNe, the favored scenario for explosion is delayed revival of the stalled shock powered by neutrino-driven convection. Despite tremendous computational advances, many simulations must use parameterized 'light-bulb' models for neutrino heating or mask out inner regions of the proto-neutron star (PNS) for computational efficiency. These approximations can fail to capture hydrodynamical processes in the core of the PNS where nearly all the binding energy resides, and from which much of the explosion energy may originate. We show that gravity (buoyancy) waves excited by core PNS convection (within the central 20 km of the PNS) may represent a significant heating source for the post-shock region. The gravity waves propagate out of the PNS and transform into acoustic waves before depositing their energy at the shock, converting a small fraction of the PNS binding energy into explosion energy. Using 1D simulations, we calculate the wave heating rate in the post-shock region out to one second after core bounce, showing that wave heating rates in excess of 10^{51} erg/s may persist for several hundreds of milliseconds, even after neutrino heating rates have declined to smaller values. Waves excited by PNS convection may therefore significantly contribute to shock revival and, subsequently, a successful and energetic explosion. We discuss how simulations can miss the effect of waves (or have not recognized them), and how future simulations can more accurately quantify wave heating rates.

Author(s): Sarah Gossan[1], Jim Fuller[1], Luke Roberts[2]
Institution(s): *1. California Institute of Technology, 2. Michigan State University*

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411 – Astronomy Education Across the Human Continuum: Research, Programs, Practice, & More!

411.01 – Middle School Teacher Misconceptions and Anxieties Concerning Space Science Disciplinary Core Ideas in NGSS

The Disciplinary Core Ideas (DCI) of the Next Generation Science Standards (NGSS) are grouped into the broad disciplinary areas of Physical Sciences, Life Sciences, Earth and Space Sciences, and

Engineering, Technology and Application of Science, and feature learning progressions based on endpoint targets for each grade band. Since the Middle School DCIs build on the expected learning achievements to be reached by the end of Fifth Grade, and High School DCI similarly build on the expected learning achievements expected for the end of Eighth Grade, the Middle School grade band is of particular importance as the bridge between the Elementary and High School curriculum. In states where there is not a special Middle School Certification many of these science classes are taught by teachers prepared to teach at the Elementary level (and who may have limited content background). As a result, some pre-service and in-service teachers have expressed reduced self-confidence in both their own science content knowledge and their ability to apply it in the NGSS-based classroom, while decades of research has demonstrated the pervasiveness of science misconceptions among teachers. Thus the adoption of NGSS has the potential to drive talented teachers out of the profession who feel that they are ill-prepared for this sweeping transition. The key is providing rigorous education in both content and pedagogy for pre-service teachers and quality targeted professional development for in-service teachers. This report focuses on the Middle School Space Sciences grade band DCIs and presents research on specific difficulties, misconceptions and uncertainties with the material demonstrated by pre-service education students over the past four years in a required university science content course, as well as two year-long granted workshop series for current Middle School teachers. This information is relevant to the development of both new content courses aligned with NGSS for pre-service teachers and professional development for in-service teachers.

Author(s): Kristine Larsen[1]
Institution(s): *1. Central Connecticut State University*

411.02 – Analyzing Tibetan Monastic Conceptions of the Universe Through Individual Drawings

Every culture and tradition has its own representation of the universe that continues to evolve due to the influence of new technologies, discoveries, and cultural exchanges. With the recent introduction of Western science into the Tibetan Buddhist monasteries in India, this study explores monastic conceptions of the universe prior to formal instruction in astronomy. The drawings of 59 Buddhist monks and nuns were analyzed using Tversky's three criteria for drawing analysis—segmentation, order, and hierarchical structure of knowledge. We found that 22 out of 59 monastics drew a geocentric model of the universe with the Solar System as the dominant physical system, reflecting little influence of modern astronomical knowledge. Only six monastics drew the traditional Buddhist model of the world, generally known as the Mount Meru Cosmology. The implication of the monastics' representation of the universe for their assimilation into modern science is discussed.

Author(s): Tenzin Sonam[1], Chris David Impey[1]
Institution(s): *1. university of arizona*

411.03 – Educating the Public about the 2017 Total Solar Eclipse

On behalf of the International Astronomical Union's Working Group on Solar Eclipses, I have long worked to bring knowledge about eclipses and how to observe the safely to the people of the various countries from which partial, annular, or total solar eclipses are visible. In 2017, we have first a chance to educate the people of South America on the occasion of the February 26 annular eclipse through southern Chile and Argentina that is partial throughout almost the entire continent (and an eclipse workshop will be held February 22-24 in Esquel, Argentina: http://sion.frm.utn.edu.ar/WDEAII) and then a chance to educate the 300 million people of the United States and others in adjacent countries as far south as northern South America about the glories of totality and how to observe partial phases. Our website, a compendium of links to information about maps, safe observing, science, and more is at http://eclipses.info. We link to important mapping sites at EclipseWise.com, GreatAmericanEclipse.com, and http://xjubier.free.fr/en/site_pages/solar_eclipses/xSE_GoogleMap3.php?Ecl=+20170821&Acc=2&Umb=1&Lmt=1&Mag=1&Max=1, and information about cloudiness statistics at http://eclipsophile.com, as well as simulation sites at https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4314 and http://eyes.jpl.nasa.gov. The American Astronomical Society's task force on the 2017 eclipse has a website at http://eclipse.aas.org. We are working to disseminate accurate information about how and why to observe the total solar eclipse, trying among other things to head off common misinformation about the hazards of looking at the sun at eclipses or otherwise. About 12 million Americans live within the 70-mile-wide band of totality, and we encourage others to travel into it, trying to make clear the difference between even a 99% partial eclipse and a total eclipse, with its glorious Baily's beads, diamond rings, and totality that on this occasion lasts between 2 minutes and 2 minutes 40 seconds on the centerline. Our research on the 2017 total solar eclipse is supported by grants from the Committee for Research and Exploration of the National Geographic Society and from the Solar Terrestrial Program of the Atmospheric and Geospace Sciences Division of the National Science Foundation.

Author(s): Jay M. Pasachoff[1]
Institution(s): *1. Williams College*

411.04 – NASA's Universe of Learning: Connecting Scientists, Educators, and Learners

NASA's Universe of Learning (UoL) is one of 27 competitively awarded education programs selected by NASA's Science Mission Directorate (SMD) in its newly restructured education effort. Through these 27 programs, SMD aims to infuse NASA science experts and content more effectively and efficiently into learning environments serving audiences of all ages. UoL is a unique partnership between the Space Telescope Science Institute, Chandra X-ray Center, IPAC at Caltech, Jet Propulsion Laboratory Exoplanet Exploration Program, and Sonoma State University that will connect the scientists, engineers, science, technology and adventure of NASA Astrophysics with audience needs, proven infrastructure, and a network of partners to advance SMD education objectives. External evaluation is provided through a partnership with Goodman Research Group and Cornerstone Evaluation Associates. The multi-institutional team is working to develop and deliver a unified, consolidated and externally evaluated suite of education products, programs, and professional development offerings that spans the full spectrum of NASA Astrophysics, including the Cosmic Origins, Physics of the Cosmos, and Exoplanet Exploration themes. Products and programs focus on out-of-school-time learning environments and include enabling educational use of Astrophysics mission data and offering participatory experiences; creating multimedia and immersive experiences; designing exhibits and community programs; and producing resources for special needs and underserved/underrepresented audiences. The UoL team also works with a network of partners to provide professional learning experiences for informal educators, pre-service educators, and undergraduate instructors. This presentation will provide an overview of the UoL team's approach to partnering scientists and educators to engage learners in Astrophysics discoveries and data; progress to date; and pathways for science community involvement.

Author(s): Denise A. Smith[7], Kathleen Lestition[5], Gordon K. Squires[3], W. M Greene[4], Anya A Biferno[4], Lynn R. Cominsky[6], Irene Goodman[2], Allyson Walker[1]
Institution(s): *1. Cornerstone Evaluation Associates, 2. Goodman Research Group, 3. IPAC at Caltech, 4. Jet Propulsion Laboratory, 5. Smithsonian Astrophysical Observatory, 6. Sonoma State University, 7. STScI*
Contributing team(s): Universe of Learning Team

411.05 – Astrophysics for Older adults in Chicago.

Gerontology research continues to show that the adage "Use it or Lose it" is a clinical fact when it comes to cognitive engagement post-retirement. Here, I'll discuss a new program developed at the Kavli Institute for Cosmological Physics, bringing classes on astrophysics to older adults throughout the city, at retirement homes, at senior center, and at public libraries, bookended by an engaging trip to the Adler Planetarium. In my presentation, I'll present the gerontological and policy motivations for this program, the presenter training techniques, our partner collaboration strategy, and the results of our effort, which engaged hundreds of older adults throughout Chicago from a variety of socioeconomic strata.

Author(s): Daniel Grin[2], Randall H. Landsberg3, Karen Flude[1]
Institution(s): *1. Age with Ease, 2. Haverford College, 3. University of Chicago*

411.06 – Bringing the Science of JWST to the Public

The James Webb Space Telescope is the successor to the Hubble Space Telescope. STScI and the Office of Public Outreach are committed to bringing awareness of the technology, the excitement, and the future science potential of this great observatory to the public and to the scientific community, prior to its 2018 launch. The challenges in ensuring the high profile of JWST (understanding the infrared, the vast distance to the telescope's final position, and the unfamiliar science territory) requires us to lay the proper background, particularly in the area of spectroscopy. We currently engage the full range of the public and scientific communities using a variety of high impact, memorable initiatives, in combination with modern technologies to extend reach, linking the science goals of Webb to the ongoing discoveries being made by Hubble. Webbtelescope.org, the public hub for scientific information related to JWST, is now open. We have injected Webb-specific content into ongoing outreach programs: for example, partnering with high impact science communicators such as MinutePhysics to produce timely and concise content; partnering with musicians and artists to link science and art. Augmented reality apps showcase NASA's telescopes in a format usable by anyone with a smartphone, and visuals from increasingly affordable 3D VR technologies.

Author(s): Joel D. Green[1], Denise A. Smith[1], Brandon L. Lawton[1], Bonnie K. Meinke[1], Hussein Jirdeh[1]
Institution(s): *1. Space Telescope Science Institute*

411.07 – Bringing Live Astronomy into the Classroom and to the Public

Slooh makes astronomy incredibly easy, engaging and affordable for anyone with a desire to explore and study the cosmos for themselves. Since 2003 Slooh has connected telescopes to the Internet for access by the public, schools and colleges. Slooh's fully robotic observatories process FITS data in real-time for broadcast to the Internet. Slooh's technology is protected by Patent No.: US 7,194,146 B2 which was awarded in 2006.

Slooh members have taken over 6-million images of over 50,000 celestial objects, participated in research with leading astronomical institutions, and made over 6,000 Near-Earth Object submissions to the Minor Planet Center. They were also the major contributor of ground based observations of comet 67P/Churyumov-Gerasimenko to the ESA Pro-Am campaign during the Rosetta mission.

Slooh's flagship observatories are located at the Observatorio del Teide, in partnership with the Institute of Astrophysics of the Canary Islands (IAC), and in Chile, in partnership with the Pontificia Universidad Católica de Chile.

Slooh's free live broadcasts of celestial events and phenomena, including eclipses, solar activity, NEAs, comets, lunar cycles, etc. feature narration by astronomy experts Paul Cox and Bob Berman, and are syndicated to media outlets worldwide.

Currently in beta, the new "Slooh Classroom" program is due to launch in Q1 2017. This pairs participating schools in the USA to schools in Africa to collaborate on lesson plans that incorporate the use of Slooh's telescopes live in-class.

Author(s): Paul Cox[1]
Institution(s): *1. Slooh LLC*

411.08 – *Solar System Symphony:* Combining astronomy with live classical music

Solar System Symphony is an educational outreach show which combines astronomy visualizations and live classical music. As musicians perform excerpts from Holst's "The Planets" and other orchestral works, visualizations developed using WorldWide Telescope and NASA images and animations are projected on-stage. Between each movement of music, a narrator guides the audience through scientific highlights of the solar system. The content of *Solar System Symphony* is geared toward a general audience, particularly targeting K-12 students. The hour-long show not only presents a new medium for exposing a broad audience to astronomy, but also provides universities an effective tool for facilitating interdisciplinary collaboration between two divergent fields. The show was premiered at Northwestern University in May 2016 in partnership with Northwestern's Bienen School of Music and was recently performed at the Colburn Conservatory of Music in November 2016.

Author(s): Kyle Kremer[1]
Institution(s): *1. CIERA-Northwestern University*
Contributing team(s): WorldWide Telescope

411.09 – Do Facilitate, Don't Demonstrate: Meaningful Engagement for Science Outreach

We are encouraged to hand over the learning experience to the students who must do the learning. After the 1957 launch of Sputnik it seemed that learning by discovery would replace lectures and other forms of learning by rote. The innovative Physical Science Study Committee (PSSC), Chemical Education Materials Study (ChEMS), and Biological Sciences Curriculum Study (BSCS) provided teachers with hands-on, activity-based curriculum materials emphasizing problem solving, process skills, and creativity. Our current reforms, based on the Next Generation Science Standards, stress that learner-centered strategies need to become commonplace throughout the classrooms of our formal education system. In this presentation, we share tips on how to double check your style of interactions for science outreach, to ensure the audience is working with a facilitator rather than simply enjoying an expert's entertaining demonstration.

Author(s): Richard Gelderman[1]
Institution(s): *1. Western Kentucky University*

412 – Plenary Talk: The 21st Century: The Century of Biology on Earth and Beyond, Jill Tarter (SETI Institute)

412.01 – The 21st Century: The Century of Biology on Earth and Beyond

In a bold 2004 paper, Craig Venter and Daniel Cohen* claimed that whereas the 20th century had been the Century of Physics (Special and General Relativity, Quantum Mechanics, Big Bang Cosmology, Dark Matter and Dark Energy, the Standard Model of Particle Physics...) the 21st century would be the century of biology. They outlined the fantastic potential of genomic research to define the current century. Wondrous as these predictions were, and as rapidly as they have played out and over-delivered during this past decade, these predictions were too parochial. This century will permit us the first opportunities to study biology beyond Earth; biology as we don't yet know it, and biology that we have exported off the surface of our planet.

The technologies needed for discovering biology beyond Earth are different depending on whether you are searching for microbes or mathematicians, and depending on whether you are searching in-situ or remotely. In many cases the necessary technologies do not yet exist, but like genomics, they will probably develop more rapidly, and in more ways, than anyone of us can now imagine. The developing toolkit of the astronomers (stellar, planetary, and exoplanetary) will be shaped and improved as a result of this focus for at least the rest of this century.

* New Perspectives Quarterly, Vol 21, pp. 73-77, 2004

Author(s): Jill C. Tarter[1]
Institution(s): *1. SETI Institute*
Contributing team(s): SETI Team

424 – The Sun & Solar System Late Poster Session

424.01 – Multi-site Observations of the March 2016 Total Solar Eclipse: Calibration of Images to Simulate Continuous Monitoring

During the total solar eclipse of March 9, 2016, five teams of astronomers participating in the Citizen Continental America Telescopic Eclipse (CATE) experiment, traveled to different locations in Indonesia to observe the eclipse. Data was acquired to continuously monitor the progression of features in the inner solar corona: a region of the solar atmosphere where time evolution is not well understood. Image data from the eclipse consisted of sets of 7 exposure times 0.4, 1.3, 4, 13, 40, 130, and 400 milliseconds which are used to create a high dynamic range composite image. Eclipse data from these sites were then processed and calibrated using sets of dark and flat images. Further data processing included the compilation of exposures into high dynamic range images and were subsequently spatially filtered. Using these processing techniques, data from each site was aligned and compiled as frames in videos of the eclipse, each consisting of over 140 frames with the goal of being combined. Lessons learned from the data obtained in the observations of the 2016 total solar eclipse are being used to improve the procedure which will be used in the CATE experiment during the North American 2017 total solar eclipse.

Author(s): Robert Bosh[9], Matthew J. Penn[4], Myles McKay[7], Robert Baer[6], David Garrison[3], Richard Gelderman[9], Honor Hare[9], Fred Isberner[6], Logan Jensen[8], Sarah Kovac[6], Adriana Mitchell[4], Michael Pierce[8], Patricia Thompson[9], Andrei Ursache[3], John R. Varsik[1], Donald K. Walter[5], Zachary Watson[4], David Young[2]
Institution(s): *1. Big Bear Solar Observatory, 2. Citizen CATE Team, 3. Mathworks Inc., 4. National Solar Observatory, 5. South Carolina State University, 6. Southern Illinois University, 7. Space Telescope Science Institute, 8. University of Wyoming, 9. Western Kentucky University*
Contributing team(s): Citizen Cate Team

424.02 – DIY Astrophysics: Examining diurnal and seasonal fluctuations in the effects of solar gravity using a three-axis accelerometer

On the surface of the Earth, the acceleration due to the influence of the Sun's gravity is approximately 0.06% of that due to the Earth's own gravity (0.0006*g*). Nevertheless, it may be detected using a sensitive three-axis accelerometer such as the InvenSense MPU-6050, which is compatible with low-cost microcontrollers such as the Arduino and Raspberry Pi and hence provides an affordable means of investigation. Unlike the gravitational force between the Earth and an object on its surface, the *x*-, *y*-, and *z*-components of the gravitational force between the Sun and an earthbound observer are not constant: the vector direction of the gravitational acceleration caused by the Sun — denoted $g_\odot$ — fluctuates as a function of the Earth's rotation (i.e., the time of day) and position in orbit (i.e., the time of year). The present investigation derives mathematical expressions for the instantaneous value of each component of $g_\odot$ in terms of both quantities. It also outlines a method of using the InvenSense MPU-6050 to detect the corresponding fluctuations in total gravity (and, thus, the influence of the Sun's gravity) experimentally.

Author(s): Kristine Romich[1], Andrew Kruger[1]
Institution(s): *1. City Colleges of Chicago*

424.03 – Albedos of Centaurs, Jovian Trojans and Hildas

I present optical V band albedo distributions for samples of outer solar system minor bodies including Centaurs, Jovian Trojans and Hildas. Diameters come almost entirely from the NEOWISE catalog (Mainzer etal 2016- Planetary Data System). Optical photometry (H values) for about 2/3 of the approximately 2700 objects studied are from PanStarrrs (Veres et al 2015 Icarus 261, 34). The PanStarrs optical photometry is supplemented by H values from JPL Horizons (corrected to be on the same photometric system as the PanStarrs data) for the objects in the NEOWISE catalog that are not in the PanStarrs catalog. I compare the albedo distributions of various pairs of subsamples using the nonparametric Wilcoxon rank sum test. Examples of potentially interesting comparisons include: (1) the median L5 Trojan cloud albedo is about 10% darker than that of the L4 cloud at a high level of statistical significance and (2) the median albedo of the gray Centaurs lies between that of the L4 and L5 Trojan groups.

Author(s): William Romanishin[1]
Institution(s): *1. Univ. of Oklahoma*

424.04 – Shape Modeling and Boulder Mapping of Asteroid 1992 UY4

1992 UY4 is a near-Earth asteroid discovered by Carolyn Shoemaker on 25 October 1992. In August 2005, UY4 made a 0.04 AU flyby of Earth. Between the dates of 1-10 August 2005, UY4 was the target of delay-Doppler radar imaging by the Arecibo Observatory and the DSS-14 antenna at the Goldstone Deep Space Communications Complex. The images achieve a resolution as fine as 7.5 m/pixel and reveal a lumpy and modestly asymmetric object. The images also revealed the presence of numerous large boulders/blocks on the surface of 1992 UY4. The distribution of boulders/blocks can vary widely across a given asteroid. The boulder distribution on an object is important both for mission planning and for understanding the history of the asteroid concerned. We used the SHAPE software to analyze the delay-Doppler images of UY4.

During our process for modeling 1992 UY4 in the SHAPE software, we found two potential pole directions: one at $\lambda = 285$, $\beta = -80$ and one at $\lambda = 110$, $\beta = 75$, the mirror direction. The two potential pole directions represent a north-south ambiguity: UY4 may rotate either prograde or retrograde. The fit of $\lambda = 285$, $\beta = -80$ matches the observations much better than the mirror fit of $\lambda = 110$, $\beta = 75$. Thus, 1992 UY4 is most likely a retrograde rotator.

We have identified 18 boulder candidates on UY4's surface. Their distribution in longitude is concentrated in those longitudes that were seen on multiple days from Arecibo. The edges of the portion of UY4's surface that were visible to Arecibo show few boulders. This is likely observing bias. With the available data, we cannot determine if boulders are uniformly distributed across the surface of 1992 UY4 or not. Further observations would be needed to map the rest of the asteroid. Unfortunately, there are no upcoming opportunities for future ground-based radar observations, since 1992 UY4 will not pass as near to Earth as it did in 2005 for the next several hundred years.

Author(s): Nicholas Duong[2], Michael W. Busch[1]
Institution(s): *1. SETI Institute, 2. University of Louisville*

424.05 – Simulation of Rogue Planet Encounters with the Solar System: Is Planet 9 a Captured Rogue?

Rogue, or free-floating, planets may be abundant in the Galaxy. Several have been observed in the solar neighborhood. They have been predicted to even outnumber stars by a large fraction, and may partially account for dark matter in the disk of the galaxy, as the result of circumbinary planet formation. We performed N-body simulations of rogue encounters with the solar system with a variety of impact parameters. We find that Jupiter mass and higher rogues leave a significant imprint on planetary system architecture. Rogue formation models are therefore constrained by observed planetary system structure. We speculate that if rogue planets are abundant as predicted, then, Planet 9 may be a captured rogue.

Author(s): James Vesper[1], Paul A. Mason[1]
Institution(s): *1. New Mexico State University*

424.06 – Matching intermediate-term, multi-angle averages of CIRS FP1+FP3 observations for the He VMR and cloud in Saturn's atmosphere

Introduction
Saturn's atmosphere is a complicated system that is affected by many internal and external variables. To better understand these variables and how they affect Saturn's atmospheric system we rely on data obtained from spacecraft and Earth based observatories. For this particular study, we used data from Cassini's Composite Infrared Spectrometer (CIRS) instrument.
Currently we do not know the exact amount of helium (He) with respect to molecular hydrogen gas (H2) in Saturn's atmosphere. This He and H2 volume mixing ratio (VMR) is extremely important in understanding the structure and evolution of Saturn's atmosphere. The CIRS team was not able to identify reliable matching spectra with data obtained from Focal Plane 1 (FP1) and Focal Plane 3 (FP3) of the CIRS instrument.
Methods
All the data sets we have worked with range from the years 2005-2012. Each year's data sets were organized into 6 month intervals spanning the months January-June and July-December with data for FP1 and FP3 being completely separate. Each data set is also binned by planetographic latitude.
Each data point consists of a spectra wavenumber, radiance value, and an emission angle. The emission angle is then converted to the unit μ, the value of this unit is simply the cosine of the emission angle. Initially all data was binned by year, latitude, and calculated μ value. This data was then plotted as a function of radiance and wavenumber to identify areas of spectral overlap data overlap in corresponding FP1 and FP3 data sets. These data sets were then prepped to be processed by a radiative transfer retrieval algorithm called NEMESIS.
Results
Further binning of the data sets by looking at abundance of spectra values at certain μ values allows us to increase our confidence that these data sets are populated with enough spectra for NEMESIS to work with. NEMESIS has been operating with assumed He and H2 values derived from results of other studies, this means that narrowing down a more accurate He and H2 VMR will take more time and further data processing.

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425 – Extrasolar Planets Late Poster Session

425.01 – Transiting Planets with LSST: Finding exoplanets in the Large Magellanic Cloud

The Large Synoptic Survey Telescope (LSST) will survey over 18,000 square degrees of the sky for ten years. LSST will collect several hundred multi-band photometric observations of approximately one billion stars, while a small portion of the sky (around 100 square degrees) will be observed around ten thousand times. LSST was not designed to detect exoplanets; however, we have demonstrated that several kinds of transiting exoplanets can be recovered in simulated LSST observations. We focus on one of the more exotic populations by exploring the potential of the Large Magellanic Cloud being observed at high cadence. We find that LSST will likely be able to find a significant number of transiting exoplanets with current algorithms, resulting in the first detections of a population of extragalactic planets. An understanding of the occurrance rate of exoplanets in the LMC will also provide insight into how stellar environments play a role in planet formation.

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425.02 – Planets, Moons, and Multiple Stars – Gravitational Microlensing by Three-Body Systems

Gravitational microlensing has proved to be a useful tool for detecting exoplanets, particularly those separated a few AU from the lens star. Of the 43 microlensing-detected planets published so far, four are members of two-planet systems, and a further three are associated with binary stars (two circumprimary and one circumbinary). While the lensing by a single star with a single planet is well understood, systematic insight into the substantially more diverse lensing by three-body systems is still lacking. We introduce efficient methods for studying and visualizing the different regimes of lensing by a triple lens with a given combination of masses. For illustration, we present here full analyses of critical-curve regimes of the following lenses in arbitrary spatial configuration: an equal-mass triple, an equal-mass binary with a planet, and a hierarchical star-planet-moon system. Such studies can facilitate the interpretation and analysis of observed microlensing light curves due to triple lenses.

Author(s): David Heyrovsky[1], Kamil Danek[1]
Institution(s): *1. Charles University*

425.03 – The metallicity distribution and hot Jupiter rate of the Kepler field: Hectochelle High-resolution spectroscopy for 776 Kepler target stars

The occurrence rate of hot Jupiters from the Kepler transit survey is roughly half that of radial velocity surveys targeting solar neighborhood stars. One hypothesis to explain this difference is that the two surveys target stars with different stellar metallicity distributions. To test this hypothesis, we measure the metallicity distribution of the Kepler targets using the Hectochelle multi-fiber, high-resolution spectrograph. Limiting our spectroscopic analysis to 610 dwarf stars in our sample with log(g) > 3.5, we measure a metallicity distribution characterized by a mean of [M/H]_{mean} = -0.045 +/- 0.009, in agreement with previous studies of the Kepler field target stars. In comparison, the metallicity distribution of the California Planet Search radial velocity sample has a mean of [M/H]_{CPS, mean} = -0.005 +\- 0.006, and the samples come from different parent populations according to a Kolmogorov-Smirnov test. We refit the exponential relation between the fraction of stars hosting a close-in giant planet and the host star metallicity using a sample of dwarf stars from the California Planet Search with updated metallicities. The best-fit relation tells us that the difference in metallicity between the two samples is insufficient to explain the discrepant Hot Jupiter occurrence rates; the metallicity difference would need to be 0.2-0.3 dex for perfect agreement. We also show that (sub)giant contamination in the Kepler sample cannot reconcile the two occurrence calculations. We conclude that other factors, such as binary contamination and imperfect stellar properties, must also be at play.

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425.04 – Insights on the spectral signatures of RV jitter from PCA

Stellar activity features such as spots and faculae can mimic radial velocity (RV) motion by creating spurious time-varying centroid shifts in the stellar spectral lines. This "RV jitter" hinders the detection of large planetary signals (100 m s^{-1}) around young, active stars, and it dominates the Keplerian signals of Earth-analogs (10 to 20 cm s^{-1}) even around quiet stars. However, appropriate statistical techniques may be able to distinguish these phenomena by exploiting the spectral-line dependence and temporal coherence of RV jitter.

We produce simulated disk-integrated time-series spectra of a rotating star with a spot, with a facula, or with a planet of various sizes using the SOAP 2.0 code, which uses real high-resolution and high-S/N spectra of the quiet solar photosphere and sunspots as a starting point. Principal component analysis (PCA) is used to identify and quantify the wavelength-dependent intensity variations of the spectra in each of these cases. We find that the PCA signatures of these three phenomena are distinct, suggesting that they can be distinguished in theory. We then lower the resolution and S/N of these simulated spectra and use PCA to quantify their information content. We find that high-resolution (R > 100,000) observations are better able to recover information in the spectra of spots and faculae than would be expected compared to an equivalent increase in S/N. This effect is especially pronounced for large spots and faculae (S ≥ 1%), suggesting that high-resolution spectrographs will be particularly well-suited for characterizing stellar activity.

Author(s): Allen Bradford Davis3, Jessica Cisewski3, Xavier Dumusque[2], Debra Fischer3, Eric B. Ford[1]
Institution(s): *1. The Pennsylvania State University, 2. University of Geneva, 3. Yale University*

425.05 – The Escaping Upper Atmospheres of Hot Jupiters

Hot Jupiters are massive gaseous planets which orbit closely to their parent star. The strong stellar irradiation at these small orbital separations causes the temperature of the upper atmosphere of the planet to rise. This can cause the planet's atmosphere to escape into space, creating an exoplanet outflow. We ascertained which factors determine the presence and structure of these outflows by creating one dimensional simulations of the density, pressure, velocity, optical depth, and neutral fraction of hot Jupiter atmospheres. This was done for planets of masses and radii ranging from 0.5-1.5 M_j and 0.5-1.5 R_j. We found the outflow rate to be highest for a planet of 0.5 M_j and 1.5 R_j at 5.3×10^{-14} M_j/Yr. We also found that the higher the escape velocity, the lower the chance of the planet having an outflow.

Author(s): Eric Davidson[1], Gabrielle Jones[2], Ana Uribe[1], Joseph Carson[1]
Institution(s): *1. College of Charleston, 2. South Carolina State University*

425.07 – ZEIT: Searching for Young Stars in K2

Nearby young, open clusters such as the Hyades, Pleiades, and Praesepe provide an important reference point for the properties of stellar systems in general. In each cluster, all stars are of the same known age. As such, observations of planetary systems around these stars can be used to gain insight into the early stages of planetary system formation. *K2*, the revived *Kepler* mission, has provided a vast number of light curves for young stars in the clusters and elsewhere in the *K2* field. We aim to compute rotational periods from sunspot patterns for all *K2* target stars and use gyrochronometric relationships derived from cluster stars to determine their ages. From there, we will search for planets around young stars outside the clusters with the ultimate goal of shedding light on how planets and planetary systems evolve with time.

Author(s): Nathan Morris[1], Andrew W Mann[1]
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425.08 – A Novel Statistical Technique for Determining the Properties of Exrasolar Planets

By detecting light from extrasolar planets, we can measure their compositions and bulk physical properties. The technologies used to make these measurements are still in their infancy, and a lack of self-consistency suggests that previous observations have underestimated their systematic errors. We demonstrate a statistical method, newly applied to exoplanet characterization, which allows some amount of the data to have underestimated errorbars. This method compares the photometry on the substellar companion GJ 758b to custom atmospheric models to determine the exoplanet's atmospheric properties. It also demonstrates that some of the data is inconsistent with the models, and produces a probability distribution of atmospheric properties including temperature, gravity, cloud thickness, and chemical abundance for GJ 758b which automatically weights the photometry by the probability that it is correct at each wavelength.

Author(s): Cassandra Starr Henderson[1], Andrew Skemer[1], Caroline Morley[1], Jonathan J. Fortney[1]
Institution(s): *1. UC Santa Cruz*

425.09 – pyLIMA : an open source microlensing software

Planetary microlensing is a unique tool to detect cold planets around low-mass stars which is approaching a watershed in discoveries as near-future missions incorporate dedicated surveys. NASA and ESA have decided to complement WFIRST-AFTA and Euclid with microlensing programs to enrich our statistics about this planetary population. Of the nany challenges in- herent in these missions, the data analysis is of primary importance, yet is often perceived as time consuming, complex and daunting barrier to participation in the field. We present the first open source modeling software to conduct a microlensing analysis. This software is written in Python and use as much as possible existing packages.

Author(s): Etienne Bachelet[1]
Institution(s): *1. LCO*

425.10 – A population of planetary systems from Kepler data that are characterized by short-period, Earth-sized planets

From an analysis of the Quarter 1-17 Kepler planet candidate catalog we compare systems with single transiting planets to systems with multiple transiting planets. We find a distinct population of exoplanetary systems that is characterized by short-period, Earth sized planets. This difference in system architecture likely indicates a different branch in the system's formation or dynamical evolution relative to the typical Kepler system. We estimate that at least 17% of systems containing a hot Earth planet are members of this population. When we account for detection efficiency, these systems occur with a frequency similar to the hot Jupiters.

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425.11 – Extra Solar Planet Science With a Non Redundant Mask

To detect faint planetary companions near a much brighter star, at the Resolution Limit of the James Webb Space Telescope (JWST) the Near-Infrared Imager and Slitless Spectrograph (NIRISS) will use a non-redundant aperture mask (NRM) for high contrast imaging. I simulated NIRISS data of stars with and without planets, and run these through the code that measures interferometric image properties to determine how sensitive planetary detection is to our knowledge of instrumental parameters, starting with the pixel scale. I measured the position angle, distance, and contrast ratio of the planet (with respect to the star) to characterize the binary pair. To organize this data I am creating programs that will automatically and systematically explore multi-dimensional instrument parameter spaces and binary characteristics. In the future my code will also be applied to explore any other parameters we can simulate.

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Contributing team(s): Anand Sivaramakrishnan,Alexandra Greenbaum,Kathryn St Laurent , Deeparshi Thatte

425.12 – Investigating Exoplanets Within Stellar

Clusters
Recent surveys exploring nearby open clusters have yielded noticeable differences in the planetary population from that seen in the Field. This is surprising, as it is widely accepted that a majority of stars form within clustered environments before dispersing throughout the galaxy. Though dynamical arguments have been used to explain this discrepancy in the past, previous surveys' observational statistics and detection biases can also be used to argue that the open cluster planet population is indistinguishable from the Field.
Our group aims to explore the role of stellar close encounters and interplanetary interactions in producing the observed exoplanet populations for both open cluster stars and Field stars. We employ a variety of different computational techniques to investigate these effects, ranging from traditional Monte Carlo scattering experiments to multi-scale n-body simulations. We are interested in: the effects of stellar binaries; Hot Jupiter migrations; long-period ice giants; and the habitability history of terrestrial planets.

Author(s): Joseph Paul Glaser[1], Tyler Reisinger[1], Jonathan Thornton[1], Stephen L. W. McMillan[1]
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426 – Galaxy Clusters and the IGM Late Poster Session

426.01 – The dark matter distribution of merging galaxy cluster PLCKG287.0+32.9 by weak lensing

The merging galaxy cluster, PLCKG287.0+32.9, is the second most significant detection of the Planck SZ survey. As part of a sample of galaxy clusters being investigated by the Merging Cluster Collaboration (MC^2), PLCKG287.0+32.9 is studied to further constrain dark matter properties and improve our understanding of galaxy cluster physics. The galaxy cluster hosts two megaparsec sized radio relics and a radio halo, evidence of its merger nature. The radio relics are located approximately one and three megaparsecs from the X-ray peak, requiring a somewhat complex merging scenario. A detailed study of the dark matter distribution will provide key information to constrain the merger scenario. With Subaru g- and r-band data, we perform a weak-lensing analysis and determine the dark matter distribution of the merging galaxy cluster. We fit a 2-parameter NFW profile to the tangential shear to quantify the mass. We find that the dark matter peak is aligned with the luminosity peak. Using the dark matter mass distribution, we discuss the significance of the merging constituents and their relation to the luminous emissions.

Author(s): Kyle Finner4, James Jee4, William Dawson[1], Nathan Golovich3, Daniel Gruen[2], Brian Lemaux3, David M. Wittman3
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426.02 – Helium Reionization in From New Sightlines

A very small number of sightlines to z~3 quasars have been studied in detail to show the progress of helium reionization. Although studying the same sightlines with each new UV spectrograph lead to a better understanding of them, the sightline variance is very strong during this patchy and extended process. We discuss detailed R>10,000 COS data from new sightlines, and what they reveal about the progress and end of helium reionization.

Author(s): David Syphers[1]
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426.03 – Magnetic Draping as a Possible Solution to Turbulent Heating of the ICM in Kinetic Mode AGN Feedback

Recent x-ray measurements of the Perseus Cluster intracluster medium (ICM) by the Hitomi Mission found a velocity dispersion measure of $\sigma \sim 150$ km/s, indicating a large-scale turbulent energy of approximately 4% of the thermal energy. If this energy is transferred to small scales via a turbulent cascade and dissipated as heat, radiative cooling can be offset and the cluster can remain in its observed thermal equilibrium. We investigate the role of AGN feedback in turbulent heating of galaxy clusters. Specifically, we analyze the production of turbulence by g-modes generated by the supersonic expansion and buoyant rise of AGN-driven bubbles. Previous work has shown that this process is inefficient, with less that 1% of the injected energy ending up in turbulence. This inefficiency is primarily due to the fact that the bubbles are shredded apart by hydrodynamic instabilies before they can excite sufficiently strong g-modes. Using a plane-parallel model of the ICM and 3D ideal MHD simulations, we examine the role of a large-scale magnetic field which is able to drape around these rising bubbles, preserving them from hydrodynamic instabilities. We present results for a magnetic field perpendicular to our gravitational field as well as for a helical field geometry. We find that, while magnetic draping is able to better preserve AGN-driven bubbles and excite stronger g-modes, the production of turbulence is still inefficient. This fact is likely due to the magnetic tension force preventing the production of vortices in the ICM plasma. Our work shows that ideal MHD is an insufficient description for the cluster feedback process, and we discuss future work such as the inclusion of anisotropic viscosity as a means of simulating high β plasma kinetic effects.

Author(s): Christopher John Bambic[1], Christopher S. Reynolds[1], Brian Morsony[1]
Institution(s): *1. University of Maryland, College Park*

426.04 – Probing Galaxy Clusters and Substructures using Gravitational Lensing

Gravitational lensing is one of the most promising methods of analyzing massive astronomical objects such as galaxy clusters. The weak gravitational lensing signal, which is called shear, is a measurement of the weak distortion of background galaxies in the linear regime of the lensing field. Shear analysis effectively estimates the main properties of galaxy clusters such as the mass and scale of the lensing system. The second order gravitational lensing signal, flexion, is dominant in the non-linear regime of the lensing field that bridges the strong and weak lensing regimes. It has also recently arisen as a robust method to detect substructures in galaxy clusters due to its sensitivity to the gradient of convergence and shear field. In this poster we propose that combining the shear and flexion analysis can give more information about the detailed structure of the lensing system.

Author(s): Miyoung Choi[2], Hoang Nguyen[2], Lindsay King[2], Brandyn E Lee[2], Ian McCarthy[1]
Institution(s): *1. Liverpool John Moores, 2. The University of Texas at Dallas*

426.05 – Ratio of Dust to Metal Abundance in Quasar Absorption Line Systems from 1.9 < z < 3.3

Measuring the ratio of dust to metal abundance in quasar absorption line systems will provide insight to the chemical evolution of galaxies, dust formation, and dust properties in the early universe. Quasar absorption systems allow us to study the abundance of dust from many different redshifts, in this project up to z ~ 3.3 for absorber redshift. The absorption bump at 2175 Å is a broad, but strong, dust feature within the UV-optical wavelength range. This feature, if detected, can be directly related to the optical depth of the dust in the absorbing systems. However, the 2175 Å bump is very broad, having a full-width half-maximum approximately 350 * (1 + z) Å, and therefore hard to distinguish from a single spectrum. To find this bump, it is important to co-add many quasar spectra. In this project, we look at how the abundance of dust compares to that of metals for 105 quasar spectra with strong damped Lyman alpha systems with absorber redshifts ranging from 1.9 < z < 3.3. From these spectra, we created a composite spectrum to analyze the 2175 Å bump and the absorption of heavy elements. We will present the results including the strength of the 2175 Å feature found in our composite spectrum.

Author(s): Stephanie Stawinski[1], Sangeeta Malhotra[1]
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426.06 – Observation of Weak Low-ionization Winds in Host Galaxies of Low Luminosity Active Galactic Nuclei at z ~1

A key physical manifestation of active galactic nuclei (AGN) feedback is predicted to be powerful galactic winds. However, the relative roles between AGN activity and star formation in driving such winds remain largely unexplored at high redshifts, near the peak of cosmic activity for both. We study winds in 12 X-ray AGN host galaxies at z ~ 1 in the CANDELS fields using deep Keck rest-frame UV spectroscopy. We find, using the low-ionization Fe II 2586 absorption in the stacked spectra, that the AGN show a median centroid velocity shift of -137 km/s and a median velocity dispersion of 103 km/ s. The centroid velocity and the velocity dispersions are obtained from a two component (ISM+wind) absorption line model. For comparison, a star-forming and X-ray undetected galaxies at a similar redshift, matched roughly in stellar mass and galaxy inclination, show the outflows to have a median centroid velocity of -135 km/s and a median velocity dispersion of 140 km/s. Thus, winds in the AGN are similar in velocities to those found in star-formation-driven winds, and are weak to escape and expel substantial cool gas from galaxies. A joint reanalysis of the z ~ 0.5 AGN sample and our sample yields a centroid velocity of -139 (+48, -87) km/s and a velocity dispersion of 82 (+47,-37) km/s. For the combined sample, about half the total equivalent width of the Fe II 2586 absorption is due to the wind. We do not observe winds with bulk velocities greater than 500 km/s predicted by some AGN feedback models.

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Contributing team(s): David C. Koo, S. M. Faber, J. Xavier Prochaska, Yicheng Guo, F. S. Liu, Emily C. Cunningham, Alison L. Coil, Puragra Guhathakurta

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427 – Galaxy Evolution Late Poster Session

427.01 – Galaxy Structure in the Far-Ultraviolet

Galaxy structure comparisons as a function of redshift for the purpose of evolution studies are complicated by the fact that a given galaxy can have a significantly different morphological appearance when viewed in different wavelengths. Using CAS parameters to measure galaxy structure (concentration, asymmetry, and clumpiness), we quantify this band-pass shifting effect in the far-UV as compared to multiple rest-frame wavelengths ranging up to the near-infrared. Our study includes 2073 nearby galaxies observed by GALEX (Galaxy Evolution Explorer) in the FUV and/or NUV. Through this, we provide corrective terms that can be applied to CAS measurements of higher redshift galaxies. We also find an interesting result that elliptical galaxies appear significantly more late-type in the far-UV, with CAS parameters more similar to spiral galaxies observed at red optical wavelengths. We attribute this to ongoing star formation in extended disks. Funded by a grant through NASA.

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Institution(s): *1. Arizona State University, 2. Carnegie Observatories, 3. Ohio University, 4. Penn State Wilkes-Barre, 5. Susquehanna University, 6. University of Nottingham*

427.02 – The Universe Going Green: Extraordinarily Strong [OIII]5007 in Typical Dwarf Galaxies at z~3

We constructed the average SEDs of U-dropout galaxies in the Subaru Deep Field. This sample contains more than 5000 Lyman-break galaxies at z~3. Their average near- and mid-IR colors were obtained by stacking JHK and IRAC imaging, in bins of stellar mass. At the lowest mass bins an increasingly strong excess flux is seen in the K filter. This excess can reach 1 magnitude in the broadband filter, and we attribute it to strong \OIII $\lambda{5007}$ line emission. The equivalent width is extraordinarily high, reaching almost 1000\Ang\ for the average z=3 galaxy at an i magnitude of 27. Such extreme [OIII] emission is very rare in the current epoch, only seen in a handful of metal-deficient dwarf starbursts sometimes referred to as "Green Peas". In contrast, extreme [OIII]--strong enough to dominate the entire broad-band SED--was evidently the norm for faint galaxies at high redshift. We present evidence that these small but numerous galaxies were primarily responsible for the reionization of the Universe.

Author(s): Matthew Arnold Malkan[1], Daniel Cohen[1]
Institution(s): *1. UC, Los Angeles*

427.03 – Constraining the Effect of Close-Pairs on the Measurements of the Number Density of the Most Massive Galaxies in the Early Universe

The observed number densities of the most massive galaxies in the early universe drive the ongoing pursuit of understanding the physical processes responsible for galaxy formation and evolution. We present the analysis of close-pairs serendipitously discovered among a sample of very massive ($\log(M_{star}/M_{\odot}) > 11.2$) galaxies at 1.5 < z < 3.5 selected for HST/WFC3 F160W band imaging follow-up from the UltraVISTA DR1, NMBS-II and UDS DR8 surveys. The high-resolution rest-frame optical morphologies reveal that ~1/3 of the follow-up sample shows a close companion that is unresolved in the ground-based K_S band imaging. We investigate the effect of the pairs/multiplets on the number density of massive galaxies at 1.5<*z*<3.5 by decomposing the estimated stellar masses of these systems based on the observed F160W fluxes.

Author(s): Zehra Cemile Marsan[2], Danilo Marchesini[2], Gabriel Brammer[1], Adam Muzzin3
Institution(s): *1. STScI, 2. Tufts University, 3. York University*

427.04 – Galactic Winds and Cosmic Ray Transport in a Multiphase Interstellar Medium

Making up roughly one third the pressure budget of the ISM, cosmic rays are likely to play a fundamental role in galaxy evolution. Recent 3D magnetohydrodynamic simulations have shown that advected cosmic rays puff up galactic disks and suppress star formation. Additionally, cosmic rays diffusing away from the galactic midplane can drive gas out of the galaxy with mass loss rates comparable to the star formation rate, thus regulating star formation. Yet, the impact of cosmic rays decoupling from cold, neutral gas in a multiphase interstellar medium has hithertofore not been studied. Preliminary work suggests that cosmic ray decoupling produces significantly more explosive feedback, dramatically affecting the evolution of the ISM and the efficiency of cosmic ray driven outflows.

Author(s): Ryan Farber[2], Mateusz Ruszkowski[2], Karen Hsiang-Yi[1], Ellen Gould Zweibel3
Institution(s): *1. University of Maryland, College Park, 2. University of Mihcigan, Ann Arbor, 3. University of Wisconsin-Madison*

427.05 – The multi-wavelength properties of faint submillimeter galaxies at 450 and 850um

We present a multi-wavelength analysis for galaxies selected at 450 and 850um from the deepest SCUBA-2 observations in the EGS field. The median redshifts for the 450 and 850um samples are z~1.6 and z~2.2, respectively. However, the two populations have similar IR luminosities, SFR, and stellar masses, with mean values of ~1.5x10^12 L_sun, 150 M_sun/yr, and 9x10^10 M_sun, respectively. We find that most of our sources (>80%) lie in the high-mass end of the `main sequence' of star-forming galaxies. Exploring the IRX-beta relation we find that the most luminous galaxies are consistent with the Muerer law, while the less luminous galaxies are in better agreement with the SMC relation. Using the results of a two-dimensinal modelling of the HST H_160-band, we derive a median Sersic index of n=1.4 and a median half-light radius of ~4.8kpc for the whole sample. Based on a visual-like classification in the same band we find that the dominant component for most of the galaxies at all redshift is a disk, although there is a transition from irregular disks to disks with a spheroidal component from high to low redshift, which supports the scenario of SMGs as progenitors of present-day massive elliptical galaxies.

Author(s): Jorge Zavala[1], Itziar Aretxaga[1], David Hughes[1], James Dunlop[2], Michal Michalowski[2]
Institution(s): *1. INAOE, 2. University of Edinburgh*
Contributing team(s): SCUBA-2 Cosmology Legacy Survey

427.06 – Environmental Variations in the Atomic and Molecular Gas Radial Profiles of Nearby Spiral Galaxies

We present an analysis of the radial profiles of a sample of 43 HI-flux selected spiral galaxies from the Nearby Galaxies Legacy Survey (NGLS) with resolved James Clerk Maxwell Telescope (JCMT) CO J= 3–2 and/or Very Large Array (VLA) HI maps. Comparing the Virgo and non-Virgo populations, we confirm that the HI disks are truncated in the Virgo sample, even for these relatively HI-rich galaxies. On the other hand, the H_2 distribution is enhanced for Virgo galaxies near their centres, resulting in higher H_2 to HI ratios and steeper H_2 and total gas radial profiles. This is likely due to the effects of moderate ram pressure stripping in the cluster environment, which would preferentially remove low density gas in the outskirts while enhancing higher density gas near the centre. Combined with Hα star formation rate data, we find that the star formation efficiency (SFR/H_2) is relatively constant with radius for both samples, but Virgo galaxies have a ~40% lower star formation efficiency than non-Virgo galaxies. These results suggest that the environment of spiral galaxies can play an important role in the formation of molecular gas and the star formation process.

Author(s): Angus Mok[1], Christine Wilson[1]
Institution(s): *1. McMaster University*
Contributing team(s): JCMT Nearby Galaxies Legacy Survey

427.07 – Ram Pressure Stripping and Morphological Transformation in the Coma Cluster

The two largest spiral galaxies in the Coma cluster, NGC4911 and NGC4921, exhibit signs of being vigorously ram-pressure stripped by the hot intracluster medium. HST ACS and WFC3 images have revealed galactic scale shock fronts, giant "Pillars of Creation", rivulets of dust, and spatially coherent star formation in these grand design spirals. All evidence points to these galaxies being stressed by a global external source which can only be the hot intracluster medium (ICM). Inspired by these examples, we have obtained HST WFC3 imaging of five additional large spirals to search for and investigate the effects of ram pressure stripping across the wider Coma cluster. The results are equally spectacular as the first two examples. The geometry of the interactions in some cases allows us to estimate the various time scales involved, including gas flows out of the disk leading to creation of the ICM, and the attendant triggered star formation in the galaxy disks. The global star formation patterns and wholesale tidal stripping of matter yield insights into the spatial and temporal ISM-ICM interactions driving the evolution of galaxies in clusters and ultimately transforming their morphologies from spiral to S0. These processes, much more common in the early Universe, led to the wholesale morphological transformation of Hubble types during the assembly of rich clusters, when the intergalactic populations and hot ICM were first being created and laid down from such stripping and destruction of their member galaxies.

We also report on two instrumental aspects of WFC3: 1) using the filter pair F350LP and F600LP to create an extremely broad pseudo Blue-Red color to achieve the greatest observing efficiency with HST, and 2) a WFC3 CCD effect which leads to apparent quantization of background counts, making automatic sky determination challenging when using drizzlepac routines.

Author(s): Michael Gregg[2], Michael West[1]
Institution(s): *1. Lowell Observatory, 2. University of California, Davis*

427.08 – Bar Evolution and Bar Properties from Disc Galaxies in the Early Universe

Bars in disc galaxies indicate a large collection of stars in a specific configuration of orbits that give the galaxy center a rectangular looking feature. Astronomers have discovered that these bars affect the distribution of matter in galaxies, and are also related to galaxy stellar mass and star formation history. Little is known about the specifics of how bars evolve and drive the evolution of their host galaxies because only a handful of bars have been studied in detail so far. I have examined a sample of 8,221 barred galaxies from the early universe to identify and examine correlations with galaxy properties. The data comes from Galaxy Zoo, an online citizen science project that allows anyone to classify and measure detailed properties of galaxies. I present results including the fraction of galaxies in the sample that have bars, and the variation of galaxy properties with bar length, including galaxy color and stellar mass. I also compare these results to barred galaxies in the local universe. I will discuss the implications of these results in the context of galaxy evolution overall, including the effect of dark matter on bars and galaxy evolution.

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428 – The Milky Way and Other Galaxies Late Poster Session

428.01 – Two Populations of SiO Masers in the Galactic Bulge

We present a summary of the kinematics of stellar SiO masers observed in the direction of the galactic bulge with ALMA (885 sources), and the JVLA (2,479 sources). These objects are selected by color from the MSX point source catalog, which has given an SiO detection rate of ~70%. The presented sample, along with the ~24,000 sources still being observed and reduced, enable radial velocity measurements even in regions with extreme optical extinction. These maser stars are compared to the known bulge surveys: APOGEE (~25,000 sources), BRAVA (~8000 sources), and GIBS (~6,400 sources). We have found that BAaDE stars in the direction of the bulge exist in two subpopulations: (1) A kinematically hot population exhibiting cylindrical rotation consistent with the other bulge surveys, and (2) a kinematically cold population more consistent with a disk population. In the ALMA data, we find evidence for a -200 km/s feature at (l,b) = (-9,0), possibly the symmetric complement to a previously proposed +200 km/s feature (Nidever 2012), that we do not confirm with our data.

Author(s): Adam Trapp[2], Robert Michael Rich[2], Mark Morris[2], Ylva Pihlstrom[3], Lorant Sjouwerman[1], Mark J. Claussen[1], Michael Stroh[3]
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428.02 – The Colors and Stellar Populations of Ultra-Diffuse Galaxies in the Coma and Virgo Clusters

Ultra-diffuse galaxies (UDGs) were recently discovered both within and beyond galaxy clusters. UDGs have low luminosities, yet some can be as large as the Milky Way. Their evolutionary histories are unknown, with proposed explanations including “failed” giant galaxies, or dwarfs that were quenched through cluster infall. Here we study trends in color for UDGs in the Coma and Virgo clusters, with comparisons to normal galaxies. We also use stellar population models to estimate ages and metallicities of the UDGs.

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428.03 – A New High Resolution JVLA Survey of the Fireworks Galaxy, NGC 6946

A Jansky Very Large Array high resolution survey was undertaken at three wavelengths: 20 cm, 6 cm, and 3.6 cm of the Fireworks Galaxy, NGC 6946, which is a nearby, grand design spiral galaxy with a distance of ~5 Mpc. This new radio survey has a sensitivity of two - three times previous high resolution surveys. Analysis of the radio maps allow us to identify many new compact sources. We will present a preliminary analysis of the radio maps and discuss the nature of the identified compact sources, which are expected to be supernova remnants (SNRs), HII regions, and background sources. We will compare our source lists to a previous survey conducted in 1994.

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428.04 – Simulating Galaxies: Investigating Spiral Pitch Angle and the Efficiency of Radial Mixing

Radial mixing refers to the permanent rearrangement of orbital angular momenta in a galactic disk due to interactions with transient spiral arms. A star is subject to this dynamical process when it is temporarily in a trapped orbit between the spiral arms near the corotation radius. The purpose of this research was to numerically investigate how spiral shape affects the efficiency of radial mixing. This was done by designing an orbital integrator that numerically simulated the motion of test particles in a 2D disk potential that had a steady spiral pattern and was populated using a Monte Carlo simulation. Several realizations of N=10^4 orbits were simulated and analyzed using the open source, distributed computing service Open Science Grid (OSG). The results were in agreement with previous theoretical predictions, and preliminary analysis of the data indicates that the RMS change in orbital angular momentum for stars in trapped orbits depends on spiral arm pitch angle.

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428.05 – Spectral Analysis of CLU Galaxies

In order to help select possible EM signals from gravitational wave-emitting sources, a more complete catalog of local galaxies is being created. This catalog, called the Census of the Local Universe (CLU), will attempt to find the position of all star-forming galaxies within 200 Mpc. By doing this, the area on the sky from which a gravitational wave could possibly have originated is reduced by a factor of 100. Besides providing this valuable resource for gravitational wave follow-up, the CLU survey provides an exciting new opportunity for better understanding the properties of galaxies near the same age as the Milky Way. Using spectra obtained with the Palomar 200-inch double-prime spectrograph as well as data from the WISE survey, we have created a main sequence for the CLU survey. By analyzing how this main sequence behaves in local galaxies, we can better understand the relationship between current star formation rate and total galaxy stellar mass.

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428.06 – Numerical Simulations of a Jet-Cloud Collision and Starburst: Application to Minkowski's Object

We present results of two- and three-dimensional, multi-physics simulations of an AGN jet colliding with an intergalactic cloud. The purpose of these simulations is to assess the degree of "positive feedback," i.e. jet-induced star formation, that results from such a collision. We have specifically tailored our simulation parameters to facilitate comparison with recent observations of Minkowski's Object, a stellar nursery located at the termination point of a radio jet coming from galaxy NGC 541. As shown in our simulations, such a collision triggers shocks which propagate around and through the cloud. These shock condense the gas and trigger cooling instabilities, creating runaway increases in density, to the point that individual clumps can become Jeans unstable. Our simulations provide information about the expected star formation rate, total mass converted to stars, relative velocity of the stars and gas, and column density of cold H I, He I, and H_2) gas present. Our results confirm the possibility of jet-induced star formation.

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428.07 – Near-Infrared Photometric Properties of Red Supergiant Stars in Neaby Galaxies: NGC 4214, NGC 4736 and M51

Red supergiant stars (RSGs) are post-main sequence phase of massive stars which can be easily resolved in nearby galaxies due to their bright luminosity as compared to the low-mass stars. RSGs are cool, and hence have a dominant light output at near-infrared (NIR) wavelengths. To investigate the photometric properties of RSGs in a few nearby galaxies, we observed NGC 4214, NGC 4736 and M51 by using the WFCAM detector mounted on the UKIRT telescope at Hawaii, and obtained the NIR (JHK bands) imaging data. After carrying out the photometry, the age ranges of RSGs in each galaxy were estimated by over-plotting PARSEC isochrones to the (J-K, K) colour-magnitude diagram: $\log(t_{yr})$ = 6.9 - 7.3 for NGC 4214; $\log(t_{yr})$ = 7.0 – 8.0 for NGC 4736; and $\log(t_{yr})$ = 6.7 – 6.9 for M51. The effective temperatures and luminosities of RSGs were calculated using MARCS synthetic fluxes, and these results were used to compare the properties of RSGs in Hertzsprung-Russell (H-R) diagram of dominant H II regions within each galaxy, over-plotted with PARSEC evolutionary tracks. The RSGs in NGC 4214 and NGC 4736 are found to have a mass of 9 $M_{\odot}$ - 30 $M_{\odot}$, and the maximum luminosities found to be almost constant with $\log(L/L_{\odot})$ = 5.6 - 5.7. However, the location of the RSGs in the H-R diagram are not consistent with the evolutionary tracks for M51.

(Key Words: stars: massive – supergiants – galaxies: photometry – galaxies: stellar content – infrared: stars)

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428.08 – Studying Lyman-alpha escape and reionization in Green Pea galaxies

Green Pea galaxies are low-redshift galaxies with extreme [OIII]5007 emission line. We built the first statistical sample of Green Peas observed by HST/COS and used them as analogs of high-z Lyman-alpha emitters to study Ly-alpha escape and Ly-alpha sizes. Using the HST/COS 2D spectra, we found that Ly-alpha sizes of Green Peas are larger than the UV continuum sizes. We found many *correlations* between Ly-alpha escape fraction and galactic properties -- dust extinction, Ly-alpha kinematic features, [OIII]/[OII] ratio, and gas outflow velocities. We fit an empirical relation to *predict* Ly-alpha escape fraction from dust extinction and Ly-alpha red-peak velocity. In the JWST era, we can use this relation to derive the IGM HI column density along *the line of sight of each high-z Ly-alpha emitter* and probe the reionization process.

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429 – AGN and Friends Late Poster Session

429.01 – AGN feedback in action? - outflows and star

formation in type 2 AGNs

We present the statistical constraints on the ionized gas outflows and their connection to star formation, using a large sample of ~110,000 AGNs and star-forming galaxies at z < 0.3. First, we find a dramatic difference of the outflow signatures between AGNs and star-forming galaxies based on the [OIII] emission line kinematics. While the [OIII] velocity and velocity dispersion of star forming galaxies can be entirely accounted by the gravitational potential of host galaxies, AGNs clearly show non-gravitational kinematics, which is comparable to or stronger than the virial motion caused by the gravitational potential. Second, the distribution in the [OIII] velocity - velocity dispersion diagram dramatically expands toward large values with increasing AGN luminosity, implying that the outflows are AGN-driven. Third, the fraction of AGNs with a signature of outflow kinematics, steeply increases with AGN luminosity and Eddington ratio. In particular, the majority of luminous AGNs presents strong non-gravitational kinematics in the [OIII] profile. Interestingly, we find that the specific star formation of non-outflow AGNs is much lower than that of strong outflow AGNs, while the star formation rate of strong outflow AGNs is comparable to that of star forming galaxies. We interpret this trend as a delayed AGN feedback as it takes dynamical time for the outflows to suppress star formation in galactic scales.

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429.02 – Infrared Variability and Time Lags for Periodic Quasars

The optical light curve of the quasar PG 1302-102 at z=0.278 shows a 5.2 year periodic signal, detectable over a period of 20 years. The most plausible mechanisms involve a binary supermassive black hole system with a sub-pc separation, where they will likely merge within ~10^5 years due to gravitational wave emission alone. Here, we report the infrared time lags for PG 1302-102 from WISE and Akari missions. We confirm that the periodic behavior reported in the optical light curve is reproduced at infrared, with best-fit 3.4 and 4.6 micron time lags of (2219 ± 153, 2408 ± 148) days for a near face-on orientation of the torus, or (4103 ± 153, 4292 ± 148) days for an inclined system with relativistic Doppler boosting in effect. The periodicity in the infrared light curves and the time lag to the optical support that a source within the accretion disk is responsible for the optical variability of PG 1302-102, echoed at the farther out dusty regions ~1.1-1.3 pc away. We briefly mention ongoing works to constrain the infrared variability and time lags for all the identified periodic quasars, and to relate the quantities to physical origins.

Author(s): Hyunsung David Jun3, Daniel Stern3, Matthew J. Graham[1], Stanislav G. Djorgovski[1], Amy Mainzer3, Roc M. Cutri[2], Andrew J. Drake[1], Ashish A. Mahabal[1]
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429.03 – Near-Infrared Spectroscopic Analysis of Galaxy Mergers: Revealing Obscured Accretion

Galaxy interactions are ubiquitous and are believed to play a pivotal role in the formation and evolution of galaxies via facilitating gas inflows toward the central region of galaxies. These interactions are expected to trigger accretion of matter onto the central supermassive black holes, i.e., AGN activity. Nevertheless, despite decades of searching, observationally confirmed dual AGNs remain extremely rare. We present here a thorough near-infrared characterization of six examples of interacting galaxies with unambiguous confirmation of on-going mergers that are optically quiescent but have red mid-infrared colors that are associated with extragalactic sources with powerful AGN. We show Large Binocular Telescope spectra of nuclear regions that reveal a rich variety of emission and absorption features which allow us to explore several diagnostic tests for the AGN activity as well as for properties of the underlying stellar population. We find strong evidence for AGN emission in five out of these six interacting systems, which provides strong support for the efficiency with which the mid-infrared pre-selection technique finds dual AGN, and thus could exponentially increase the population of dual accretion systems in advanced mergers.

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429.04 – Reverberation mapping of PG 0934+013

We present the variability and time lag measurements of PG 0934+013 based on the photometric and spectroscopic monitoring campaign. We obtained 46 epochs of data from the spectroscopic campaign, which was carried out using the Southern African Large Telescope with ~1 week cadence over two sets of 4 month-long observing period. We also obtained 80 epochs of *B*-band imaging data using the 2-m Faulkes Telescope North and South of the Las Cumbres Observatory Global Telescope Network and the 1-m telescope at the Mt. Lemon Optical Astronomy Observatory. Due to the seven month gap between the two periods, we separately measured the time lag of the Hβ emission line by comparing the emission line light curve with the *B*-band continuum light curve using the cross-correlation function techniques. We determined the time lag of 8.5 ± 2.0 days for Year 2, while the time lag for Year 1 was not constrained. We discuss the estimated black hole mass and the kinematics of broad line region gas based on velocity resolved measurements.

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429.05 – Constraining Quasar Properties with Variability via the Dark Energy Survey and Australian DES

I am using the unique combination of the Dark Energy Survey (DES) and Australian DES to characterize the black hole mass and its immediate environment in quasars. There is a radial temperature gradient in the accretion disk. Time delays across multiple bands can be used to constrain the overall scale of the accretion disk as well as its temperature profile. We have measured photometric time lags as a function of wavelength in over a dozen quasars with the DES data. This is a sizable increase to the number of measured disk sizes. The longer time delay between the continuum and emission lines gives the radius of the broad line region. We apply the virial theorem to calculate black hole masses with these size measurements for the broad line region, combined with the characteristic velocity width of the line. While this has been done for many local active galactic nuclei with the H Beta line, we will make these measurements out to z ~ 4 for other broad lines, as well as greatly expand the sample size. These quasars will provide new radius-luminosity relationships to allow for more accurate single-epoch black hole mass estimates over a large fraction of the age of the universe, especially at the peak of quasar activity.

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Contributing team(s): Dark Energy Survey, Australian DES

429.06 – Integrated Properties of Nearby Seyfert Galaxies Measured by 2-D Spectroscopy

We present our measurements of mosaicing long-slit spectra of 12 nearby Seyfert galaxies. We obtained these data cubes at ~6′′ spatial resolution using the Kast double spectrograph on the 3-m Shane telescope of Lick Observatory. We have measured the integrated emission lines of [O III], Hβ, Hα, [N II], and [S II]. We compare the relative strength of these lines from the galaxy nucleus with the total emission from the entire galaxy. In classification line ratio diagrams (BPT), the individual galaxy moves from the Seyfert region to the composite/star-forming locus as the effective absorbing aperture grows. This trend means that Seyfert galaxies observed at higher redshifts will become increasingly misclassified. We use our sample to quantify this systematic trend. We also estimate the rates of star formation in the host galaxies based on the emission lines.

Author(s): Junjie Xia[1], Matthew Arnold Malkan[1]
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429.07 – Galactic Winds in Galaxies with Active Black Holes

Post-starbursts galaxies are in a rapid transition from star-forming to quiescent, and are excellent candidates to test Active galactic nuclei (AGN) feedback models. A key physical manifestation of AGN feedback is predicted to be galactic-scale powerful winds. We study winds in stacked spectra of 375 post-starburst AGN and of a control sample of star-forming (non-AGN) galaxies, both taken from the Sloan Digital Sky Survey (SDSS). Using a two component (ISM+wind) absorption line model of the Na I 5890,5896 A doublet, after accounting for the stellar photospheric absorption, we find that the post-starburst AGN have a centroid wind velocity shift of -174 +/- 24 km/s and a wind velocity dispersion of 148 +/- 10 km/s. In comparison, the control sample, matched in redshift, stellar mass, axis-ratio, and the 4000 angstrom break index, has a centroid wind velocity shift of -132 +/- 7 km/s and a wind velocity dispersion of 86 +/- 5 km/s. The equivalent widths due to the winds are slightly higher in post-starburst AGN (0.25 +/- 0.03 A) than in the control sample (0.14 +/- 0.01 A) while the ISM contribution to the total equivalent widths is much higher in the AGN (0.62 +/- 0.05 A) than in the control sample (0.15 +/- 0.01 A). The observed winds in the post-starburst AGN are not powerful enough to sweep significant amount gas out of the halos of the host galaxies, thereby cause rapid and permanent quenching of star-formation.

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429.08 – NGC1448 and IC 3639: Two Concealed Black Holes Lurking in our Cosmic Backyard Unveiled by NuSTAR

We present NuSTAR observations of two nearby Active Galactic Nuclei (AGN), NGC 1448 and IC 3639, located at distances of 12 Mpc and 54 Mpc, respectively. NuSTAR high-energy X-ray (> 10 keV) observations, combined with archival lower energy X-ray observations from Chandra and Suzaku, reveal both sources to contain heavily obscured, accreting super-massive black holes. NGC 1448 is one of the nearest luminous galaxies to the Milky Way, yet the AGN at its centre was only discovered in 2009. Using state-of-the-art models, we constrain the obscuring column density (NH) of gas concealing both AGN, finding them to be extreme, with NH values well into the Compton-thick (CT) regime with N(H) > 3e24 /cm2. NGC 1448 has an intrinsic X-ray luminosity of L(24 keV) ~ 5e40 erg/s, making it one of the lowest luminosity CT AGN known. IC 3639, on the other hand, has one of the strongest iron fluorescence emission lines known. We also discuss multi-wavelength diagnostics at optical and mid-infrared energies as indirect indicators to penetrate through the obscuring veils and probe the intrinsic properties of the AGN. Through detailed studies such as we present here, NuSTAR is showing that there are still plenty of interesting discoveries awaiting to be made, even in the nearby Universe.

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430 – Cosmology and Related Topics Late Poster Session

430.01 – Cosmological constraints with weak lensing peak counts and second-order statistics in a large-field survey

Peak statistics in weak lensing maps access the non-Gaussian information contained in the large-scale distribution of matter in the Universe. They are therefore a promising complementary probe to two-point and higher-order statistics to constrain our cosmological models. To prepare for the high precision afforded by next-generation weak lensing surveys, we assess the constraining power of peak counts in a simulated *Euclid*-like survey on the cosmological parameters Ω_m, σ_8, and w_0^{de}. In particular, we study how CAMELUS---a fast stochastic model for predicting peaks---can be applied to such large surveys. The algorithm avoids the need for time-costly N-body simulations, and its stochastic approach provides full PDF information of observables. We measure the abundance histogram of peaks in a mock shear catalogue of approximately 5,000 deg^2 using a multiscale mass map filtering technique, and we then constrain the parameters of the mock survey using CAMELUS combined with approximate Bayesian computation, a robust likelihood-free inference algorithm. We find that peak statistics yield a tight but significantly biased constraint in the σ_8-Ω_m plane, indicating the need to better understand and control the model's systematics before applying it to a real survey of this size or larger. We perform a calibration of the model to remove the bias and compare results to those from the two-point correlation functions (2PCF) measured on the same field. In this case, we find the derived parameter $\Sigma_8 = \sigma_8(\Omega_m/0.27)^\alpha$ = 0.76 (-0.03 +0.02) with α = 0.65 for peaks, while for 2PCF the values are Σ_8 = 0.76 (-0.01 +0.02) and α = 0.70. We conclude that the constraining power can therefore be comparable between the two weak lensing observables in large-field surveys. Furthermore, the tilt in the σ_8-Ω_m degeneracy direction for peaks with respect to that of 2PCF suggests that a combined analysis would yield tighter constraints than either measure alone. As expected, w_0^{de} cannot be well constrained without a tomographic analysis, but its degeneracy directions with the other two varied parameters are still clear for both peaks and 2PCF.

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430.02 – A large sample of binary quasars: Does quasar bias tracks from Mpc scale to kpc scales?

We present the most precise estimate to date of the bias of quasars on very small scales, based on a measurement of the clustering of 47 spectroscopically confirmed binary quasars with proper transverse separations of ~25 h^{-1} kpc. The quasars in our sample, which is an order-of-magnitude larger than previous samples, are targeted using a Kernel Density Estimation technique (KDE) applied to Sloan Digital Sky Survey (SDSS) imaging over most of the SDSS area. Our sample is "complete," in that all possible pairs of binary quasars across our area of interest have been spectroscopically confirmed from a combination of previous surveys and our own long-slit observational campaign. We determine the projected correlation function of quasars (\bar W_p) in four bins of proper transverse scale over the range 17.0 \lesssim R_{prop} \lesssim 36.2 h^{-1} kpc. Due to our large sample size, our measured projected correlation function in each of these four bins of scale is more than twice as precise as any previous measurement made over our {\em full} range of scales. We also measure the bias of our quasar sample in four slices of redshift across the range 0.43 \le z \le 2.26 and compare our results to similar measurements of how quasar bias evolves on Mpc-scales. This measurement addresses the question of whether it is reasonable to assume that quasar bias evolves with redshift in a similar fashion on both Mpc and kpc scales. Our results can meaningfully constrain the one-halo term of the Halo Occupation Distribution (HOD) of quasars and how it evolves with redshift.

This work was partially supported by NSF grant 1515404.

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430.03 – Deep Learning the Universe

Weak gravitational lensing is an effective tool to map the structure of matter in the universe, and has been used for more than ten years as a probe of the nature of dark energy. Beyond the well-established two-point summary statistics, attention is now turning to methods that use the full statistical information available in the lensing observables, through analysis of the reconstructed shear field. This offers an opportunity to take advantage of powerful deep learning methods for image analysis. We present two early studies that demonstrate that deep learning can be used to characterise features in weak lensing convergence maps, and to identify the underlying cosmological model that produced them.
We developed an unsupervised Denoising Convolutional Autoencoder model in order to learn an abstract representation directly from our data. This model uses a convolution-deconvolution architecture, which is fed with input data (corrupted with binomial noise to prevent over-fitting). Our model effectively trains itself to minimize the mean-squared error between the input and the output using gradient descent, resulting in a model which, theoretically, is broad enough to tackle other similarly structured problems. Using this model we were able to successfully reconstruct simulated convergence maps and identify the structures in them. We also determined which structures had the highest "importance" - i.e. which structures were most typical of the data. We note that the structures that had the highest importance in our reconstruction were around high mass concentrations, but were highly non-Gaussian.
We also developed a supervised Convolutional Neural Network (CNN) for classification of weak lensing convergence maps from two different simulated theoretical models. The CNN uses a softmax classifier which minimizes a binary cross-entropy loss between the estimated distribution and true distribution. In other words, given an unseen convergence map the trained CNN determines probabilistically which theoretical model fits the data best. This preliminary work demonstrates that we can classify the cosmological model that produced the convergence maps with 80% accuracy.

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430.04 – The Primordial Inflation Polarization Explorer (PIPER)

We present an overview of PIPER, the Primordial Inflation Polarization Explorer. PIPER is a balloon-borne telescope designed to map the large scale polarization of the Cosmic Microwave Background as well as the polarized emission from galactic dust at 200, 270, 350, and 600 GHz, with 21, 15, 14, and 14 arcminutes of angular resolution respectively. PIPER uses twin telescopes with Variable-delay Polarization Modulators to simultaneously map Stokes I, Q, U and V. Cold optics and the lack of a warm window allow the instrument to achieve background limited sensitivity. Over the course of 8 conventional balloon flights from the Northern and Southern hemisphere, PIPER will map 85% of the sky, measuring the B-mode polarization spectrum from the reionization bump to l~300, and placing an upper limit on the tensor-to-scalar ratio of r<0.007. PIPER's first science flight will be in June 2017 from Palestine, Texas.

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430.05 – Massive Black Hole Binary Mergers and their Gravitational Waves

Gravitational Waves (GW) from stellar-mass BH binaries have recently been observed by LIGO, but GW from their supermassive counterparts have remained elusive. Recent upper limits from Pulsar Timing Arrays (PTA) have excluded significant portions of the predicted parameter space. Most previous studies, however, have assumed that most or all Massive Black Hole (MBH) Binaries merge effectively and quickly. I will present results derived—for the first time—from cosmological, hydrodynamic simulations with self-consistently coevolved populations of MBH particles. We perform post-processing simulations of the MBH merger process, using realistic galactic environments, including models of dynamical friction, stellar scattering, gas drag from a circumbinary disk, and GW emission—with no assumptions of merger fractions or timescales. We find that despite only the most massive systems merging effectively (and still on gigayear timescales), the GW Background is only just below current detection limits with PTA. Our models suggest that PTA should make detections within the next decade, and will provide information about MBH binary populations, environments, and even eccentricities. I'll also briefly discuss prospects for observations of dual-AGN, and the possible importance of MBH triples in the merger process.

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430.06 – The Wave Turbulence Approach to Gravitational Collapse in Anti-de Sitter Space

Over the last few decades there has been a great deal of research relating gravity to the dynamics of fluids. In the weakly turbulent regime fluids can be described using the formulation of wave turbulence rather than full-blown Kolmogorov turbulence, which uses vortices. It is with these two ideas in mind that we construct the wave equation describing gravitational collapse of a scalar field in anti de-Sitter (AdS) space using Einstein's field equations. By using the appropriate limits we reach a solution with truncated terms for increasingly complicated mode interactions. While this formulation has implications in the AdS/CFT correspondence we are more concerned with the implications of this wave turbulence formulation as it relates to gravitational waves in asymptotically flat space. When there is negligible interaction between modes the wave acts as a simple harmonic oscillator, but for nonlinear time scales ($\sim 1/A^{2}$) the interactions become important and we simulate the cascade from one mode of the wave to the next using numerical techniques. Future research will be focused on geometrodynamics as it relates to compact objects and the analysis of data being generated by gravitational wave interferometers.

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430.07 – Gravitational lensing of gravitational wave

Gravitational lensing phenomena are widespread in electromagnetic astrophysics, and in principle may also be uncovered with gravitational waves. We examine gravitational wave events lensed by elliptical galaxies in the limit of geometric optics, where we expect to see multiple signals from the same event with

different arrival times and amplitudes. By using mass functions for compact binaries from population-synthesis simulations and a lensing probability calculated from Planck data, we estimate the rate of lensed signals for future gravitational wave missions.

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431 – Neutron Stars & Friends Late Poster Session

431.01 – Exploring the Physical Conditions in Millisecond Pulsar Emission Regions

The five-component profile of the 2.7-ms pulsar J0337+1715 appears to exhibit the best example to date of a core/double-cone emission-beam structure in a millisecond pulsar (MSP). Moreover, three other MSPs, the Binary Pulsar B1913+16, B1953+29 and J1022+1001, seem to exhibit core/single-cone profiles. These configurations are remarkable and important because it has not been clear whether MSPs and slow pulsars exhibit similar emission-beam configurations despite having radically different magnetospheric sizes and magnetic field strengths. MSPs thus provide an extreme context for studying pulsar radio emission. Particle currents along the magnetic polar fluxtube connect processes just above the polar cap through the radio-emission region to the light-cylinder and the external environment. In slow pulsars radio-emission heights are typically about 500 km where the magnetic field is nearly dipolar, and estimates of the physical conditions there point to radiation below the plasma frequency and emission from charged solitons by the curvature process. We are able to estimate emission heights for the four MSPs and carry out a similar estimation of physical conditions in their much lower emission regions. We find strong evidence that MSPs also radiate by curvature emission from charged solitons.

Author(s): Joanna M. Rankin[1]
Institution(s): *1. Univ. of Vermont*

431.02 – Polarization Behavior Across Profile Modes For B0329+54: What Consistent Non-RVM Polarization Tells About the Emission Processes

In this paper, we analyze the quirky polarization behavior across different profile modes for the pulsar B0329+54. We have multi-frequency observations in both the normal and abnormal profile modes, and have identified a non-RVM polarization kink in the core component of the emission. Mitra et al initially identified this kink in the normal profile mode of the pulsar in 2007, and a mirror analysis has been done here for abnormal profile modes at three different frequencies. This kink is intensity dependent, showing up only in the abberated/retarded high intensity pulses, and is frequency independent. This parallel between profile modes shows that the same geometric phenomenon—a height dependent amplifier—is responsible for the non-RVM polarization behavior in each. The question then arises: what can be the source of the profile change, which does not change the polarization characteristics of the pulsar. This pulsar gives us a unique opportunity to study the process of pulsar emission by showing what cannot be responsible for switches in profile mode, and thus profile shape.

Author(s): Casey Brinkman-Traverse[2], Joanna M. Rankin[2], Dipanjan Mitra[1]
Institution(s): *1. NCRA, TIFR, 2. University of Vermont*

431.03 – Single Pulse Searches for Pulsars in the Galactic Center

The discovery of the magnetar J1745-2900 within 3'' of Sgr A* by Mori et al. (2013) has renewed strong interest in Galactic Center (GC) pulsars and motivated expanded searches for their pulses due to their extensive applications to gravitational and plasma physics. There are currently 5 known pulsars within 15' of the Sgr A*; however, gamma ray excesses from the GC suggest a source population of 10^2-10^3 millisecond pulsars within the same region. Although this discrepancy is readily explained by the hyper-strong scattering environment of the GC which obscures pulses, the discovery of J1745-2900 challenges this attribution and further observations and analysis are needed to reconcile the observed GC pulsar population with theory. We present a pipeline developed to search for these "missing" GC pulsars using a single pulse search algorithm. Observations of the GC using the Deep Space Network 70m antenna were taken in the high frequency regime in order to minimize scattering, and search parameters were calibrated using pulses from RRAT J1819-1458. Any detected pulses that are distinct from those of J1745-2900 warrant extensive follow-up observations and analysis, and confirmed new members of the elusive GC pulsar population would be incredibly valuable as probes of the GC's magnetic and potential fields.

Author(s): Daniel Joseph Cushey[1], Walid A. Majid[2], Thomas Allen Prince[1]
Institution(s): *1. California Institute of Technology, 2. Jet Propulsion Laboratory*

431.04 – Searching for Magnetar SGR 0755-2933

We observed SGR 0755-2933 in multiple sessions using C-band to observe it at the middle frequency of 6 GHz and S-band to observe it at 2 GHz.
Although other radio telescopes have attempted to detect this candidate magnetar, the main thing we wanted to do differently with the Green Bank Radio Telescope is to observe it at high frequencies. We decided to do this because the Chandra X-ray spectrum hinted at there being a high column of neutral hydrogen density which could mean more scattering and mean the possibility of a high dispersion measurement. In high frequencies, high DM doesn't effect the magnetar signal as much. Also higher frequencies are better to detect a magnetar's signal because the intensity of the pulses increase.

We performed a single pulse search since magnetars have long periods and period pulses could get lost in the noise. SGR 0755-2933 was observed in X-ray to have a long rotational period of 308 which is unprecedented. This could mean it has the strongest known magnetic field being 10^16 G or would change our understanding of neutron stars magnetic field theory. Unfortunately, we were unable to detect a strong signal so we cannot confirm whether SGR 0755-2933 is a magnetar and even more specifically a radio magnetar, the 5th known radio magnetar. With no radio data, we cannot do pulsar timing, calculate spin down nor confirm if this magnetar is in a binary system with a main sequence star.

Author(s): Amanda Harrison[1]
Institution(s): *1. Green Bank Telescope*
Contributing team(s): Ryan Lynch, NRAO Green Bank Telescope

431.05 – Contrasting Magnetohydrodynamic Turbulence with alpha-Viscosity in Simulations of Black Hole Accretion

Many analytic, semi-analytic, and even some numerical treatments of black hole accretion parametrize the stresses within the disk as an effective viscosity, even though the true source of stresses is likely to be turbulence driven by the magneto-rotational instability. Despite some attempts to quantify the differences between these treatments, it remains unclear exactly what the consequences of a viscous treatment are, especially in the context of the temporal and spatial variability of global disk parameters. We use the astrophysics code, Cosmos++, to create two accretion disk simulations using alpha-viscosity, one thin and one thick. These simulations are then compared to similar work done using MHD in order to analyze the extent of the validity of the alpha-model. One expected result, which we, nevertheless, demonstrate is the greater spatial and temporal variability of MHD.

Author(s): P. Christopher Christopher Fragile[2], Sarina Marie Etheridge[2], Peter Anninos[3], Bhupendra Mishra[1]
Institution(s): *1. CAMK, 2. College of Charleston, 3. Lawrence Livermore National Laboratory*

431.06 – Signatures of strong gravity in the light curves of tidal disruption events

A star whose orbit takes it on a sufficiently close approach to a massive black hole (MBH) will be shredded by the black hole's tides. Accretion of stellar debris on the MBH gives rise to a characteristic light curve which has been used as a smoking gun in observational searches for tidal disruption events (TDEs) in the past 20 years. Disruptive encounters that occur very close to the MBHs are subject to relativistic effects, leading to an intriguing possibility that information about the space-time of an MBH can be encoded in the light curve of a TDE. We explore the effect on the fallback rate of the general relativistic precession of the debris deep in the potential well of a Schwarzschild MBH. We investigate the distribution of orbital energy and angular momentum of the debris in such scenarios and use it to assess the magnitude of relativistic effects that may be imprinted in the light curves of TDEs.

Author(s): Júlia Alsina Oriol[1], Tamara Bogdanovic[1]
Institution(s): *1. Georgia Institute of Technology*

431.07 – Tracking the Disk Wind Behavior of MAXI J1305-704

There is still much to be understood about black hole accretion disks and their relationship to black hole disk winds. In an attempt to better understand these relationships, we have analyzed the x-ray transient black hole binary MAXI J1305-704 during its outburst in 2012 in order to draw conclusions about the parameters of its disk. The source showed strong absorption signs, as detected by Chandra, on April 21, 2012. From this date on, we analyzed SWIFT observations of the source, using XSPEC from HEASOFT, in order to find strong signals of absorption. By modeling 67 successive observations over the period of 74 days, we were able to closely track the evolution of various disk properties, from inner disk temperature, to power law index, to column density. We could also analyze various parameter relationships in order to determine if there is a statistically significant correlation between any of the properties of a disk. We found that there are strong linear relationships between disk temperature & ionization, photon index & disk temperature, and photon index & ionization. These relationships seem to imply that the corona, in addition to the disk, may be driving the wind properties. Additionally, the counterintuitive relationship between disk temperature and ionization, where disk temperature increases as ionization decreases, seems to imply that there are mechanisms at play in the disk system that are not yet fully understood.

Author(s): Kimberly Poppy Sinclair[1], Jon M. Miller[1]
Institution(s): *1. University of Michigan*

431.08 – Mass Constraints on the Black Hole Candidate in M62

We present initial results in constraining the mass of the accretor in M62-VLA1 through the radial velocity curve of the donor star. Observations were made with the STIS instrument onboard HST, and supplemented with data from the MUSE instrument at the VLT. Through double peaked, transient H alpha emission and filling of other Balmer lines, the optical spectrum shows clear evidence of a variable, low accretion rate. The donor star is an early G / late F subgiant, with some small variation in effective temperature in some observations. Here we show the best fit radial velocity curve for the donor star and the posterior mass distribution folded through possible inclination angles and mass ratios, and compare this mass probability distribution to other known compact objects.

Author(s): Christopher Britt[3], Jay Strader[3], Laura Chomiuk[3], Thomas J. Maccarone[4], Laura Shishkovsky[3], James Miller-Jones[1], Vlad Tudor[1], Evangelina Tremou[3], Arash Bahramian[3], Sebastian Kamann[2]
Institution(s): *1. Curtin University, 2. Institute for Astrophysics Göttingen , 3. Michigan State University, 4. Texas Tech University*

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432 – Star Formation, Young Stars and Clusters Late Poster Session

432.01 – Revealing the Jets in the BHR 71 Protostellar System

The BHR 71 low-mass protostellar binary system powers two highly collimated outflows, with the outflow from the primary (IRS1) producing shock-induced chemical activity only seen in a handful of other outflows (notably L1157, but also L1448 and IRAS04166). This may represent a very short phase in the outflow process that we don't yet understand. The shocks are likely caused by jets with velocities > 50 km/s impacting on the ambient material, but unlike in the other outflows mentioned above, no such jet has yet been identified in BHR 71, although hints are found in low-resolution Herschel water observations. We report on ALMA observations of SiO toward both protostars within BHR 71, with surprising results.

Author(s): Tyler L. Bourke[3], John J. Tobin[4], Antoine Gusdorf[1], Hector G. Arce[5], Mario Tafalla[2]
Institution(s): *1. LERMA/ENS, 2. OAN, 3. SKA Organisation, 4. University of Oklahoma, 5. Yale*

432.02 – High Resolution SOFIA/EXES Spectroscopy of CH_4 and SO_2 toward Massive Young Stellar Objects

The ro-vibrational transitions of molecules in the near to mid-infrared are excellent tracers of the composition, dynamics, and excitation of the inner regions of Young Stellar Objects (YSOs). They sample a wide range of excitations in a short wavelength range, they can be seen in absorption against strong hot dust continuum sources, and they trace molecules without permanent dipole moment not observable at radio wavelengths. In particular, at high infrared spectral resolution, spatial scales smaller than those imaged by millimeter wave interferometers can be studied dynamically.

We present high resolution ($R=\lambda/\Delta\lambda\sim$50,000-100,000; 6-12 km/s) infrared (7-8 μm) spectra of massive YSOs observed with the Echelon-Cross-Echelle Spectrograph (EXES) on the Stratospheric Observatory For Infrared Astronomy (SOFIA). Absorption lines of gas phase methane (CH_4) are detected in our Cycle 2 observations. CH_4 is thought to be a starting point of the formation of carbon chain molecules. Abundances are derived in the different dynamical regions along the sight-line towards the central star by comparing the line profiles to those of CO and other species observed at ground based facilities such as EXES' sister instrument TEXES at IRTF and Gemini. A search is also conducted for sulfur-dioxide, using data from our ongoing Cycle 4 program. SO_2 was previously detected towards these massive YSOs with the space-based ISO/SWS instrument (Keane et al. 2001, A&A 376, L5) at much lower spectral resolution (R~2,000). At high spectral resolution we should be able to pin-point the dynamical location of this SO_2 gas. Up to 98% of the sulfur in dense clouds and protostellar envelopes is presently missing, and we are searching for that with the EXES/SOFIA observations.

Author(s): Abraham C. A. Boogert[7], Matt Richter[5], Curtis DeWitt[5], Nick Indriolo[4], David A. Neufeld[3], Agata Karska[1], Edwin A. Bergin[6], Rachel L. Smith[2], Edward Montiel[5]
Institution(s): *1. Adam Mickiewics University, 2. Appalachian State University, 3. Johns Hopkins University, 4. STScI, 5. UC Davis, 6. University of Michigan, 7. USRA-Stratospheric Observatory for Infrared Astronomy, NASA Ames Research Center*

432.03 – Size Distribution of Star Clusters and Stellar Groups in IC2574

We present an HST/ACS archival study of compact and dispersed star clusters and stellar groups found in the nearby galaxy IC 2574. In this work, we identified and characterized the properties of clusters with spatially unresolved stars. We combined these properties with those found in a companion work on the dispersed stellar groups in IC 2574 with spatially resolved stars. We find that the size distribution of all young stellar groups, sparse and compact together, is consistent with the hierarchical model of star formation.

Author(s): Anne Pellerin[2], Martin J. Meyer[1], Daniela Calzetti3
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433 – Stars of Many Stripes Late Poster Session

433.01 – Investigation into the Morphology and Temporal Variability of Auroral Hα Emission from LSR J1835+3259

The emergence of auroral phenomena at the end of the main sequence has been heralded by the detections of strong radio pulses in the atmospheres of ultracool dwarfs. These findings have been led by the detailed study of benchmark targets, like LSR J1835+3259, displaying the key observations indicative of auroral radio emission and the corresponding auroral surface features (Hallinan et al. 2015). Building on these findings, I present a preliminary investigation into the morphology and variability of the Hα emission of LSR J1835+3259 using high-resolution optical spectroscopy with Keck HIRES. We monitored the target for a full night to determine the shape of the Hα line profile and how the profile changes with rotational period. We examined these profiles to determine the nature of the emission and reconstruct the stellar emission surface through doppler imaging techniques. We find that the emission is consistent with a high-latitude auroral surface feature being responsible for the rotationally varying Hα emission.

Author(s): J. Sebastian Pineda[1], Gregg Hallinan[1], Stuart Littlefair[4], Chris Watson[2], Gibor S. Basri3
Institution(s): *1. Caltech, 2. Queen's University - ARC, 3. UC Berkeley, 4. University of Sheffield*

433.02 – Using Model Point Spread Functions to Identifying Binary Brown Dwarf Systems

A Brown Dwarf (BD) is a celestial object that is not massive enough to undergo hydrogen fusion in its core. BDs can form in pairs called binaries. Due to the great distances between Earth and these BDs, they act as point sources of light and the angular separation between binary BDs can be small enough to appear as a single, unresolved object in images, according to Rayleigh Criterion. It is not currently possible to resolve some of these objects into separate light sources. Stephens and Noll (2006) developed a method that used model point spread functions (PSFs) to identify binary Trans-Neptunian Objects, we will use this method to identify binary BD systems in the Hubble Space Telescope archive. This method works by comparing model PSFs of single and binary sources to the observed PSFs. We also use a method to compare model spectral data for single and binary fits to determine the best parameter values for each component of the system. We describe these methods, its challenges and other possible uses in this poster.

Author(s): Kyle Matt[1], Denise C. Stephens[1], Leanne T Lunsford[1]
Institution(s): *1. Brigham Young University*

433.03 – Searching for GALEX FUV and NUV Detections of BOSS Ultracool Dwarfs

We present the results of a search for GALEX ultraviolet (1350-2800A) detections of late-M and L dwarf stars in the BOSS Ultracool Dwarf sample.

Author(s): Jonathan Wheatley[2], Sarah J. Schmidt[1], Barry Welsh[2]
Institution(s): *1. AIP Leibniz, 2. University of California Berkeley*

433.04 – The Red Supergiants of M33: Determining Physical Properties

We investigate a sample of red supergiants in the nearby unbarred spiral galaxy M33 with the goals of (1) determining the physical properties of these stars, (2) understanding the effects of metallicity on massive star evolution, and (3) comparing results to current models proposed by the Geneva group. M33 provides an ideal environment in which to conduct this examination because of a gradient of metallicity within its disk as well as its proximity to the Milky Way, which allows us to observe a complete sample of red supergiants. We employ MARCS atmosphere models and fit spectral features of our stars to determine effective temperatures and spectral types, then we use this information in combination with photometry to calculate bolometric luminosities. After placing these objects on the H-R diagram, we notice some discrepancies with what the Geneva solar-metallicity evolutionary tracks (Ekstrom et al. 2012) predict, namely that the tracks may not extend to cool enough temperatures and high enough luminosities and masses to comply with what we see observationally. We propose this may be the result of a mismatch between M33's metallicity and the solar-metallicity Geneva models; we hope to make comparisons in the future as these new evolutionary tracks become available. This work was supported by the NSF through grant numbers AST-1461200 and AST-1612874.

Author(s): Madeleine Beck[2], Philip Massey[1]
Institution(s): *1. Lowell Observatory, 2. Wellesley College*

433.05 – Regimes of Internal Rotation in Differentially Rotating White Dwarfs

Most viable models of Type Ia supernovae (SN Ia) require the thermonuclear explosion of a carbon/oxygen white dwarf that has evolved in a binary system. Rotation could be an important aspect of any model for SN Ia, whether single or double degenerate, with the white dwarf mass at, below, or above the Chandrasekhar limit. Differential rotation is specifically invoked in attempts to account for the apparent excess mass in the super--Chandrasekhar events. Some earlier work has suggested that only uniform rotation is consistent with the expected mechanisms of angular momentum transport in white dwarfs, while others have found pronounced differential rotation. We show that if the baroclinic instability is active in degenerate matter and the effects of magnetic fields are neglected, both nearly-uniform and strongly-differential rotation are possible. We classify rotation regimes in terms of the Richardson number, Ri. At small values of Ri < 0.1, we find both the low-viscosity Zahn regime with a non-monotonic angular velocity profile and a new differential rotation regime for which the viscosity is high and scales linearly with the shear, σ. Employment of Kelvin-Helmholtz viscosity alone yields differential rotation. Large values of Ri >> 1 produce a regime of nearly-uniform rotation for which the baroclinic viscosity is of intermediate value and scales as σ^3. We discuss the gap in understanding of the behavior at intermediate values of Ri and how observations may constrain the rotation regimes attained by nature.

Author(s): J. Craig Wheeler[2], Pranab Ghosh[1]
Institution(s): *1. Tata Institute of Fundamental Research, 2. Univ. of Texas*

433.06 – The Betelgeuse Project: Constraints from Rotation

In order to constrain the evolutionary state of the red supergiant Betelgeuse, we have produced a suite of models with ZAMS masses from 15 to 25 Msun in intervals of 1 Msun including the effects of rotation computed with the stellar evolutionary code MESA. For non--rotating models we find results that are similar to other work. It is somewhat difficult to find models that agree within 1 σ of the observed values of R, T_{eff} and L, but modestly easy within 3 σ uncertainty. Incorporating the nominal observed rotational velocity, ~15 km/s, yields significantly different, and challenging, constraints. This velocity constraint is only matched when the models first approach the base of the red supergiant branch (RSB), having crossed the Hertzsprung gap, but not yet having ascended the RSB and most violate even generous error bars on R, T_{eff} and L. Models at the tip of the RSB typically rotate at only ~0.1 km/s, independent of any reasonable choice of initial rotation. We discuss the possible uncertainties in our modeling and the observations, including the distance to Betelgeuse, the rotation velocity, and model parameters. We summarize various options to account for the rotational velocity and suggest that one possibility is that Betelgeuse merged with a companion star of about 1 Msun as it ascended the RSB, in the process producing the ring structure observed at about 7' away. A past coalescence would complicate attempts to understand the evolutionary history and future of Betelgeuse. To that end, we also present asteroseismology models with acoustic waves driven by inner convective regions that could elucidate the inner structure and evolutionary state.

Author(s): Manuel Diaz[1], Sarafina Nance[1], James Sullivan[1], J. Craig Wheeler[1]
Institution(s): *1. The University of Texas at Austin*

433.07 – Magnesium Amplification: The Last Missing Piece in Integrated Light Studies

We have gauged the effects of altered C, N, O, Si, Na, and Fe, each element separately varied, on stellar evolutionary isochrones. Stellar temperatures, luminosities, and lifetimes in each evolutionary phase are affected. The effects have been gauged by using the MESA "star" routines with altered chemical mixtures for $0.06 < M < 3.0$ assuming a gray atmosphere outer boundary condition. Due to numerical glitching, there is considerable difficulty in reducing the effects to easily summarized trends. We describe two polynomial based methods for extracting the trends in lifetime, L, and T as a function of stellar parameters and chemical composition. The temperature effects were carried through to integrated light models and then compared to galaxy observations.

"Magnesium amplification" is a hypothetical positive feedback where enhancement of (only) one element causes a slight cooling of the giant branch, increasing the line strength beyond the increase expected from increased numbers of absorbers. Our experiment shows that magnesium amplification is real, but that it mostly arises in dwarfs, not giants. Applied to elliptical galaxies, the literature enhancement of Mg is often quoted as [Mg/Fe] = 0.3, but with this effect properly included, for an abundance pattern approximating that of giant elliptical galaxies, that drops to [Mg/Fe] = 0.15. Similar, large recalibrations will apply to all of the most abundance heavy elements, significantly altering our perception of the giant elliptical abundance mixture.

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Author(s): Guy Worthey[1]
Institution(s): *1. Washington State Univ.*

433.08 – The Diversity of Chemical Composition and the Effects on Stellar Evolution and Planetary Habitability

For my dissertation under the supervision of Dr. Young, I investigate how stars of different mass and composition evolve, and how stellar evolution impacts the location of the habitable zone around a star. Current research into habitability of exoplanets focuses mostly on the concept of the classical HZ – the range of distances from a star over which liquid water could exist on a planet's surface – determined primarily by the host star's luminosity and spectral characteristics. With the ever-accelerating discovery of new exoplanets, it is imperative to develop a more complete understanding of what factors play a role in creating the “habitable” conditions of a planet. I discuss how stellar evolution is integral to how we define a HZ, and how this work will apply to the search for habitable Earth-like planets in the future.

I developed a catalog of stellar evolution models for Sun-like stars with variable compositions; masses range from 0.1-1.2 Msol (spectral types M4-F4) at scaled metallicities of 0.1-1.5 Zsol, and O/Fe, C/Fe, and Mg/Fe values of 0.44-2.28, 0.58-1.72, and 0.54-1.84, respectively. I use a spread in abundance values based on observations of variability in nearby stars. It is important to understand how specific elements (and not just total metallicity) can impact evolutionary lifetime. The time-dependent HZ boundaries have also been calculated for each stellar track. Additionally, I recently created a grid of models for M-dwarfs, and I am currently working to make preliminary estimates of stellar activity vs. age for each representative star in the catalog.

My results indicate that to gauge the habitability potential of a given system, both the evolutionary history as well as the detailed chemical characterization of the host star must be considered. This work can be used to assess whether a planet discovered in the HZ of its star has had sufficient time to develop a biosphere capable of producing detectable biosignatures. The catalog is designed for use by the astrobiology and exoplanet communities to characterize stars and their surrounding HZs for real planetary candidates of interest.

Author(s): Amanda Truitt[1], Patrick A. Young[1]
Institution(s): *1. Arizona State University, School of Earth and Space Exploration*

433.09 – BVRI Photometric Study of V1695 Aquilae, an Extreme Mass Ratio, High fill-out Contact Binary

CCD, BVRI light curves of **V1695 AQL** were taken during the Fall 2016 season at the Cerro Tololo InterAmerican Observatory with the 0.6-m reflector of the SARA South observatory in remote mode. It is an eclipsing binary with a period of 0.4128251d. The light curves yield a total eclipse (eclipse duration: 51 minutes) but all have amplitudes of only ~0.3 mags. The spectral type is ~G8V (~5500 K). Four times of minimum light were calculated, all primary eclipses, from our present observations:

HJD I = 2457614.68359 ±0.0002, 2457634.49320 ±0.00037, 2457636.56250 ±0.00006, and 2457635.68247 ±0.00002d

The following quadratic ephemerides was determined from all available times of minimum light.

JD Hel MinI = 2457636.56135±0.00131d + 0.4128407±0.000011 $\times$ E + 0.00000000097 ±0.00000000009 $\times$ E^2

A 14 year period study reveals a period increase in the orbital period with high confidence. Thus, the mass ratio may be tending to more extreme values as the binary coalesces. The solution is that of an Extreme Mass Ratio Binary. The mass ratio is only 0.15. Its Roche Lobe fill-out is a hefty 42%. As expected in binaries of this type, it has cool spot regions. The secondary component has a temperature of ~5800 K, which makes it a W-type W UMa Binary. More details of our results will be given.

Author(s): Ronald G. Samec[2], Daniel B. Caton[1], Danny R. Faulkner[4], Walter V. Van Hamme[3], Christopher R Gray[2]
Institution(s): *1. Dark Sky Observatory, Appalachian State University, 2. Emmanuel College, 3. Florida International University, 4. University of South Carolina, Lancaster*

433.10 – Characterization of Detached Main Sequence Binaries Observed by Kepler, SDSS(APOGEE) and Gaia

In addition to finding planets, the Kepler Observatory obtained high precision light curves of eclipsing binaries that have subsequently been observed by SDSS and Gaia. Main sequence eclipsing binaries are important laboratories for stellar astrophysics. The determination of precise temperatures, radii, masses, and orbital parameters constrain evolution theory. We examined 28 main sequence binaries observed using Kepler, SDSS(APOGEE) and Gaia. Combining observed astrometric, photometric, and spectroscopic data places strong constraints on stellar and binary characteristics. We compare derived parameters with model calculations of these binaries and present preliminary results.

Author(s): Christina Oleander Solis[1], Paul A. Mason[1]
Institution(s): *1. NMSU-DACC*

433.11 – Eclipsing Binary Star Detection Using Kepler

Eclipsing binaries (EBs) are laboratories for precision astrophysics, because use of the orbital information of the system allows the determination of the physical parameters of the stars to a much higher degree of precision than is possible for single stars. The Kepler Space Telescope, while designed to hunt for planets, has also been a valuable tool in detecting and characterizing EBs and has already observed over 2200 specimens. Kepler suffered a failure in 2013 that affected its pointing ability, but some ingenious engineering adjustments have allowed it to continue collecting photometric data from new fields of view. Our goals were to develop an algorithm for EB detection using Kepler data, and then with the help of FGCU's K2 Aperture Photometry Pipeline to extend that algorithm to discover new EBs in the K2 fields. Here we report on our progess to date as well as future plans.

Author(s): Ekaterina Vydra[1], Derek L. Buzasi[1]
Institution(s): *1. Florida Gulf Coast University*

433.12 – Dynamical Tide in Action: Tidally Excited Oscillations in Kepler Heartbeat Stars

We perform a global variability study of heartbeat stars, a class of eccentric binaries whose light curves resemble a cardiogram. The equilibrium tide is modeled by the light curve synthesis code ELC, taking advantage of the information of many possible stellar pairings from a MESA isochrone.
We examine the power spectra of light curve residuals closely, searching for signatures of rotation and oscillations. Special attention is given to systems that show tidally excited oscillations/pulsations. Pulsation phases (w.r.t periastron passage) are extracted to identify the azimuthal number m, the degree of detuning (i.e., the difference between the driving frequency and the intrinsic eigenfrequency of stars), and the possibility of resonance-locking. To study non-linear mode coupling, we also search for tidally excited non-orbital-harmonic frequencies.
For four particular double-lined systems with Keck HIRES spectra, we derive the orbital and fundamental parameters which can lead to further detailed asteroseismic modeling.

Author(s): Zhao Guo[1], Douglas R. Gies[1], Avi Shporer[2], Jim Fuller[2], Howard T. Isaacson3
Institution(s): *1. Georgia State University, 2. JPL,Caltech, 3. University of California, Berkeley*
Contributing team(s): Kepler Eclipsing Binary Working Group

433.13 – BVRI Photometric Study of the Twin, Detached, Near-Contact W UMA Binary, GQ Cancri

CCD BV$R_c I_c$ light curves of GQ Cancri were observed in April, 2013 on the SARA North 0.9-m Telescope at Kitt Peak National Observatory in Arizona in remote mode. It is a high amplitude (V~0.9-mag) K0-type eclipsing binary (T_1~5250 K) with a photometrically determined mass ratio of M_2/M_1= 0.99. Its spectral type classifies it as a pre-contact W UMa Binary (PCWB). Binary Maker fits and the Wilson-Devinney Mode 2 solutions show that the binary has a detached binary configuration with fill-outs of 94 and 98% for the primary and secondary component, respectively. As expected, the light curve is asymmetric due to spot activity.
Three times of minimum light were calculated, for 2 primary and 1 secondary eclipses from our present observations:
HJD I = 2456390.66196±0.00002, 2456406.7056±0.0001
HJD II = 2456405.6505±0.0002
In total, some 20 times of minimum light covering 17 years of observation were used to determine the following linear ephemeris:
JDHelMinI=2456406.70556±0. 00088d + 0. 42220887± 0.00000009 × E
An ephemeris with a weak negative quadratic term with a one probable error significance.
It is noted that the solution remained in a detached state for every iteration of the computer runs. The components are truly twins with a computed temperature difference of only 25 K, with the flux of the primary component accounting for 52% of the systems light in B,V,R_c and I_c. A 15 degree equatorial hot spot was iterated on the primary component.

Author(s): Daniel B. Caton[1], Ronald G. Samec[2], Amber Olsen[2], Walter V. Van Hamme3, Danny R. Faulkner4
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433.14 – Numerical Simulations of Close and Contact Binary Systems Having Bipolytropic Equation of State

I present the results of the numerical simulations of the mass transfer in close and contact binary systems with both stars having a bipolytropic (composite polytropic) equation of state. The initial binary systems are obtained by a modifying Hachisu's self-consistent field technique. Both the stars have fully resolved cores with a molecular weight jump at the core-envelope interface. The initial properties of these simulations are chosen such that they satisfy the mass-radius relation, composition and period of a late W-type contact binary system. The simulations are carried out using two different Eulerian hydrocodes, Flow-ER with a fixed cylindrical grid, and Octo-tiger with an AMR capable cartesian grid. The detailed comparison of the simulations suggests an agreement between the results obtained from the two codes at different resolutions. The set of simulations can be treated as a benchmark, enabling us to reliably simulate mass transfer and merger scenarios of binary systems involving bipolytropic components.

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433.15 – Characterizing RR Lyraes using SDSS, Single-Epoch Spectroscopy

Starting with Data Release-7, the Sloan Digital Sky Survey (SDSS) has made available the single-epoch spectra (SES) that were previously combined to produce the final composite spectra available for stars and galaxies. These SES can be used to probe time-variability through spectral line strength variations. RR Lyrae stars (RRL) have typically been identified using periodic variations in their light curves. Today, using the SDSS-SES it is possible to, in some cases, identify RRL from changes in the line strengths of the Ca-IIK, H-β, H-γ, and H-δ lines. Similarly, it is possible to construct composite spectra that are free of phase-blending, by grouping SES that have similar spectral line strengths, for an individual star. We have developed a method for comparing SES with synthetic spectra spanning a range of T = [5500,8500]K, log g = [1.0-4.0] and [Fe/H]=[-3.0-0.0] to produce temperatures, surface gravities and metallicities for all SES taken for a given star. Using this method we are able to search for variations in temperature that are 2-sigma beyond the computed uncertainty, indicating that spectral variation is occurring. We will show results using a sample of bright RRL stars of known pulsation phase and stars from SDSS-Stripe82 which have published light curves for several hundred RRLs. We will also present a temperature-phase diagram that shows stars with consistent phases can be produced allowing us to construct composite spectra that are of the same phase for a given star. This is crucially important to the accurate determination of metal abundance for stars in the SDSS spectral foot-print. We will also show details of the compiled Catalina Surveys for stars with SDSS spectroscopy.

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433.16 – In Search of Stellar Music: Finding Pulsators for the TESS Mission

The Transiting Exoplanet Survey Satellite (TESS) will search for small transiting exoplanets orbiting bright stars. One of the additional mission objectives is to observe oscillating variable stars to precisely measure these stars' masses, radii, and internal structures. Since TESS can observe only a limited number of stars with high enough cadence to detect these oscillations, it is necessary to identify candidates that will yield the most valuable results. Using data from the Kilodegree Extremely Little Telescope (KELT), we searched for bright stars showing oscillations to be included as TESS targets. We found 2,108 variable stars with B-V < 0.5 and P < 5 days. Further analysis will be carried out to establish final candidates. This project was funded by the National Science Foundation grant PHY-1359195 to the Lehigh University REU program.

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Contributing team(s): KELT Collaboration

433.17 – Searching for frequency multiplets in the pulsating subdwarf B star PG 1219+534

Subdwarf B (sdB) stars represent the stripped cores of horizontal branch stars. Pulsating sdB stars allow us to probe this important stage in evolution. Thanks to Kepler data, we now know that sdB star rotation periods are long; on the order of tens of days. This explains why they were not measured using ground-based follow-up data, which typically only spanned a week or two. Azimuthal pulsation degeneracies are removed by rotation, and so by detected pulsation frequency multiplets, we can determine pulsation modes and apply constraints to models, which tell us stellar structure. We need the ground-based observations as Kepler did not detect many p-mode pulsators, but rather almost exclusively g-mode pulsators. The shorter-period p-modes occur in hotter sdB stars, and so we need these to measure the pulsation dependence across the horizontal branch. During 2015, we observed PG 1219+534 (hereafter PG1219) over several months using our local 16 inch robotic telescope. Here we report preliminary results of processing those data to search for pulsation multiplets.

Author(s): John Crooke[1], Ryan Roessler[1], Michael Reed[1]
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433.18 – Mira Period-Luminosity Relations at Near-Infrared

We built *JHK* template light curves for ~200 Oxygen-rich Miras in LMC by scaling their *I*-band light curves. The *I*-(*JHK*) colors at individual epochs were derived using a Gaussian process method, and then modeled as a function of generic parameters. We obtained their *JHK* Period-Luminosity relations (PLRs) at maximum light and mean light with dispersions comparable to Cepheid PLRs. We also derived Mira PLRs in M33 and obtained a Mira distance to this system. We present the method for template development and preliminary results.

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433.19 – The Initial-Final Mass Relation: Analysis of White Dwarfs in the M7 Open Cluster

The initial-final mass relation (IFMR) is a direct comparison of the mass a star forms with on the main sequence to its final mass as a white dwarf. This provides critical information for our understanding of stellar evolution and mass loss, and how these are dependent on initial mass. Our group has done detailed analysis of the known white dwarfs in star clusters to improve the semi-empirical IFMR, but limited data (most importantly at the highest masses) causes remaining uncertainties. Our new wide-field photometric and spectroscopic observations of the young and nearby M7 open cluster have discovered and confirmed five new white dwarfs consistent with single-star membership. Four are intermediate-mass white dwarfs (0.65 to 0.85 Msun) and the final is a white dwarf estimated to be at 1.25 Msun and with an estimated initial mass of 6.75 Msun. Higher signal-to-noise follow-up spectra are required, but these and similar observations of other young and nearby clusters will begin to characterize the poorly explored ultra-high-mass end of the IFMR.

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433.20 – Planet-Planet Scattering and White Dwarf Pollution

About one-quarter to one-half of white dwarfs are observed to have polluted atmospheres. White dwarfs (WD) are expected to be chemically stratified, with heavy elements rapidly sinking. The frequent observation of heavy element pollution in WD atmospheres indicates that there must be a copious and frequent supply of rocky material from remnant planetary systems acting as a pollutant. Recently, the white dwarf WD 1145+017 has been observed to have been transited by a rocky body apparently in the process of disintegrating (Vanderburg et al. 2015).

Post-main sequence expansion may render the planetary system unstable (Veras 2016). Planets orbiting the white dwarf may perturb and scatter one another. If this scattering happens, any moons can be scattered about the system. As such, one possible source of the material polluting WDs is destabilized exomoons (Payne et al. 2016a, 2016b). Moons offer a plausible source of pollution due to their large total mass (in the Solar system), and their generally rocky composition that matches that found in the atmospheric pollution of WDs.

During a planet-planet scattering event, the probability that a moon will be ejected from its parent planet is a function of the velocity of the perturbing planet and the distance between the perturbed moon and the perturbing planet (as well as the initial orbit of the moon). We review the results of Payne et al. (2016a, 2016b) and present new results illustrating the probability of moon ejection as a function of these key parameters. We demonstrate the utility of these results for (a) the pollution and WDs, and for (b) general planet-planet scattering scenarios around main-sequence stars.

Author(s): Arielle Joasil[1], Matthew John Payne[1], Dimitri Veras[2]
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433.21 – Low States of Polars from CRTS Optical Light Curves

We present a study of light curves from the 10 year baseline for 98 polars observed using the Catalina Realtime Transit Survey (CRTS). In particular we investigate the stability of high and low luminosity states, for which these highly magnetic binaries are known. We identify several classes of behavior. Some polars have stable low states, (EF Eri, AR UMa, AM Her) in which they spend considerable time. About as many dip in brightness to low states followed by quick returns, (CE Gru, BM CrB). A few like FL Cet show 3 distinctive states.

Author(s): Joshua Santana[1], Paul A. Mason[1]
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433.22 – Shaping the Outbursts of Dwarf Novae with Convection and Magnetorotational Turbulence

I examine the accretion disks which power outbursts in white dwarf binary systems called dwarf novae. Accretion disks in dwarf novae are thermally unstable, leading to the observable variation in these systems. The source of this variation ultimately originates from the hydrogen ionization transition. This ionization transition causes significant temperature dependence in opacities and equation of state, culminating in the occurrence of convection within these accretion disks. Local stratified shearing-box simulations were used to show that this convection has a significant impact on the turbulence and dynamos generated by the magnetorotational instability (MRI). Most notably, convection enhances the stress to pressure ratio, often denoted by alpha. These results were then incorporated into the disk instability model to generate the first theoretical lightcurves for dwarf novae outbursts which incorporate MRI physics.

Author(s): Matthew S. B. Coleman[1]
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433.23 – The Habitable Zone of the Binary System Kepler-16

We report on the current results and envisioned future work from our study of the binary star system Kepler-16, which consists of a K-type main-sequence star and an M dwarf as well as a circumbinary Saturnian planet, Kepler-16b. We focus on the calculation of the location and extent of the habitable zone while considering several criteria for both the inner and outer boundaries previously given in the literature. In particular, we investigate the impact of the two stellar components (especially Kepler-16A) as well as of the system's binarity regarding the provision of circumbinary habitability. Another aspect of our work consists in a careful assessment of how the extent of the system's habitable zone is impacted by the relative uncertainties of the stellar and system parameters. Finally, we comment on the likelihood of habitable objects in the system by taking into account both radiative criteria and the need of orbital stability.

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434 – Supernovae et Multo Amplius Late Poster Session

434.01 – Observations of the Ultraviolet-Bright Type IIP Supernova ASASSN-14ha

We present ASASSN-14ha, an ultraviolet-bright type IIP supernova (SN) observed by the Swift Ultra- Violet/Optical Telescope (UVOT). Swift/UVOT has observed numerous SNe II, mostly at very low redshifts, giving a great sampling of the fading UV flux and the changing fraction of luminosity coming from the ultraviolet (UV). We present photometric properties of a sample of Type IIP SNe from the Swift Optical/Ultraviolet Supernova Archive (SOUSA), comparing their absolute magnitudes and color evolution. Through comparison to other Type IIP SNe observed by Swift, we find ASASSN-14ha to be the bluest of the sample in the UV colors while demonstrating normal behavior in the optical. We further compare ASASSN-14ha to models of Type IIP SNe to explore which progenitor parameters could explain it's unique color behavior.

Author(s): Andrew Quick[1], Peter J Brown[1], Nicholas B. Suntzeff[1]
Institution(s): *1. Texas A&M University*

434.02 – Correlations Between Hubble Residuals and Local Stellar Populations of Type Ia Supernovae

There appears to be correlations between SN Ia Hubble diagram residuals and host galaxy mass, metallicity, and star formation history. An uncorrected bias may produce a systematic offset in cosmological measurements. Rigault et al. (2013) found that the local environment can correlate with Hubble residuals and possibly impact precision Hubble Constant measurements. Global properties are the luminosity average of local environments, therefore the properties of local environments may hold stronger correlations than their global counterparts. We analyze host galaxies from the SDSS-II survey using both ground-based and Hubble Space Telescope imaging. We generate local stellar environmental properties by selecting a best fit Flexible Stellar Population Synthesis model that matches the SDSS Scene Modeling data. The derived properties, such as metallicity, stellar age, and star formation history, are then compared to the SN Ia's Hubble residual in the search for correlations.

Author(s): Benjamin Rose[1], Peter M. Garnavich[1]
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434.03 – SuperNovae Analysis aPplication (SNAP): A new analysis tool for understanding the physics of supernovae

The explosive death of massive stars, known as supernovae (SNe), are responsible for chemically enriching the universe in heavy elements. Presently, we discover ~300 SNe per year. By 2020 new all sky surveys will be on-line and this will increase to 100,000 discovered annually. Additionally, the mechanics and physics of the explosion itself are not solved problems. We need a rapid way to determine the properties of new SNe and a way to compare new models to observations. SNAP is a comparative data base system that contains archived observations, light curve models, and correlation software. We will be able to study SNe events to determine degeneracies in parameters and determine the important physics needed to describe these catastrophic events.

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434.04 – Two Years and Five Images of Supernova Refsdal

In 1964, Sjur Refsdal hypothesized that a supernova (SN) whose light takes multiple paths to reach us around a strong gravitational lens could be used as a highly powerful probe. For such a system, the time delays between the images of the SN should depend sensitively on the cosmic expansion rate and the distribution of matter within the lens. I will present observations of the first strongly lensed SN resolved into multiple images, which was found in near-infrared imaging taken in early November 2014 with the Hubble Space Telescope (HST). SN `Refsdal' appeared in an Einstein cross configuration around an early-type galaxy in the MACS J1149.6+2223 cluster (z=0.54), and its light curve and spectrum are broadly similar to those of the peculiar and well-studied SN 1987A. Models of the cluster potential predicted that the SN would reappear within two years in a different image of its spiral host galaxy (z=1.49) closer to the cluster's center. In early December 2015, we detected the new image of the SN with the HST, and we anticipate being able to measure its relative time delay with a 1-2% precision, providing a rare test of blind model predictions.

Author(s): Patrick Kelly[1]
Institution(s): *1. California - Berkeley, University of*

434.05 – Creation of a Unified Set of Core-Collapse Supernovae for Training of Photometric Classifiers

One of the key tasks for future supernova cosmology analyses is to photometrically distinguish type Ia supernovae (SNe) from their core collapse (CC) counterparts. In order to train programs for this purpose, it is necessary to train on a large number of core-collapse

SNe. However, there are only a handful used for current programs. We plan to use the large amount of CC lightcurves available on the Open Supernova Catalog (OSC). Since this data is scraped from many different surveys, it is given in a number of photometric systems with different calibration and filters. We therefore created a program to fit smooth lightcurves (as a function of time) to photometric observations of arbitrary SNe. The Supercal method is then used to translate the smoothed lightcurves to a single photometric system. We can thus compile a training set of 782 supernovae, of which 127 are not type Ia. These smoothed lightcurves are also being contributed upstream to the OSC as derived data.

Author(s): William D'Arcy Kenworthy[1], Daniel Scolnic[2], Richard Kessler[2]
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434.06 – Post-Merger Evolution of Betelgeuse

Betelgeuse appears to rotate anomalously rapidly. One possible explanation is that if merged with a companion of about 1 solar mass when it evolved up the Hyashi track to become a red giant. We have used the MESA evolutionary code to explore the effects of such a merger. We have added a solar mass of matter with angular momentum corresponding to the Keplerian angular velocity at the current radius of Betelgeuse and then followed the evolution of that mass and angular momentum. A wave of angular momentum propagates in toward the core where it is stalled by the composition barrier at the boundary with the helium core. There is also a rearrangement of the envelope material that results in a decrease in the surface gravity, yielding a result in closer agreement with observations than either non-rotating models or models evolved from rotating ZAMS models.

Author(s): James Sullivan[1], J. Craig Wheeler[1], Sarafina Nance[1], Manuel Diaz[1]
Institution(s): *1. University of Texas at Austin*

434.07 – Modeling Type-IIn Interacting Supernovae

Spectra of Type-IIn Supernovae (SNe) have shown evidence of interaction between SN ejecta and a surrounding circumstellar medium (CSM). Namely, narrow Hydrogen lines indicate that the fast moving ejecta slows after it collides with the slow moving CSM. However, observations of eta-Carinae and spectropolarimetry of SN2009ip during its 2012 explosion have shown that the CSM may often be asymmetric. In this study, we investigate the ability of an asymmetric CSM to disguise the characteristic narrow H lines expected from Type-IIn SNe.

We perform two-dimensional hydrodynamic simulations of the interaction between supernova ejecta and CSM. The simulations are run using the moving-mesh hydrodynamics code JET. Previous studies have ignored possible asymmetries by limiting their calculations to one-dimension or assuming a spherically symmetric CSM. We calculate shock propagation within the disk and CSM heating rate to produce mock-bolometric light curves. We also track unshocked CSM mass and speculate on its effects on the observation of H lines.

Author(s): Austin McDowell[1], Paul Duffell[1], Daniel Kasen[1]
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434.08 – Asymmetry in Supernovae

Asymmetry is observed in some supernovae remnants and this phenomenon is just beginning to be studied in simulations. Multiple physical processes have been suggested to explain these asymmetries even though the detailed physics of supernovae explosions is not known. We present three dimensional smoothed particle hydrodynamic simulations of supernova remnant development under the effects of density and velocity perturbations within the oxygen shell of two distinct progenitors. We produced explosion asymmetries of varying degrees. Multiple types and modes of perturbations were explored. Unperturbed models were also generated for comparison. We discuss how these perturbations may explain the observed asymmetries of supernovae remnants.

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434.09 – Asymmetries in the bright and moderately extincted SN Ia ASASSN-14lp

Spectropolarimetry of supernovae, or measuring the polarization of their light as a function of wavelength, records the intricate details about the geometry of the explosion for each epoch obtained. The Type Ia supernova (SN Ia) ASASSN-14lp was the second brightest supernova in 2014 and suffers from a moderate amount of extinction (Shappee et al. 2016). We obtained spectropolarimetric observations spanning -9 to +150 days, relative to B-maximum, using the CCD Imaging/Spectropolarimeter (SPOL) on the 1.5-m Kuiper, 2.3-m Bok, and 6.5-m MMT telescopes and the Kast spectrograph on the 3-m Shane telescope at Lick Observatory. We investigate the evolution of the polarization intrinsic to the supernova which describes asymmetries in the ejecta of the explosion and comment on the extragalactic dust of the host galaxy, NGC 4666.

Author(s): Amber L. Porter[1], Peter Milne3, Grant Williams3, Jon Mauerhan[2], Mark D. Leising[1], Paul S. Smith3
Institution(s): *1. Clemson University, 2. UC Berkeley, 3. University of Arizona*

434.10 – A *Chandra* Observation of the Luminous Northeastern Rim of the Galactic Supernova Remnant W28 (G6.4-0.1): Spatially-Resolved Spectroscopic Analysis and Radial Fitting

We present an analysis of a 50 kilosecond observation made with the *Chandra* X-ray Observatory of the northeastern rim of the Galactic supernova remnant (SNR) W28 (G6.4-0.1). W28 is well-known as the archetypical Galactic mixed-morphology SNR (MMSNRs): MMSNRs are a class of sources that feature a contrasting shell-like radio morphology with a center-filled X-ray morphology. The origin of these contrasting morphologies remains elusive: because MMSNRs all appear to be interacting strongly with ambient molecular clouds, it is suspected that these clouds and these interactions play a prominent role in dictating the appearance of these differing morphologies. The northeastern rim of W28 is particularly remarkable in that it is the only feature of the whole SNR that is detected in X-ray, optical and radio wavelengths: it is also the site of a high number density of hydroxyl (OH) masers which are well-known signposts of interactions between SNRs and molecular clouds. Our observation presented here features the highest angular resolution in X-ray ever attained in the study of this rim. We have performed spatially-resolved X-ray spectroscopy of this rim to search for variations in the spectral properties of individual features. We have also performed radial fitting to the X-ray emission to estimate the volume occupied by the X-ray emitting material.

Author(s): Thomas Pannuti3, Glenn E. Allen[1], Bradley Mahaffey3, Parker Poulos[2]
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434.11 – Synthesizing Planetary Nebulae for Large Scale Surveys: Predictions for LSST

The short-lived planetary nebula (PN) phase of stellar evolution is characterized by a hot central star and a bright, ionized, nebula. The PN phase forms after a low- to intermediate-mass star stops burning hydrogen in its core, ascends the asymptotic giant branch, and expels its outer layers of material into space. The exposed hot core produces ionizing UV photons and a fast stellar wind that sweeps up the surrounding material into a dense shell of ionized gas known as the PN. This fleeting stage of stellar evolution provides insight into rare atomic processes and the nucleosynthesis of elements in stars. The inherent brightness of the PNe allow them to be used to obtain distances to nearby stellar systems via the PN luminosity function and as kinematic tracers in other galaxies. However, the prevalence of non-spherical morphologies of PNe challenge the current paradigm of PN formation. The role of binarity in the shaping of the PN has recently gained traction ultimately suggesting single stars might not form PN. Searches for binary central stars have increased the binary fraction but the current PN sample is incomplete. Future wide-field, multi-epoch surveys like the Large Synoptic Survey Telescope (LSST) can impact studies of PNe and improve our understanding of their origin and formation. Using a suite of Cloudy radiative transfer calculations, we study the detectability of PNe in the proposed LSST multiband observations. We compare our synthetic PNe to common sources (stars, galaxies, quasars) and establish discrimination techniques. Finally, we discuss follow-up strategies to verify new LSST-discovered PNe and use limiting distances to estimate the potential sample of PNe enabled by LSST.

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434.12 – The Korean 1592—1593 Record of a Guest Star: A Luminous Transient of the Cassiopeia A Supernova?

Cassiopeia A (Cas A) is one of the youngest supernova remnants (SNRs) in the Milky Way. It was discovered in 1940s as a bright radio source, and since then it has been extensively studied over all wavebands. In particular, the supernova (SN) flash light at the time of explosion was detected in 2008 as the SN light 'echo', which confirmed that Cas A is a remnant of core-collapse SN of Type IIb. It is relatively nearby, i.e., at 3.4 kpc, and the proper motion studies of almost freely-expanding SN material have yielded an accurate date of SN event, i.e., AD 1670—1680.

The searches for historical observations of the Cas A SN event have found two suspicious records: Korean records on a 'guest star' that appeared near Cas A for three months in 1592-1593 and the record of the 6-th magnitude star '3 Cas' by John Flamsteed on August 16 in 1680. The former was ruled out because of ≥80 years of gap in the explosion date, while the Flamsteed's 3 Cas is most likely a non-existing star resulting from combining measurements of two different stars by mistake. Therefore, there is no unambiguous historical record of this SN event occurred in the telescope era, which is puzzling.

Here we investigate the possibility that the guest star in 1592—1593 in Korean history books could have been an 'impostor' of the Cas A SN, i.e., a luminous transient that appeared to be a SN but did not destroy the progenitor star, with strong mass loss to have provided extra circumstellar extinction to hide the SN event. We first review the Korean records and show that a spatial coincidence between the guest star and Cas A cannot be ruled out, as opposed to previous studies. We then argue that Cas A could have had an impostor and derive its anticipated properties. It turned out that the Cas A SN impostor must have been bright (M_V=-14.7±2.2 mag) and an amount of dust with visual extinction of ≧2.8±2.2 mag should have formed in the ejected envelope and/or in a strong wind afterwards. The mass loss needs to have been spherically asymmetric in order to see the light echo from the SN event but not the one from the impostor event.

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435 – The ISM, Dust and Circumstellar Disks Late Poster Session

435.01 – Revisiting the Trend of Debris Disks with regards to the Improved Ages of Early-Type Stars

Finding excess infrared emission around a star can indicate the presence of a debris disk, a collection of dust in orbit around a star as a result of large-body collisions (such as between asteroids). In order to see how these disks evolve, it is crucial to be able to define the ages of a large sample of stars. David and Hillenbrand (2015) were able to derive their own uniform technique for deriving the ages of 3,493 early-type stars using specialized photometry to derive parameters such as surface gravity and effective temperature. Correlating their sample of stars with infrared data from the Wide-field Infrared Survey Explorer (WISE) and 2 Micron All Sky Survey (2MASS) missions, we improved available trends among debris disk presence, stellar age, and spectral type. We did this by plotting different color-color and box-and-whisker diagrams in order to determine excess emission in the WISE and 2MASS bands. Colors k_S-W3 and k_S-W4 were chosen as our standard colors to detect circumstellar disk candidates after considering the reliability of the data. Stars above 1σ were considered to be stars with candidates. The percent frequency of sources with evidence of excess in k_S-W3 is 6.4 ± 2.0% with ages <600 Myr and declines to 2% for older sources. The percent frequency of sources with evidence of excess in k_S-W4 is 7.1 ± 2.1% with ages <600 Myr and declines to 4.4% for older sources.

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435.02 – Characterizing Dusty Debris Disks with the Gemini Planet Imager

We have been awarded 87 hours of Gemini Observatory time to obtain multi-wavelength observations of HST resolved debris disks using the Gemini Planet Imager. We have executed ~51 hours of telescope time during the 2015B-2016B semesters observing 12 nearby, young debris disks. We have been using the GPI Spec and Pol modes to better constrain the properties of the circumstellar dust, specifically, measuring the near-infrared total intensity and polarization fraction colors, and searching for solid-state spectral features of nearby beta Pic-like disks. We expect that our observations will allow us to break the degeneracy among the particle properties such as composition, size, porosity, and shape. We present some early results from our observations.

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435.03 – A Discovery of a Compact High Velocity Cloud-Galactic Supershell System

High velocity clouds (HVCs) are neutral hydrogen (HI) gas clouds having very different radial velocities from those of the Galactic disk material. While some large HVC complexes are known to be gas streams tidally stripped from satellite galaxies of the Milky Way, there are relatively isolated and small angular-sized HVCs, so called "compact HVCs (CHVCs)", the origin of which remains controversial. There are about 300 known CHVCs in the Milky Way, and many of them show a head-tail structure, implying a ram pressure interaction with the diffuse Galactic halo gas. It is, however, not clear whether CHVCs are completely dissipated in the

Galactic halo to feed the multi-phase circumgalactic medium or they can survive their trip through the halo and collide with the Galactic disk. The colliding CHVCs may leave a gigantic trail in the disk, and it had been suggested that some of HI supershells that require ≧ 3 x 10^{52} erg may be produced by the collision of such HVCs.

Here we report the detection of a kiloparsec (kpc)-size supershell in the outskirts of the Milky Way with the compact HVC 040+01−282 (hereafter, CHVC040) at its geometrical center using the "Inner-Galaxy Arecibo L-band Feed Array" HI 21 cm survey data. The morphological and physical properties of both objects suggest that CHVC040, which is either a fragment of a nearby disrupted galaxy or a cloud that originated from an intergalactic accreting flow, collided with the disk ~5 Myr ago to form the supershell. Our results show that some compact HVCs can survive their trip through the Galactic halo and inject energy and momentum into the Milky Way disk.

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435.04 – The generation, destination, and astrophysical applications of magnetohydrodynamic turbulence

The ubiquitous turbulence in the interstellar medium (ISM) participates in astrophysical processes over a huge dynamic range of scales. Understanding the turbulence properties in the multiphase, magnetized, partially ionized, and compressible ISM is the fundamental step prior to the studies of the ISM physics and other fields of astrophysics. I feel that a triad of analytical, numerical and observational efforts provides a winning combination to understand this complex system and solve long-standing puzzles. I have intensively studied the fundamental physics of magnetohydrodynamic (MHD) turbulence, and focused on two primary domains, dynamo and dissipation, which concern the origin of strong magnetic fields and the destination of turbulence, respectively. I further applied my theoretical studies in interpreting numerical results and observational data in various astrophysical contexts. The advanced analyses of MHD turbulence enable me to address a number of challenging astrophysical problems, e.g. the importance of magnetic fields for star formation in the early and present-day universe, new methods of measuring magnetic fields, the density distribution in the Galaxy and the host galaxy of a fast radio burst, the diffusion and acceleration of cosmic rays in partially ionized ISM phases.

Author(s): Siyao Xu[1], Alex Lazarian3, Bing Zhang[2]
Institution(s): *1. Peking University, 2. University of Nevada Las Vegas, 3. University of Wisconsin-Madison*

435.05 – Spatial Variations of Turbulent Properties in Neutral Hydrogen Observations of the Small Magellanic Cloud Using Structure Function Analysis

Turbulence is known to play a key role in shaping the many structures and features which make the Interstellar Medium (ISM) so interesting to study. It is still not understood, however, which processes are responsible for the turbulence in the ISM, and the scales at which these processes dominate. In our study, we use the structure function to analyze neutral hydrogen (HI) observations of the Small Magellanic Cloud (SMC) to search for spacial variations in turbulent properties. Using an estimate of the star formation surface density as a guide, we separate the HI SMC observations into a central region which contains star formation rate (SFR) regions above a certain contour level, and an outer region which has SFR values below the chosen contour level. Our contour level begins at 1e-3 $M_{\odot} yr^{-1} kpc^{-2}$ and is raised to 5e-3 $M_{\odot} yr^{-1} kpc^{-2}$ by increments of 1e-4 $M_{\odot} yr^{-1} kpc^{-2}$. At each contour level, we calculate the HI structure function slope for both the central and outer region by applying the Velocity Channel Analysis (VCA) and progressively averaging HI velocity channels. Our preliminary results suggest a difference in the slopes of both velocity and density fields between the inner and outer SMC.

Author(s): David Nestingen-Palm[2], Snezana Stanimirovic[2], Brian L Babler[2], DIEGO GONZALEZ CASANOVA[2], Katherine Jameson[1], Alberto D. Bolatto[1]
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435.06 – Toward a Kinetic Model of Silicon Carbide Condensation in Type II Supernovae

One of the most interesting types of dust grain extracted from terrestrial meteorites is the silicon carbide X-grain (SiC-X). These grains bear distinct isotopic signatures which classify them as supernova condensates, but their formation within the ejecta has not been well-studied. Using a kinetic chemistry network, we investigate possible pathways that lead to the formation of silicon carbide grains in the cooling outflows of type II supernovae.

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436 – GRBs and Space Missions Late Poster Session

436.01 – Comparing Data from Telescopic X-Ray Instruments: Can We Trust All Satellites?

In astronomy and astrophysics, X-ray emissions from cosmic entities aid in revealing what type of sources they emanate from. Swift, NASA's latest X-ray satellite, has not been operating at its intended configurations. The satellite is experiencing difficulties maintaining a stable temperature in its charge capture device. This research intends to determine if this complication causes discrepancies in Swift's collected data by using gamma-ray burst data. Gamma-ray bursts are excellent comparison candidates due to their brightness and fluctuations. We compared archived data of GRB 130427A and GRB 090423A from Swift and the European Space Agency's XMM-Newton observatory. Next, we reduced the data and produced the respective spectra. We then analyzed and compared the spectra to one another to find any discrepancies. We have determined, based on data analysis of the spectra, that Swift is working properly despite the cooling malfunction.

Author(s): Quianah T. Joyce[1], Alexander Fortenberry[1], Bruce Gendre[1]
Institution(s): *1. University of the Virgin Islands*

436.03 – Image Analysis of OSIRIS-REx Touch-And-Go Camera System (TAGCAMS) Thermal Vacuum Test Images

The objective of NASA's OSIRIS-REx Asteroid Sample Return Mission, which launched in September 2016, is to travel to the near-Earth asteroid 101955 Bennu, survey and map the asteroid, and return a scientifically interesting sample to Earth in 2023. As a part of its suite of integrated sensors, the OSIRIS-REx spacecraft includes a Touch-And-Go Camera System (TAGCAMS). The purpose of TAGCAMS is to provide imagery during the mission to facilitate navigation to the target asteroid, acquisition of the asteroid sample, and confirmation of the asteroid sample stowage in the spacecraft's Sample Return Capsule (SRC). After first being calibrated at Malin Space Science Systems (MSSS) at the instrument level, the TAGCAMS were then transferred to Lockheed Martin (LM), where they were put through a progressive series of spacecraft-level environmental tests. These tests culminated in a several-week long, spacecraft-level thermal vacuum (TVAC) test during which hundreds of images were recorded. To analyze the images, custom codes were developed using MATLAB R2016a programming software. For analyses of the TAGCAMS dark images, the codes observed the dark current level for each of the images as a function of the camera-head temperature. Results confirm that the detector dark current noise has not increased and follows similar trends to the results measured at the instrument-level by MSSS. This indicates that the electrical performance of the camera system is stable, even after integration with the spacecraft, and will provide imagery with the required signal-to-noise ratio during spaceflight operations. During the TVAC testing, the TAGCAMS were positioned to view optical dot targets suspended in the chamber. Results for the TAGCAMS light images using a centroid analysis on the positions of the optical target holes indicate that the boresight pointing of the two navigation cameras depend on spacecraft temperature, but will not change by more than ten pixels (approximately 2.8 mrad) over the expected operational temperature range. We are continuing to investigate the causes of this apparent pointing motion.

Author(s): Kenneth Everett Gordon[1], Brent J Bos[2]
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436.04 – Updated Status and Performance of the Cosmic Origins Spectrograph on the Hubble Space Telescope

The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope (HST) in May 2009. COS was designed to perform high-sensitivity medium and low-resolution spectroscopy of astronomical objects in the far-ultraviolet (FUV) and near-ultraviolet (NUV) wavelength regimes. Here, we present updates on the time-dependent sensitivities (TDS) for the NUV and FUV detectors, NUV wavelength calibration, and the FUV and NUV dark rates. Additionally, we discuss the move to lifetime position four (LP4) planned for July 2017, including the detector location and impact on resolution.

Author(s): Mees Bernard Fix[1], Gisella De Rosa[1], Andrew Fox[1], Nick Indriolo[1], Bethan James[1], Robert I. Jedrzejewski[1], Cristina M. Oliveira[1], Steven V. Penton[1], Rachel Plesha[1], Marc Rafelski[1], Julia Roman-Duval[1], David J. Sahnow[1], Paule Sonnentrucker[1], Elaine M. Snyder[1], Joanna M. Taylor[1], James White[1]
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437 – From the Earth, We Peer Outward...Late Poster Session

437.01 – The CCAT-prime Extreme Field-of-View Submillimeter Telescope on Cerro Chajnantor

CCAT-prime is a six meter aperture off-axis submillimeter telescope that we plan to build at 5600m elevation on Cerro Chajnantor in Chile. The CCAT-prime optics are based on a cross-Dragone design with high throughput and a wide field-of-view optimized to increase the mapping speed of next generation cosmic microwave background (CMB) observations. These characteristics make CCAT-prime an excellent platform for a wide range of next generation millimeter and submillimeter science goals, and a potential platform for CMB stage-IV measurements. Here we present the telescope design for CCAT-prime and review the science goals.

Taking advantage of the high elevation site, the first generation instrument for CCAT-prime will measure seven different frequency bands from 350um to 3mm. These seven bands will enable precise measurements of the Sunyaev-Zel'dovich effects (SZE) by separating contributions from CMB, thermal SZE, kinetic SZE, bright submm galaxies, and radio sources with a goal of extracting the peculiar velocities from a large number of galaxy clusters. Additional science priorities for CCAT-prime include: Galactic Ecology studies of the dynamic intersteller medium by mapping the fine structure lines [CI], [CII] and [NII] as well as high-excitation CO lines at the shortest wavelength bands; high redshift intensity mapping of [CII] emission from star-forming galaxies that likely dominates cosmic reionization at z~5-9 to probe the Epoch of Reionization; and next generation CMB polarization measurements to constrain inflation and cosmological models. The CCAT-prime facility will further our understanding of astrophysical processes from moments after the Big Bang to the present-day evolution of the Milky Way.

Author(s): Brian Koopman[1], Frank Bertoldi[3], Scott Chapman[2], Michel Fich[6], Riccardo Giovanelli[1], Martha P. Haynes[1], Terry L. Herter[1], Norman W. Murray[5], Michael D. Niemack[1], Dominik Riechers[1], Peter Schilke[4], Gordon J. Stacey[1], Juergen Stutzki[4]
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Contributing team(s): CCAT-prime Collaboration

437.02 – Development of Real-Time Image Stabilization for an Airborne Infrared Spectrometer

The total solar eclipse of August 21, 2017 offers a unique opportunity for study of the infrared solar corona. The Airborne Infrared Spectrometer (AIR-Spec), currently under development, is an infrared telescope and spectrometer that will search for several magnetically sensitive coronal emission lines between 1.4 and 4 micrometers. This instrument will be the first to observe several of these lines, and the measurement campaign will determine whether any lines may be useful for future direct observations of the coronal magnetic field. AIR-Spec will be mounted on an NSF/NCAR Gulfstream V jet and will observe the eclipse from an altitude greater than 14.9 km, above the bulk of IR-absorbing atmospheric water vapor.

To ensure that the images taken for analysis have adequate spatial resolution, the AIR-Spec line-of-sight must be stabilized to 1.9 arc-seconds RMS over a 1 second exposure time. Image stabilization is achieved by using a fiber-optic gyroscope to measure aircraft rotation and a fast-steering mirror to adjust the line-of-sight accordingly. The stabilization algorithm runs in a programmable automation controller, which interfaces with the gyroscope and mirror. Software was developed to implement the stabilization algorithm in the controller and to integrate the controller with a user interface, allowing for data display and logging, user guided attitude calibration, and manual control of the fast-steering mirror. The current system stabilizes images to 1.9 arc-seconds in 60 percent of 1 second camera exposures under laboratory conditions. This software will be operational during test flights in Fall 2016 and Spring 2017, and will be optimized for the eclipse flight in Summer 2017.

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437.03 – Absorber Coatings for Mid-Infrared Astrophysics

Control over optical response is an important aspect of instrument design for astrophysical imaging. Here we consider a mid-infrared absorber coating proposed for use on HIRMES (High Resolution Mid-Infrared Spectrometer), a cryogenic spectrometer which will fly on the SOFIA (Stratospheric Observatory for Infrared Astronomy) aircraft. The aim of this effort is to develop an absorptive coating for the 20-200 microns spectral range based on a graphene loaded epoxy binder (Epotek 377H) and glass microsphere scatterers (3M K1). The coatings electromagnetic response was modeled using a Matlab script and the glass microspheres were characterized by the measured size distribution, the dielectric constant, and the filling fraction. Images of the microspheres taken by a microscope were used to determine the size distribution with an ImageJ particle analysis program. Representative test samples for optical evaluation were fabricated for characterization via infrared Fourier transform spectroscopy. The optical tests will determine the material's absorptance and reflectance. These test results will be compared to the modeled response.

Author(s): Dahlia Anne Baker[1], Edward Wollack[2], Karwan Rostem[2]
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437.04 – Development of a Low Cost Telescope System for VHE Astronomy

Ground based gamma-ray astronomy has progressed dramatically over the past 40 years. Currently there are 176 confirmed sources detected above 100 GeV ranging from Supernova Remnants (SNR) to Active Galaxies and other objects The next generation of Imaging Air Cherenkov Telescopes (IACT) is currently being developed. The CTA, or Cherenkov Telescope Array, will be a ground-breaking facility made up of a few dozen telescopes of multiple sizes with a sensitivity an order of magnitude greater than the current generation. Nevertheless, an opportunity will remain for smaller, less-expensive instruments to make important contributions to the field of Cherenkov Imaging astronomy.
We are investigating an approach that will use an inexpensive array of ground based telescopes built from commercial-off-the-shelf (COTS) products. This array will be capable of studying supernova remnants, gamma-ray-burst afterglows, and active galactic nuclei as well as other sources above 2 TeV at a cost which is much lower than larger facilities like the CTA. We are developing a single prototype telescope that will be installed at the Goddard Geophysical and Astronomical Observatory in Greenbelt, MD. We discuss issues arising from and technical solutions to challenges of using COTS components whose primary purpose is not astronomy for this application. We detail progress in the telescope development and outline future work to complete the prototype and to duplicate it for creation of a low-cost Cherenkov array.

Author(s): Rodney Querrard[2], Jeremy S Perkins[1]
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437.05 – Innovative polarization-holographic imaging Stokes polarimeter for observational studies of the solar spicules: the first results

We present an innovative polarization-holographic imaging Stokes polarimeter based on a polarization-holographic diffraction element which enables the complete real time analysis of the polarization state of an incoming light. An element, recorded in a laboratory by a special holographic schema using circularly and linearly polarized beams, decomposes an incoming light into diffraction orders the intensities of which vary depending on the polarization state of a light source. After the CCD intensity measurements of the corresponding points or areas in the diffraction orders and further data reduction through the calibration parameters we get the real-time Stokes images of a light source or spectral line profiles which allows to determine full polarization state of a point or extended space object in narrow or wide spectral range. The operating spectral range of the polarimeter is 500-1600 nm with diffraction efficiency equal to 20% at 532 nm, 16% at 635 nm and 2% at 1550 nm. The theoretical model of relations between measured intensities in different diffraction orders and Stokes parameters, developed by the authors (Kilosanidze B., Kakauridze G. SPIE Proceedings, vol. 8082-126, 2011), were used to calibrate the polarimeter. The laboratory tests show that the resulting errors are near of 1% or better. First observations of the solar spicules show the ability of the proposed polarimeter to measure the joint Hanle and Zeeman effects. The polarimeter is compact, light weight and could be installed both on ground-based or airborne telescopes.

Author(s): Teimuraz Kvernadze[1], George Kurkhuli[1], George Kakauridze[2], Barbara Kilosanidze[2], Vazha Kulijanishvili[1], Eldar Khutsishvili[1], David Khutsishvili[1]
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437.06 – Economical Emission-Line Mapping: ISM Properties of Nearby Protogalaxy Analogs

Optical emission line imaging can produce a wealth of information about the conditions of the interstellar medium, but a full set of custom emission-line filters for a professional-grade telescope camera can cost many thousands of dollars. A cheaper alternative is to use commercially-produced 2-inch narrow-band astrophotography filters. In order to use these standardized filters with professional-grade telescope cameras, custom filter mounts must be manufactured for each individual filter wheel. These custom filter adaptors are produced by 3-D printing rather than standard machining, which further lowers the total cost.

I demonstrate the feasibility of this technique with H-alpha, H-beta, and [OIII] emission line mapping of the low metallicity star-forming galaxies IC10 and NGC 1569, taken with my astrophotography filter set on three different 2-meter class telescopes in Southern Arizona.

Author(s): Jacqueline A. Monkiewicz[1]
Institution(s): *1. Arizona State University*

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438 – Catalogs, Surveys, Computation, etc. Late Poster Session

438.01 – Searching for short-duration transients in the Chandra archive

The official Chandra Source Catalog (Evans et al. 2010) is optimized for steady or variable sources and leaves essentially unexplored the region of the parameter space containing short transients (~< 1000 s). To open up such discovery space we have implemented a blind-search for finding such short-duration X-ray transients in a suitable subsample of Chandra observations. Chandra is very well suited to study short transients, and indeed has occasionally already detected some in the past (see for example Rutledge et al. 2000). Nonetheless, no systematic search has been carried out up to now. Our pipeline uses both custom-written tools and tools from the official Chandra CIAO package. Based on the Bayesian Block algorithm of Scargle et al. (2013), it is time-scale-agnostic, i.e., can trigger on transients of any duration. We will describe our search on over 4000 Chandra observations, and present our preliminary results.

Author(s): Giacomo Vianello[2], Nitika Yadlapalli[1]
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Contributing team(s): the EXTraS project (http://www.extras-fp7.eu/)

438.02 – A Jupyter-based Interactive Visualization Tool for Astronomical Catalogs

The ever-growing datasets in observational astronomy have challenged scientists in many aspects, including an efficient and interactive data exploration and visualization. Many tools have been developed to confront this challenge. However, they usually focus on displaying the actual images or focus on visualizing patterns within catalogs. Here we present Vizic, a Python visualization library that builds the connection between images and catalogs through an interactive map of the sky region. Vizic visualizes catalog data over a custom background canvas using the shape, size and orientation of each object in the catalog. The displayed objects in the map are highly interactive and customizable comparing to those in the observation images. These objects can be filtered by or colored by their property values, such as redshift and/or magnitude or can be sub-selected using a lasso-like tool. In addition, Vizic also allows custom overlays to be appended dynamically on top of the image. We have implemented a minimum spanning tree overlay and a Voronoi diagram overlay. Both overlays can be generated, added or removed with just a click of a button. All the data is kept in a non relational database, and the interfaces were developed in JavaScript and Python to work on Jupyter notebooks which allows to create custom widgets, user generated scripts to analyze and plot the data selected/displayed in the interactive map.
Vizic can be adopted in variety of exercises, for example, data

inspection, clustering analysis, galaxy alignment studies or public data release for large surveys.

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438.03 – MeerKAT Large Area Survey

We present the goals and strategies for a large area MeerKAT survey, that is expected to be proposed under the MeerKAT open time call. The survey will be at least 400 square degrees, detect galaxies up to high redshift and cover various science interests that will exploit synergies with complementary data at other wavebands. For as high impact and legacy value as possible, the survey is open to synergies from the community.

Author(s): Lerothodi Leeuw[1]
Institution(s): *1. University of South Africa*

438.04 – The *JWST* North Ecliptic Pole Survey Field for Time-domain Studies

The *JWST* North Ecliptic Pole (NEP) Survey field is located within *JWST*'s northern Continuous Viewing Zone, will span ~14′ in diameter (~10′ with NIRISS coverage) and will be roughly circular in shape (initially sampled during Cycle 1 at 4 distinct orientations with *JWST*/NIRCam's 4.4′×2.2′ FoV —the *JWST* "windmill") and will have NIRISS slitless grism spectroscopy taken in parallel, overlapping an alternate NIRCam orientation. This is the ***only*** region in the sky where *JWST* can observe a clean extragalactic deep survey field (free of bright foreground stars and with low Galactic foreground extinction A_V) ***at arbitrary cadence*** or at ***arbitrary orientation***. This will crucially enable a wide range of new and exciting time-domain science, including high redshift transient searches and monitoring (e.g., SNe), variability studies from Active Galactic Nuclei to brown dwarf atmospheres, as well as proper motions of extreme scattered Kuiper Belt and Oort Cloud Objects, and of nearby Galactic brown dwarfs, low-mass stars, and ultracool white dwarfs. We therefore welcome and encourage follow-up through GO programs of the initial GTO observations to realize its potential as a *JWST* time-domain ***community field***.
The *JWST* NEP Survey field was selected from an analysis of *WISE* 3.4+4.6 micron, 2MASS JHK_S, and SDSS *ugriz* source counts and of Galactic foreground extinction, and is one of ***very few*** such ~10′ fields that are devoid of sources brighter than m_{AB} = 16 mag. We have secured deep (m_{AB} ~ 26 mag) wide-field (~23′×25′) *Ugrz* images of this field and its surroundings with *LBT*/LBC. We also expect that deep *MMT*/MMIRS *YJHK* images, deep 8–12 GHz *VLA* radio observations (pending), and possibly *HST* ACS/WFC and WFC3/UVIS ultraviolet–visible images will be available before *JWST* launches in Oct 2018.

Author(s): Rolf A Jansen[1], Mehmet Alpaslan[5], Matthew Ashby[3], Teresa Ashcraft[1], Seth H. Cohen[1], James J. Condon[8], Christopher Conselice[12], Andrea Ferrara[9], Brenda L. Frye[14], Norman A. Grogin[10], Heidi B. Hammel[2], Nimish P. Hathi[4], Bhavin Joshi[1], Duho Kim[1], Anton M. Koekemoer[10], Matt Mechtley[1], Stefanie N. Milam[6], Steven A. Rodney[15], Michael J. Rutkowski[13], Louis-Gregory Strolger[10], Chadwick A. Trujillo[7], Christopher Willmer[14], Rogier A. Windhorst[1], Haojing Yan[11]
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438.05 – Extended X-ray Objects in the Galactic Bulge Survey

The goal of this project was to locate extended X-ray objects in the galactic bulge. Data was taken from the Chandra X-ray Observatory and analyzed using vtpdetect, a program that scans for overdensities of photons in FITS files. The regions flagged by the program were further investigated to determine whether the sources were real extended objects. The original list of detected sources was narrowed down to 7 candidates which are now being further analyzed to determine what specifically the objects are. For this poster I will describe the elimination process for each flagged object and discuss future analysis techniques to determine the identity of the remaining candidates.

Author(s): Brandon Matthews[1]
Institution(s): *1. Texas Tech University*

438.06 – Ultra-deep Large Binocular Camera U-band Imaging of the GOODS-North Field: Depth vs. Resolution

We present a study of the trade-off between depth and resolution using a large number of U-band images in the GOODS-North field obtained with the Large Binocular Camera (LBC) on the Large Binocular Telescope (LBT). Having acquired over 30 hours of total exposure time (315 images, each 5-6 min), we generated multiple image mosaics, starting with the subset of images with the best (FWHM < 0."8) atmospheric seeing (~10% of the total data set). For subsequent mosaics, we added in data with larger seeing values until the final, deepest mosaic included all images with FWHM < 1."8 (~94% of the total data set). For each mosaic, we created object catalogs to compare the optimal-resolution, yet shallower image to the low-resolution but deeper image and found the number counts for both images are ~90% complete to AB = 26 mag. In the optimal-resolution image, object counts start to drop-off dramatically, fainter than AB ~ 27 mag, while in the deepest image the drop is more gradual because of the better surface-brightness sensitivity (SB ~ 32 mag arcsec^{-2}). We conclude that for studies of brighter galaxies and features within them, the optimal-resolution image should be used. However, to fully explore and understand the faintest objects, the deeper imaging with lower resolution are also required. We also discuss how high-resolution F336W *HST* data complements our LBT mosaics.
For 220 brighter galaxies with U < 24 mag, we find only marginal differences (< 0.07 mag in total integrated flux) between the optimal-resolution and low-resolution light-profiles to SB ~ 32 mag arcsec^{-2}. This helps constrain how much flux can be missed in galaxy outskirts, which is important for studies of Extragalactic Background Light.
In the future, we will expand our analysis of the GOODS-N field to ~26 hours of LBT/LBC R-band surface photometry to similar depths.

Author(s): Teresa Ashcraft[1], Rogier A. Windhorst[1], Rolf A Jansen[1], Seth H. Cohen[1], Andrea Grazian[3], Konstantina Boutsia[2], Adriano Fontana[3], Emanuele Giallongo[3], Robert W. O'Connell[6], Diego Paris[3], Michael J. Rutkowski[4], Claudia Scarlata[5], Vincenzo Testa[3]
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438.07 – Hot Star Extension to the Hubble Space Telescope Stellar Spectral Library

CCD spectra of 36 stars were obtained from the Space Telescope Imaging Spectrograph (STIS) installed in the Hubble Space Telescope (HST) using three low resolution gratings - G230LB, G430L, and G750L, combined in processing to make single, continuous spectra from 0.2 to 1.0 micrometers. These spectra will be added to the Next Generation Stellar Library (NGSL) after completing the data analysis, reduction, and the required corrections. The stars include normal O-type stars, helium-burning stars, and post-asymptotic giant branch (PAGB) stars. Difficult steps in the data reduction process were removing the cosmic rays from the raw images and defringing of the G750L spectra using fringe flats. Most stars have detectable dust extinction. To aid in analysis, synthetic spectra were generated with various effective temperatures and surface gravities. A five parameter analytic model for the dust extinction correction was adopted. The parameters were varied in order to fit especially the ultraviolet portion of the observed and comparison synthetic spectra. Cross-correlation was used to bring the spectra to a common, final, zero velocity wavelength scale. Some star temperatures obtained from fitting synthetic versus observed spectra vary significantly from literature values. The dust extinction correction parameters also varied for several stars, mostly O stars, indicating variations in dust properties for different lines of sight. Analysis of scattered light effects showed that it was significant only for our two coolest stars.

Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Science Institute. STScI is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contract NAS 5-26555.

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438.08 – PyXel: A Python Package for Astronomical X-ray Data Modeling

PyXel is a open-source Python package for modeling astronomical X-ray imaging data. It is primarily built on NumPy, SciPy, Astropy, and emcee. The package aims to provide a common set of image analysis tools for astronomers working with extended X-ray sources. I will present an overview of its features, and analysis examples based on public Chandra data.

The code is available for download on GitHub (https://github.com/gogrean/PyXel), and contributions to it are welcome.

Author(s): Georgiana Ogrean[1]
Institution(s): *1. Stanford University*

438.09 – What's New in CASA: 'tclean' and the Cycle 4 ALMA Pipeline

CASA, the Common Astronomy Software Applications package, undergoes continuous development to support calibration and imaging of astronomical data at radio wavelengths for both single dish and interferometric telescopes. It is largely focused on supporting the post-processing needs of the next generation of radio telescopes such as ALMA and the JVLA. The most recent release of CASA, version 4.7, includes major upgrades in its imaging capabilities via the implementation of a task called 'tclean', which will eventually replace the current imaging task 'clean'. It has a new, more straightforward interface, allows more combinations of imaging algorithms, has a more flexible outlier approach, and includes algorithms for autoboxing. Further, the new 'tclean' task has been implemented in the Cycle 4 ALMA Interferometric Pipeline with great success; this pipeline software can be obtained bundled with CASA 4.7 at https://casa.nrao.edu/. A major goal of the ALMA project [and the National Radio Astronomical Observatory (NRAO)] is to provide Science-Ready Data Products to our user community, and the ALMA Cycle 4 Pipeline is a major step forward in that direction.

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Institution(s): *1. NRAO*
Contributing team(s): CASA Development Team, ALMA Pipeline Working Group, NAASC Software Support Team

439 – Education and Public Outreach Late Poster Session

439.01 – Starry Campus: Reducing Light Pollution at Smith College

This is the start of a program to teach Smith College students about the dangers posed by light pollution and inspire them to help make Smith a better dark sky area. This will focus both on general astronomy education to catch their interest and speciic light pollution information as well. My advisor is creating an initiative for dark skies education and preservation on college campuses, with this as the pilot program. College students can help both on campus and off when they will be able to take what they learn to inform their decisions about lighting when they move out on their own. The ultimate goal is to convince Smith College to make the changes it needs to reduce its light pollution as well as to motivate its students to learn more about astronomy and light pollution. I am developing an education and outreach program using venues such as house teas, lectures, and meetings to teach other students, the staff, and faculty about the issue. I am also working with existing clubs and organizations on campus such as the Green Team, the landscape studies department, and the Center for the Environment, Ecological Design, and Sustainability. This will help to develop campus lighting standards. These lighting standards will be proposed to the college, as there are no current standards in place for lighting around campus.

Author(s): Alexandria Brenon[1]
Institution(s): *1. Smith College*

439.02 – ASTRO 850: Teaching Teachers about Exoplanets

The Earth and Space Science Partnership (ESSP) is a collaboration among Penn State scientists, science educators and seven school districts across Pennsylvania. Penn State also offers through its fully online World Campus the opportunity for In-Service science teachers to earn an M.Ed. degree in Earth Science, and we currently offer a required online astronomy course for that program. We have previously presented descriptions of how have incorporated research-based pedagogical practices into ESSP-sponsored workshops for in-service teachers (Palma et al. 2013), a pilot section of introductory astronomy for non-science majors (Palma et al. 2014), and into the design of an online elective course on exoplanets for the M.Ed. in Earth Science (Barringer and Palma, 2016). Here, we present the finished version of that exoplanet course, ASTRO 850. We gratefully acknowledge support from the NSF MSP program award DUE#0962792.

Author(s): Daniel Barringer[1], Christopher Palma[1]
Institution(s): *1. Pennsylvania State University*

439.04 – Virtual Reality Astronomy Education Using AAS WorldWide Telescope and Oculus Rift

The Boyd E. Christenberry Planetarium at Samford University (Birmingham, AL) offers family friendly, live, and interactive planetarium presentations that educate the public on topics from astronomy basics to current cutting edge astronomical discoveries. With limited funding, it is not possible to provide state of the art planetarium hardware for these community audiences. In a society in which many people, even young children, have access to high resolution smart phones and highly realistic video games, it is important to leverage cutting-edge technology to intrigue young and old minds alike. We use an Oculus Rift virtual reality headset running AAS WorldWide Telescope software to visualize 3D data in a fully immersive environment. We create interactive experiences and videos to highlight astronomical concepts and also to communicate the beauty of our universe. The ease of portability enables us to set up at Virtual Reality (VR) experience at various events, festivals, and even in classrooms to provide a community outreach that a fixed planetarium cannot. This VR experience adds the “wow” factor that encourages children and adults to engage in our various planetarium events to learn more about astronomy and continue to explore the final frontier of space. These VR experiences encourages our college students to participate in our astronomy education resulting in increased interest in STEM fields, particularly physics and math.

Author(s): A. David Weigel[1], Christina D Moraitis[1]
Institution(s): *1. Samford University*

439.05 – Youth for Astronomy & Engineering Program: Engaging Local Families and Partners

Youth for Astronomy and Engineering (YAE) is a program in the Space Telescope Science Institute's Office of Communication and Public Outreach designed to engage the local community in science, technology, engineering, and mathematics (STEM). This is accomplished through a series of yearly events such as astronomy and engineering clubs for students, family nights, and star parties. These events leverage our mission science to expose participants to the latest science discoveries (Hubble), new developments in space technology (James Webb), STEM career information, and activities that are representative of the work done by individuals in the astronomical and engineering fields. The YAE program helps provide a progression of opportunities for audiences by attracting and identifying highly-engaged individuals for participation in more intensive experiences. It also helps increase our impact by creating a network for piloting educational outreach initiatives at the local level before nationwide release. This poster will highlight the YAE program.

Author(s): Tania Anderson[1]
Institution(s): *1. Space Telescope Science Institute*

439.06 – Adding Interferometer Restoration and Upgrade: Learning by Doing with the NINE Program

During the summer of 2016, participants in the National and International Non-Traditional Exchange (NINE) Program were responsible for the restoration and upgrade of N2I2, an instructional interferometer located on New Mexico Tech's Socorro campus. The NINE program is a National Radio Astronomy Observatory (NRAO) initiative geared towards providing training in project management and other STEM functional areas to underrepresented groups around the world. A description of this restoration project illustrates both the experience of a NINE program participant and, more specifically, how principles of engineering and project management were applied to achieve project objectives.

N2I2 was created by a joint NRAO-New Mexico Tech (NMT) team and became operational in 2004. The original instrument comprised two ten-foot dishes which recieved signals that were added using a simple power combiner, and data was interpreted using software on computers located in a nearby control room. The theory of adding interferometry was re-discovered for the design of this unique telescope. N2I2 was built using simple hardware with the intention of allowing interested community members and students from middle school to graduate school to learn about the principles of radio astronomy.

Unfortunately, between 2008 and 2016 N2I2 was not used on a regular basis and fell into disrepair. NINE program director Lory Wingate accepted the responsibility of restoring the instrument as an experiential learning opportunity for the Socorro, New Mexico NINE team.

During their 9 week assignment, the NINE team created a project plan, replaced and upgraded antenna hardware, developed operation and maintenance manuals, and refurbished the control room. A project plan was created for the addition of a third antenna and that plan was successfully carried out during August and September of 2016.

Ultimately, functionality was successfully restored and improved, a maintenance plan was put into place, and community interest in the instrument was reignited.

Author(s): Linnea Saby[1]
Institution(s): *1. Piedmont Virginia Community College*

439.07 – Reaching for the Stars: NASA Science for Girl Scouts (*Girl Scout Stars*)

Girl Scout Stars aims to enhance STEM experiences for Girl Scouts in grades K-12. New space science badges are being created for every Girl Scout level. Using best practices, we engage girls and volunteers with the fundamental STEM concepts that underpin our human quest to explore the universe. Through early and sustained exposure to the people and assets of NASA and the excitement of NASA's Mission, they explore STEM content, discoveries, and careers. Today's tech savvy Girl Scout volunteers prefer just-in-time materials and asynchronous learning. The Volunteer Tool Kit taps into the wealth of NASA's online materials for the new space science badges. Training volunteers supports troop activities for the younger girls. For older girls, we enhance Girl Scout summer camp activities, support in-depth experiences at Univ. of Arizona's Astronomy Camp, and "Destination" events for the 2017 total solar eclipse. We partner with the Night Sky Network to engage amateur astronomers with Girl Scouts. Univ. of Arizona also leads Astronomy Camp for Girl Scout volunteers. Aires Scientific leads eclipse preparation and summer sessions at NASA Goddard Space Flight Center for teams of volunteers, amateur astronomers and older Girl Scouts.
There are 1,900,000 Girl Scouts and 800,000 volunteers in the USA. During development, we work with the Girl Scouts of Northern California (50,000 girl members and 31,000 volunteers) and expand across the USA to 121 Girl Scout councils over five years. SETI Institute leads the space science educators and scientists at Astronomical Society of the Pacific, Univ. of Arizona, and Aires Scientific. Girl Scouts of the USA leads dissemination of *Girl Scout Star*s with support of Girl Scouts of Northern California. Through professional development of Girl Scout volunteers, *Girl Scout Stars* enhances public science literacy. *Girl Scout Stars* supports the NASA Science Mission Directorate Science Education Objectives and NASA's STEM Engagement and Educator Professional Development lines of business. The Girl Scout Research Institute at GSUSA leads program evaluation with Rockman, et al, external evaluators. Funded by NASA: NNX16AB90A.

Author(s): Edna DeVore[1], Pamela Harman[1]
Institution(s): *1. SETI Institute*
Contributing team(s): Girl Scouts of the USA, Girl Scouts of Northern California, University of Arizona, Astronomical Society of the Pacific, and Aires Scientific

439.08 – Exploring Systems Engineering (and the Universe) Through the RadioJOVE telescope

Amateur projects in radio astronomy are popular methods to engage in what often seems to be an inaccessible field, and pre-made kits are becoming increasingly available to hobbyists and educators. One such kit is the RadioJOVE, which is attractive due to its simplicity, accessibility and its extensive support network and community of users. When coupled with an education in project management, building the RadioJOVE provides a perfect framework to learn about best practices in completing a project. We will primarily discuss the use of the RadioJOVE project to enhance study in project management and systems engineering. We also intend to discuss the importance of amateur projects such as the RadioJOVE in gaining a holistic understanding of radio astronomy and the project's potential to spark interest in radio astronomy in students of various disciplines.

Author(s): Anya Aditi Raj[1]
Institution(s): *1. University of Washington*

413 – Extrasolar Planets: Characterization & Theory VII

413.01D – Optical-to-UV correlations and particle fluxes for M dwarf exoplanet host stars

UV stellar radiation can significantly impact planetary atmospheres through heating and photochemistry, even regulating production of potential biomarkers. M dwarfs emit the majority of their UV radiation in the form of emission lines, and the incident UV radiation on habitable-zone planets is significant owing to their small orbital radii. Only recently have the UV spectral energy distributions (SEDs) of average M dwarfs been explored (e.g., the MUSCLES Treasury Survey). Emission lines tracing hot plasma in the stellar chromosphere and transition region dominate the far-UV spectra, even for optically inactive M dwarfs (i.e., those displaying Hα absorption spectra). Lyα (1216 Å) is the strongest of the UV emission lines, but resonant scattering from the interstellar medium makes direct observations of the intrinsic Lyα emission of even nearby stars challenging. I reconstruct the intrinsic Lyα profiles using an MCMC technique and use them to estimate the extreme-UV SED.

Monitoring the long-term (years-to-decades) UV activity of M dwarfs will be important for assessing the potential habitability of short-period planets, but will only be feasible from the ground via optical proxies. Therefore, I also quantify correlations between UV and optical emission lines of the MUSCLES stars and other M dwarfs, for use when direct UV observations of M dwarf exoplanet host stars are not available. Recent habitability studies of M dwarf exoplanets have sought to address the impact of frequent flaring and are just beginning to include the damaging impact of stellar energetic particles that are typically associated with large flares. Working under the necessary assumption of solar-like particle production, I present a new technique for estimating >10 MeV proton flux during far-UV flares, and analyze a sample of the flares observed in the MUSCLES Treasury Survey.

Author(s): Allison Youngblood[1]
Institution(s): *1. University of Colorado at Boulder*

413.02 – Leveraging Ensemble Dynamical Properties to Prioritize Exoplanet Follow-Up Observations

The number of transiting exoplanets now exceeds several thousand, enabling ensemble studies of the dynamical properties of exoplanetary systems. We require a mixture model of dynamical conditions (whether frozen in from formation or sculpted by planet-planet interactions) to recover Kepler's yield of transiting planets. Around M dwarfs, which will be predominate sites of exoplanet follow-up atmospheric study in the next decade, even a modest orbital eccentricity can sterilize a planet. I will describe efforts to link cheap observables, such as number of transiting planets and presence of transit timing variations, to eccentricity and mutual inclination in exoplanet systems. The addition of a second transiting planet, for example, halves the expected orbital eccentricity. For the vast majority of TESS targets, the light curve alone will furnish the sum total of data about the exoplanet. Extracting information about orbital properties from these light curves will help prioritize precious follow-up resources.

Author(s): Sarah Ballard[1]
Institution(s): *1. MIT*

413.03 – Identifying Young Kepler Planet Host Stars from Keck-HIRES Spectra of Lithium

The lithium doublet at 6708 A provides an age diagnostic for FGK stars. We measured the abundance of lithium in 1149 stars with detected transiting planets from the Kepler Mission using high resolution spectroscopy. Our catalog of lithium measurements from this sample have a range of abundance from A(Li) = 3.13 +/- 0.05 to a lower limit of -0.79. For a magnitude-limited sample that comprises 930 of the 1149 stars, our Keck-HIRES spectra have a median S/N = 45 per pixel at spectral resolution R = 55,000. We identify 79 young stars that have A(Li) values greater than the Hyades at their respective effective temperatures; these stars are younger than ~650 Myr old, the approximate age of the Hyades. We then compare the distribution of A(Li) with planet size, disposition, multiplicity, orbital period, and insolation flux.

Author(s): Travis Allen Berger[1], Andrew Howard[1], Ann M. Boesgaard[1]
Institution(s): *1. University of Hawaii at Manoa*

413.04 – A New Method for the Quick Determination of S-Type and P-Type Habitable Zones in Binary Systems

More than 3500 exoplanets have been confirmed nowadays, including a very large number of planets discovered by the *Kepler* mission. Additional exoplanets are expected to be found by ongoing missions as, e.g., K2 as well as future missions such as TESS. Exoplanets, especially terrestrial planets, located in stellar habitable zones are drawing great attention from the community and the public at large due to their potential for hosting alien life – a prospect that makes the adequate determination of stellar habitable zones an important goal of exoplanetary research. In the local Galactic neighborhood, binary systems occur relatively frequently. Thus, it is the aim of my presentation to offer a method for the quick determination for the existence of habitable zones in binaries. Therefore, fitting formulas for binary habitable zones regarding both S-type and P-type star-planet configurations are provided. Based on previous work in the literature, a joint constraint regarding radiative habitable zones and planetary orbital stability limits is used. Models of stellar habitable zones utilize updated computations for planetary climate models as given by Kopparapu et al. (2013, 2014) [ApJ 765, 131; ApJL 787, L29]. Cases studies showing the quality of the fit formulas, as well as applications to observed systems, are presented as well.

Author(s): Zhaopeng Wang[1], Manfred Cuntz[1]
Institution(s): *1. University of Texas at Arlington*

413.05 – Jupiter's Phase Variations from Cassini: a testbed for future direct-imaging missions

Phase curves are important for our understanding of the energy balance and scattering behavior of an exoplanet's atmosphere. In preparation for future direct-imaging missions of Jupiter-like planets, in particular WFIRST, we present phase curves of Jupiter from 0--150 degrees as measured in multiple optical bandpasses by Cassini/ISS during the Millennium flyby of Jupiter in late 2000 to early 2001. We demonstrate and confirm that Jupiter is not well represented by a Lambertian phase function and that its color is more variable with phase angle than predicted by Jupiter-like models. This indicates that a Jupiter-twin observed near quadrature may not be as straightforward to classify as a Jupiter-like planet and comment on the implications for future missions.

Author(s): Laura Mayorga4, Jason Jackiewicz4, Kathy Rages5, Robert A. West[2], Ben Knowles[1], Nikole K. Lewis[6], Mark S. Marley3
Institution(s): *1. CICLOPS/Space Science Institute, 2. JPL, 3. NASA Ames Research Center, 4. New Mexico State University, 5. SETI Institute, 6. Space Telescope Science Institute*

413.06 – Compositions of Small Planets & Implications for Planetary Dynamics

The composition of rocky planets has major implications for their core sizes and their ability to sustain plate tectonics. We report on our measurements of the major rock-building elements O, Mg, Si and Fe for the host stars of known small planets using high-resolution spectra from the APOGEE survey. We discuss the role that these abundance ratios play in the mantle minerology and core formation and speculate on the consequences for habitability of rocky exoplanets.

Author(s): Jennifer Johnson4, Johanna Teske[2], Diogo Souto3, Katia M. L. Cunha3, Cayman T. Unterborn[1], Wendy Panero4
Institution(s): *1. Arizona State University, 2. Carnegie Observatories, 3. Observatorio Nacional, 4. Ohio State Univ.*
Contributing team(s): SDSS/APOGEE team

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414 – AGN, QSO, Blazars: Nuclear Regions & Black Holes

414.01 – The Sloan Digital Sky Survey Reverberation Mapping Project: Quasar Reverberation Mapping Studies

The Sloan Digital Sky Survey Reverberation Mapping Project (SDSS-RM) has completed its first three years of spectroscopic observations of a sample of ~850 quasars with the SDSS-III BOSS spectrograph. From January-July in 2014, 2015, and 2016, more than 55 epochs of spectroscopy were obtained for this quasar sample, and continued monitoring has been approved for 2017. Supporting photometric observations were also carried out at the Canada-France-Hawaii Telescope and the Steward Observatory Bok telescope. In addition, the SDSS-RM field overlaps with the

Pan-STARRS 1 Medium Deep Field MD07, so we have photometric data for three years prior to the SDSS-RM observations, which considerably extends the time delay sensitivity of the campaign. Preliminary reverberation mapping results were presented by Shen et al. (2015) and the program has also yielded ancillary science results in regimes such as broad absorption line variability, quasar ensemble variability characteristics, quasar emission line studies, SDSS quasar redshift measurements, and host galaxy properties. I will discuss the current status of the SDSS-RM program, including recent reverberation mapping results from the wider 850-quasar sample using the full set of first-year photometric and spectroscopic data.

Author(s): Catherine Grier[1]
Institution(s): *1. Pennsylvania State University*
Contributing team(s): The SDSS-RM Collaboration

414.02D – Reverberation Mapping of AGN Accretion Disks

I will discuss new reverberation mapping results that allow us to investigate the temperature structure of AGN accretion disks. By measuring time-delays between broad-band continuum light curves, we can determine the size of the disk as a function of wavelength. I will discuss the detection of continuum lags in NGC 5548 reported by the AGN STORM project and implications for the accretion disk. I will also present evidence for continuum lags in two other AGN for which we recently measured black hole masses from continuum-Hbeta reverberations. The mass measurements allow us to compare the continuum lags to predictions from standard thin disk theory, and our results indicate that the accretion disks are larger than the simplest expectations.

Author(s): Michael Fausnaugh[1]
Institution(s): *1. The Ohio State University*
Contributing team(s): AGN STORM Collaboration

414.03 – Reverberation Mapping Results for NGC 4151

In the spring of 2014 and 2015, reverberation mapping data were collected for the AGN NGC 4151. Spectroscopy and photometry were obtained from Apache Point Observatory (Sunspot, NM) and supplemental photometry was gathered from Hard Labor Creek Observatory (Rutledge, GA). In our preliminary results, we compare our supermassive black hole mass calculations to previously published values. We investigate the gravity-dominated, virialized BLR model by expanding the expected $R_{BLR} \propto V^{-2}$ size-velocity relationship for NGC 4151, providing results for the broad emission lines at multiple luminosities of the AGN. With these luminosities and BLR radii, we create a Hβ R_{BLR}-$L_{5100Å}$ relationship for NGC 4151, and we compare it against the population average Hβ R_{BLR}-$L_{5100Å}$ relationship and to Hβ R_{BLR}-$L_{5100Å}$ relationships for AGN in the literature.

Author(s): Caroline Anna Roberts[1], Misty C. Bentz[1], Merida Batiste[1]
Institution(s): *1. Georgia State University*

414.04 – The Lick AGN Monitoring Project 2016: Extending Reverberation Mapping to Higher Luminosity AGNs

The technique of reverberation mapping has been used to estimate virial black hole masses and, more fundamentally, to probe the broad line region structure in Seyfert I galaxies. Efforts from the previous Lick AGN Monitoring Project (LAMP) campaigns and other studies to date have culminated in a large sample of reverberation mapped AGNs and measurements of their black hole masses, which in turn enabled major improvement to various AGN scaling relations. However, the high-luminosity end of such relations remains poorly constrained; this is because of observational challenges presented by the weaker continuum flux variations and longer time dilation in these sources. To this end, we have initiated a new LAMP2016 campaign to target AGNs with luminosities of 10^44 erg/s, with predicted H-beta lags of ~20 - 60 days or black hole masses of 10^7 - 10^8.5 Msun. Designed to monitor ~20 AGNs biweekly from Spring 2016 through Winter 2017 with the Kast spectrograph on the 3-m Shane Telescope at Lick Observatory, we aim to probe luminosity-dependent trends in broad line region structure and dynamics, improve calibrations for single-epoch estimates of high-redshift quasar black hole masses, and test photoionization models for the radially-stratified structure of the broad line region. In this talk, I will present the overview and scope of LAMP2016 and show preliminary results from our ongoing campaign.

Author(s): Vivian U[1]
Institution(s): *1. UC Riverside*
Contributing team(s): LAMP2016 Collaboration

414.05 – Optical Variability Signatures from Massive Black Hole Binaries

The hierarchical merging of dark matter halos and their associated galaxies should lead to a population of supermassive black hole binaries (MBHBs). We consider plausible optical variability signatures from MBHBs at sub-parsec separations and search for these using data from the Catalina Real-Time Transient Survey (CRTS). Specifically, we model the impact of relativistic Doppler beaming on the accretion disk emission from the less massive, secondary black hole. We explore whether this Doppler modulation may be separated from other sources of stochastic variability in the accretion flow around the MBHBs, which we describe as a damped random walk (DRW). In the simple case of a circular orbit, relativistic beaming leads to a series of broad peaks — located at multiples of the orbital frequency — in the fluctuation power spectrum. We extend our analysis to the case of elliptical orbits and discuss the effect of beaming on the flux power spectrum and auto-correlation function using simulations. We present a code to model an observed light curve as a stochastic DRW-type time series modulated by relativistic beaming and apply the code to CRTS data.

Author(s): Vishal P. Kasliwal[1], Koby Alexander Frank[1], Adam Lidz[1]
Institution(s): *1. University of Pennsylvania*

414.06 – Diagnostic Power of Broad Emission Line Profiles in Searches for Binary Supermassive Black Holes: Comparison of Models with Observations

Motivated by observational searches for sub-parsec supermassive black hole binaries (SBHBs) we develop a semi-analytic model to describe the spectral emission line signatures of these systems. We are particularly interested in modeling the profiles of the broad emission lines, which have been used as a tool to search for SBHBs. The goal of this work is to test one of the leading models of binary accretion flows in the literature: SBHB in a circumbinary disk. In this context, we model SBHB accretion flows as a set of three accretion disks: two mini-disks that are gravitationally bound to the individual black holes and a circumbinary disk that forms a common envelope about a gravitationally bound binary. Our first generation model shows that emission line profiles tend to have different statistical properties depending on the semi-major axis, mass ratio, eccentricity of the binary, and the alignment of the triple-disk system, and can in principle be used to constrain the statistical distribution of these parameters. We present the results of a second generation model, which improves upon the treatment of radiative transfer by taking into account the effect of line-driven winds on the properties of the model emission line profiles. This improvement allows a preliminary comparison of the model profiles with the observed SBHB candidates and AGN population in general.

Author(s): Khai Nguyen[1], Tamara Bogdanovic[1], Michael Eracleous[2], Jessie C. Runnoe[2], Steinn Sigurdsson[2]
Institution(s): *1. Georgia Institute of Technology, 2. Pennsylvania State University*

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415 – Extrasolar Planets Detection: Methodology

415.01 – Identifying Long-period Planets from Single

Transit Events with the MEarth Project

The MEarth Project consists of 2 arrays of 8 telescopes each, one in the northern hemisphere at Mt. Hopkins, AZ and one in the southern hemisphere at CTIO, Chile. MEarth is monitoring the stars with estimated radii less than 0.3 solar radii and estimated distances within 33 parsecs for transiting exoplanets. Rocky planets transiting these small, nearby stars are ideal targets for atmospheric characterization with JWST and the ELTs, as the relative signal size is larger than for planets around main-sequence FGK stars, and the star's proximity ensures a high photon rate. Planets in the habitable zone of these stars will have orbital periods of several weeks. Thus, we would typically have only one or a few observable transits per observing season per site. Our strategy to discover these planets is to identify them in real time from a single (partial) transit event, and subsequently determine the orbital periods from radial velocity measurements. This, in turn, would allow us to predict future transits. MEarth generates a large number of triggers; we used machine learning methods informed by atmospheric and observatory state variables to cull this list. We are gathering radial velocity measurements for our top resulting candidates and will present an update on their status.

The MEarth Project gratefully acknowledges funding from the David and Lucile Packard Foundation and the National Science Foundation. This work was made possible by a grant from the John Templeton Foundation. EN is supported by an NSF Astronomy and Astrophysics Postdoctoral Research Fellowship.

Author(s): Jason Dittmann[2], Jonathan Irwin[2], David Charbonneau[2], Xavier Bonfils[5], Nicola Astudillo[4], Elisabeth R. Newton[3], Zachory K. Berta-Thompson[1]
Institution(s): *1. Colorado University, 2. Harvard Smithsonian, CfA, 3. Massachusetts Institute of Technology, 4. Observatoire de Geneve, 5. Universite de Grenoble*

415.02 – Searching for the First Exomoon in the Radio: A Report on GMRT Data

The field of exoplanetary research has undergone a great deal of development and growth. Achievements in theoretical studies and detection techniques have allowed the discovery of over 3,500 exoplanets in ~2,600 planetary systems to date. Despite this great success, the detection of the first exomoon is yet to be achieved. Motivated by this, we have applied a novel radio-detection method, proposed by Noyola et.al (2014, 2016). The technique is based on a planet-moon interaction observed in the Jupiter-Io system, and Io-controlled decametric radio emissions were used to demonstrate how the presence of exomoons around giant planets might be revealed by the same modulation mechanism. Three targets, selected as the best candidates for radio detection, were observed through the Giant Metrewave Radio Telescope (GMRT); located in India. The results of our data analysis will be presented and discussed.

Author(s): Marialis Rosario-Franco[2], Joaquin Noyola[2], Suman Satyal[2], Zdzislaw E. Musielak[2], Jitendra Kodilkar[1]
Institution(s): *1. Giant Metrewave Radio Telescope, 2. University of Texas at Arlington*

415.04 – Transit Clairvoyance: Enhancing TESS follow-up using artificial neural networks

The upcoming TESS mission is expected to find thousands of transiting planets around bright stars, yet for three-quarters of the fields observed, the temporal coverage will limit discoveries to planets with guaranteed measured orbital periods below 13.7 days. From the *Kepler* catalog, the mean probability of these short-period transiting planets having additional longer period transiters, which would be missed by TESS, is 18%, a value ten times higher than that of the average star. It is perhaps not surprising that this probability is not uniform but functionally dependent upon the properties of the observed short-period transiters, ranging from less than 1% up to ~50%. Using artificial neural networks (ANNs) trained on the Kepler catalog and careful feature selection accounting for the differing sensitivity of TESS, we are able to predict the most likely short-period transiters to be accompanied by additional transiters. Through cross-validation, we predict that a targeted, optimized TESS transit follow-up survey using our trained ANN would have a discovery yield improved by a factor of two. Our work should enhance the efficiency of surveys following TESS targets for additional planets, improving the science yield derived from TESS and particularly benefiting the search for habitable-zone transiting worlds.

Author(s): Christopher Lam[1], David M. Kipping[1]
Institution(s): *1. Columbia University*

415.05D – The Past, Present, and Future of Planetary Systems

We are searching for planets using the Kepler spacecraft in its extended K2 mission. K2 data processing is more challenging than Kepler, but new techniques have permitted the discovery of hundreds of planet candidates. Our discoveries are yielding intriguing insights about the past, present, and future of planetary systems -- that is, the history of how planets might form and migrate, their present-day characteristics, and the ultimate fate of planetary systems. I will discuss what we have learned, in particular from the discovery of a hot Jupiter with close planetary companions, planets orbiting nearby bright stars, and a disintegrating minor planet transiting a white dwarf. This work was supported by the National Science Foundation Graduate Research Fellowship Program.

Author(s): Andrew Vanderburg[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

415.06 – Updated Starshade Technology Gap List

NASA's Exoplanet Exploration Program (ExEP) guides the development of technology that enables the direct imaging and characterization of exo-Earths in the habitable zone of their stars, for future space observatories. Here we present the Starshade portion of the 2017 ExEP Enabling Technology Gap List, an annual update to ExEP's list of of technology to be advanced in the next 1-5 years. A Starshade is an external occulter on an independent spacecraft, allowing a space telescope to achieve exo-Earth imaging contrast requirements by blocking starlight before it enters the telescope. Building and operating a Starshade requires new technology: the occulter is a structure tens of meters in diameter that must be positioned precisely at a distance of tens of thousands of kilometers from the telescope. We review the current state-of-the-art performance and the performance level that must be achieved for a Starshade.

Author(s): Brendan P. Crill[1], Nicholas Siegler[1]
Institution(s): *1. Jet Propulsion Laboratory*

415.07 – How, when and where Life will begin on another planet after Earth by Duky's Theory

Our Sun is a Red Giant Star and in distant future it will engulf Mercury, Venus and probably Earth and Mars. This paper shows that in distant future due to increasing size & luminosity of the Sun life will begin on one of the planet after 1 duky's Unit. 1 duky's Unit is the time from now to the time when Mercury would get merged in Sun. At that time Venus would be first planet & due to closeness to Sun, its upper atmosphere would get heated up by solar wind. In a continuous process the clouds of sulfuric acid would escape its gravity. Eventually it would get drifted off into space and it become Mercury twin. On Earth after few million years moisture in air would become very good to trap infra red radiation. As it will warms up, oceans would evaporate even more & in few million years it would get covered with blanket of water vapours. Due to increasing temperature & pressure, volcanoes on Earth would become active then volcanic eruption would blast billions of tons of sulfur high into atmosphere there sulfur would mix with water vapors & form conc. Sulfuric acids. In a continuous process of few more million years whole Earth would get covered with sulphuric acids cloud. As Earth's moon is receding away from Earth, so before 1 DU, Moon will have been gone away from Earth. As a result it would get started slow down one spin about 1 million year. These would lead to massive outpouring of CO_2 & other greenhouse gasses. At that

Earth would become Venus Twin. Now it's Mars turn, according to scientists after 50 millions years from now phobo will crash onto the surface of Mars. When that would happen, Mars would have one moon like Earth. This collision would be so hard & strong that phobo would get totally immersed in the surface of Mars as a results it's possible that Mars would get tilted at about 23.5 degree. Due to collision molten lava would come out. When temperature & pressure would rise then water ice would become water. When water would get enriched with minerals, microbial life would emerge. Then under water bacteria would begin to use water, CO2 and Sun's energy to produce carbohydrate to survive that will inject vast amount of O2 into sea water & eventually in our atmosphere. Mars would become Earth's twin.

Author(s): Satveer Deol[2], Amritpal Singh Nafria[1]
Institution(s): *1. Lovely Professional University, 2. Punjabi University*

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416 – Dwarf & Irregular Galaxies II

416.02 – A new dwarf detection algorithm applied to M101

The Lambda Cold Dark Matter model for structure formation has been very successful at reproducing observations of large scale structures. However, challenges emerge at sub-galactic scales, e.g. the number of dwarfs around the Milky Way show an order of magnitude difference with simulations (the 'missing satellites problem'). There are several theories to explain this apparent discrepancy but further observations of Local Volume galaxies and their substructure is required to constrain these models by better sampling halo to halo scatter. Here we report on a survey of the M101 group from archival data and a novel dwarf detection algorithm. This survey has discovered 26 new dwarf candidates in the M101 system, extending the dwarf luminosity function by two magnitudes, to M=-7.5. These dwarf candidates also show a distinct spatial asymmetry suggestive of an infalling dwarf group.

Author(s): Paul Bennet[1], David J. Sand[1], Denija Crnojevic[1]
Institution(s): *1. Texas Tech University*

416.03 – Effects of Tides on Milky Way Dwarf Satellite Galaxies

Using detailed observations of the Local Group to study wide-ranging questions in galaxy formation and dark matter physics – has become a rich field over the past decade. In this talk, I will present frameworks that address some of these questions by combining high-precision stellar kinematic measurements with state-of-art cosmological hydrodynamical N-body simulations. I will demonstrate that the properties of dark matter subhalo of individual satellite galaxies implied by stellar kinematic data can be linked to the galaxy evolution mechanisms such as infall time and the gravitational tidal interaction with Milky Way potential. In the cold dark matter (CDM) scenario, some dwarf galaxies explicitly require to be shaped under significant gravitational tidal forces, which will leave imprints on their stellar distribution and kinematics. I will discuss how these features could serve as a test to the nature of dark matter or stellar feedback strength. I will also discuss how we can study the tidally "disturbed" or even "destroyed" satellite galaxies as building blocks to our Milky Way stellar halo by understanding the properties of their progenitors and observation limit imposed by current and future surveys.

Author(s): Mei-Yu Wang[2], Louis Strigari[2], Azadeh Fattahi[6], Carlos S Frenk[1], Andrew Cooper[1], Mark Lovell3, Julio F. Navarro[6], Till Sawala4, Andrew Zentner5
Institution(s): *1. Durham University, 2. Texas A&M University, 3. University of Amsterdam, 4. University of Helsinki, 5. University of Pittsburgh, 6. University of Victoria*

416.04 – The First Data Release of the Survey of the MAgellanic Stellar History (SMASH)

Our knowledge of the formation and evolution of dwarf galaxies is limited. To gain a better understanding of the formation history of the nearby Small and Large Magellanic Clouds, SMASH (Survey of the MAgellanic Stellar History) has imaged ~2400 square degrees (at 20% filling factor) to 24th mag in gri (uz~23). These observations are alllowing us to map the expected stellar debris, extended stellar populations, and star formation histories of the Clouds with unprecedented fidelity. We are announcing the first SMASH data release, which features catalogs from ~70 DECam fields. This release highlights the new data publication functionality of the NOAO Data Lab. The SMASH catalogs of forced-PSF photometry have high photometric precision (~0.2%) and accuracy (~1-2%) with exceptional astrometry (~20 mas) using Gaia reference stars. Our initial results include the discovery of (1) an extended stellar population around the Large Magellanic Cloud to ~19 kpc in many directions, (2) the Milky Way dwarf spheroidal galaxy Hydra II, and (3) a tidally disrupting globular cluster of the Large Magellanic Cloud (SMASH 1).

Author(s): David L. Nidever[1]
Institution(s): *1. NOAO*
Contributing team(s): SMASH

416.05 – The Survey of the MAgellanic Stellar History (SMASH): Tracing Stellar Structures in the southern disk of LMC

The Survey of the MAgellanic Stellar History (SMASH) maps the main bodies and periphery of the Magellanic Coulds, and the Leading Arm with deep *ugriz* images, down to surface brightnesses of ~35 mags/arcsec^2. Our SMASH survey allows to explore stellar components in these structures, especially in very low surface density regions for the first time. Specifically, we will present preliminary results of the stellar structures in the southern disk of the Large Magellanic Cloud (LMC). Recently, stellar overdensities have been found in the northern periphery of LMC by Mackey et al. (2016) using the Dark Energy Survey. By exploring (a)symmetric stellar structures in the LMC southern disk, we can constrain the origin of these structures.

Author(s): Yumi Choi[2], David L. Nidever[1], Knut A. Olsen[1], Gurtina Besla[2]
Institution(s): *1. NOAO, 2. University of Arizona*
Contributing team(s): SMASH team

416.06 – The Magellanic Satellites Survey: Searching for Hierarchical Structure Formation within the Local Group

A generic prediction of galaxy formation in the standard cosmological model with cold dark matter is the hierarchical assembly of structure on mass scales ranging from ultra-faint galaxies to galaxy clusters. In the Local Group, dozens of galaxies have been found orbiting the Milky Way and Andromeda. The question of whether the largest Milky Way satellites, the Large and Small Magellanic Clouds, brought in their own entourage of satellites has been a long standing puzzle, and has garnered renewed interest following the recent discovery of more than a dozen ultra-faint galaxy candidates in the southern hemisphere. The on-going Magellanic Satellites Survey (MagLiteS) aims to complete an annulus of contiguous deep optical imaging with Blanco/DECam around the periphery of the Magellanic Clouds, enabling a systematic search for ultra-faint galaxies and other low-surface-brightness stellar substructures associated with the Magellanic system. I will report on the progress of MagLiteS and discuss science highlights from the first observing season, including a new ultra-faint galaxy candidate located ~11 kpc from the Large Magellanic Cloud.

Author(s): Keith Bechtol[1]
Institution(s): *1. LSST*
Contributing team(s): Magellanic Satellites Survey (MagLiteS)

416.08 – The Dark Matter Content of the Triangulum II Ultra-Faint Dwarf Galaxy

Triangulum II is an ultra-faint galaxy with a luminosity of 450 $L_\odot$ discovered through Pan-STARRS imaging in 2015. Since then, two independent studies—including one of our own—based on

Keck/DEIMOS spectroscopy found that the galaxy has a stellar velocity dispersion of about 5 km/s, indicating a very high concentration of dark matter. Here, we present additional DEIMOS observations over six epochs. We show that a combination of radial velocity variability (likely due to binarity) and inaccuracies in the previous measurements led to a spurious detection of a velocity dispersion in excess of what would be expected from the stellar population alone. Instead, we place an upper limits of 3.4 km/s (90% C.L.) and 4.3 km/s (95% C.L.) on the velocity dispersion. While these limits are compatible with very high mass-to-light ratios (1700 at 90% C.L. or 2600 at 95% C.L.), Triangulum II no longer seems extreme compared to dwarf galaxies of similar luminosity. Because the stars still span a large range of metallicity (-2.8 < [Fe/H] < -1.5), the galactic nature of Triangulum II is not in dispute.

Author(s): Evan N Kirby[1], Judith G. Cohen[1], Joshua D. Simon[2]
Institution(s): *1. California Institute of Technology, 2. Carnegie Observatories*

417 – Binary Stellar Systems

417.01D – Tidal Interaction among Red Giants Close Binary Systems in APOGEE Database

Motivated by the newly discovered close binary systems in the Apache Point Observatory Galactic Evolution Experiment (APOGEE-1), the tidal evolution of binaries containing a red giant branch (RGB) star with a stellar or substellar companion was investigated. The tide raised by the companion in the RGB star leads to exchange of angular momentum between the orbit and the stellar spin, causing the orbit to contract. The tidal dissipation rate is computed using turbulent viscosity acting on the equilibrium tidal flow, where careful attention is paid to the effects of reduced viscosity for close-in companions. Evolutionary models for the RGB stars, from the zero-age main sequence to the present, were acquired from the MESA code. "Standard" turbulent viscosity gives rise to such a large orbital decay that many observed systems have decay times much shorter than the RGB evolution time. Several theories for "reduced" turbulent viscosity are investigated, and reduce the number of systems with uncomfortably short decay times.

Author(s): Meng Sun[2], Phil Arras[2], Steven R. Majewski[2], Nicholas William Troup[2], Nevin N. Weinberg[1]
Institution(s): *1. Department of Physics and MIT Kavli Institute, MIT, 2. University of Virginia*

417.02 – Resolving M-dwarf Binaries in Young Moving Groups (YMGs) with MagAO

With relatively well-determined ages and uniform histories, YMGs are sparse ensembles of stars that serve as benchmarks for the transition of stellar populations from their birth clusters to the field. We present data and analysis from our Magellan Adaptive Optics (MagAO) campaign to image more than 100 K- and M-dwarf members of several YMGs in the southern sky, revealing ~30 previously unresolved visual stellar companions at separations of ~3 — 300 AU. Knowledge of their binarity is instrumental to interpreting their measured properties for a variety of applications. The tighter of these systems also represent opportunities for future monitoring and dynamical mass inference.

Due to faintness and lack of clarity in their YMG memberships (until recently), the multiplicity of PMS M-dwarfs in young associations is hitherto unconstrained. Our study provides statistics for such young M-dwarf multiples in an intermediate regime of orbital distance (across the hard-soft boundary) to populate this little-explored region in the parameter space of multiple star systems. Among the ensemble properties of interest are distributions in physical separations and mass ratios for the binary components. When combined with the SACY survey (Elliott et al. 2015), whose focus is on YMG systems with earlier type primaries, we are able to provide an updated measurement of young-star multiplicity as a function of stellar mass, age, and environment, with significantly more statistical power at lower masses. We discuss implications for the universality and scalability of star formation and evolution processes, as well as comparison to measurements in related populations (e.g. cluster, field, young, old, FGK stars) which form a storyline that theory must explain.

Author(s): Yutong Shan[1], Jennifer C Yee[1], Brendan P. Bowler[2]
Institution(s): *1. Harvard University , 2. University of Texas at Austin*

417.03 – Spatial Disrtribution and Evolution of Massive Stars

Observations show that luminous blue variables (LBVs) are far more dispersed than other massive stars, and Smith & Tombleson (2015) suggested that these large separations are inconsistent with the standard single-star evolution model of LBVs. Instead, they suggest that the large distances are most consistent with some sort of binary evolution. To test these suggestions, we modeled young stellar clusters and their passive dissolution, and we find that, indeed, the single-star evolution model is inconsistent with observations. Most importantly, we find two binary scenario models that are consistent. Our crude models suggest that LBVs are either the result of mergers and are rejuvenated stars, or they are mass gainers and received a kick when the primary star exploded. In the merger scenario, LBVs have more time to disperse because they are the merger of two lesser mass, in which the primary has a mass of about 19 solar masses. In the mass gainer and kick scenario, we find that LBV isolation is consistent with an average kick of 200 km/s. In either scenario, binarity plays a major role in the isolation of LBVs. In addition to constraining the evolution of LBVs, we suggest that careful scrutiny of the spatial distribution of massive stars in general will lead to a greater understanding for the evolution of massive stars.

Author(s): Mojgan Aghakhanlootakanloo[1], Jeremiah W Murphy[1]
Institution(s): *1. fsu*

417.04 – KIC 9832227: a red nova precursor

Molnar et al. (2015) suggested that KIC 9832227 is a contact binary star in its final years before merging and producing a red nova eruption. Analysis of light curves spanning 1999 to 2014 showed a negative time derivative and second derivative of the orbital period. The timing data were found to be well fit by the empirical exponential formula that Tylenda et al. (2011) used to describe preoutburst data of V1309 Sco. While it could not be concluded that this was the correct interpretation of the data, the prediction made for the near future was specific and falsifiable.

We will present light curve data from 2015-2016 which is consistent with the extrapolation of the previous fit. As predicted, the period derivative now exceeds the range measured for other contact systems. Reanalysis of the Kepler spacecraft timing data shows a low amplitude modulation consistent with a third star with an orbital period of 1.7 y and msin i = 0.11 solar masses. We will also present spectroscopic data that show the signature of both binary components. These data rule out the presence of any additional main sequence stars with mass greater than 0.4 solar masses. Based on an updated fit to the exponential formula, we now estimate the time of merger to be the year 2022.2 with a random uncertainty of 0.6 years.

These results greatly strengthen the original suggestion. The system presents an unprecedented opportunity to study the mechanism of stellar merger through targeted observations of a precursor.

Molnar, L. et al. (2015), AAS Meeting #225, id.415.05.
Tylenda, R., et al. (2011), AA, 528, A114.

Author(s): Lawrence A. Molnar[2], Daniel Van Noord[2], Karen Kinemuchi[1], Jason P. Smolinski[2], Cara E. Alexander[2], Henry A. Kobulnicky[3], Evan M. Cook[2], Byoungchan Jang[2], Steven D. Steenwyk[2]
Institution(s): *1. Apache Point Observatory, 2. Calvin College, 3. University of Wyoming*

417.05 – Estimating Parallax Error Due to Orbital Motion for *HST*/WFC3 Spatial Scan Observations of 19 Long-period Classical Cepheids

We employ the Hubble Space Telescope's Wide Field Camera 3 (*HST*/WFC3) in spatial scanning mode to measure 30 – 40μas parallax of 19 classical Cepheids in the Milky Way with the aim of improving the calibration of the cosmic distance scale (Riess et al. 2014; Casertano et al. 2016). The measured parallaxes are an order of magnitude more precise than parallaxes from the first Gaia data release and thus furthermore provide important cross-checks for Gaia data processing.

Here we present our work aimed at estimating the parallax error due to orbital motion caused by undetected companion stars (Anderson et al. 2016). We have secured more than 1600 high-precision radial velocity (RV) measurements of the 19 long-period (P_{puls} > 9d) Cepheids in our sample using ground-based telescopes on both hemispheres to investigate the presence of spectroscopic companions. We model the RV variability together with orbital motion using a grid of input orbital periods, P_{orb}. We determine upper limits on the (unsigned) projected parallax error induced by hypothetical companions using the orbital configuration upper limits determined by modeling RV data. We thus show that our HST/WFC3 parallax measurements are subject to an error of less than 2% in parallax (i.e., typically less than ±7μas) for 16 stars in the sample, and < 4% for two Cepheids with fewer RV observations. For YZ Carinae, however, we correct the previously published orbital solution and show that the astrometric model must take into account orbital motion to avoid significant (approx. ±100μas) parallax error.

We have further investigated long-timescale (P_{orb} > 10yr) orbital motion using literature data and RV templates based on our new data. We thus discover new evidence for RV signals due to long-term orbital motion for 4 Cepheids and critically assess putative evidence for spectroscopic binarity previously reported based on data of much lesser quality. We caution that astrometric measurements of binaries with P_{orb} on the order of decades may be subject to a currently not quantified systematic error in the Tycho-Gaia Astrometric Solution.

Author(s): Richard Irving Anderson[2], Stefano Casertano[1], Adam G. Riess[2]
Institution(s): *1. STScI, 2. The Johns Hopkins University*

418 – Dark Matter, Dark Energy & CMB

418.02D – Hidden Sector Hydrogen as Dark Matter: Predictions for Small-scale Structure

I will discuss the atomic physics and the astrophysical implications of a model in which the dark matter is the analog of hydrogen in a secluded sector. The self interactions between dark matter particles include both elastic scatterings as well as inelastic processes due to a hyperfine transition. The self-interaction cross sections are computed by numerically solving the coupled Schrodinger equations for this system. The velocity-dependence of the self-interaction cross sections produces the low dark matter density cores seen in spiral galaxies while maintaining consistency with constraints from observations of galaxy clusters. Significant cooling losses may occur due to inelastic excitations to the hyperfine state and subsequent decays (up to about 10% of the collisional heating rate) in this region of parameter space, with implications for the evolution of low mass halos and early growth of black holes. Finally, the minimum halo mass is in the range of 10^3 to 10^7 solar masses for viable regions of parameter space, which is significantly larger than the typical predictions for weakly-interacting dark matter models.

Author(s): Anna Kwa[2], Kimberly Boddy[3], Manoj Kaplinghat[2], Annika Peter[1]
Institution(s): *1. The Ohio State University, 2. University of California, Irvine, 3. University of Hawaii*

418.03 – Simulated Studies of Supernova Cosmology for LSST

We discuss methods for simulating Type Ia SN observations from LSST based on the Operation Simulation (OpSim) ouptuts supplied by the LSST project and emperical, data driven models of supernovae. Such simulations can be used to assess the Survey strategies implemented in OpSim in terms of the success of different programs in supernova cosmology based on the results of analysis of the simulations.

Author(s): Rahul Biswas[1]
Institution(s): *1. University of Washington*

418.04D – Complex Scalar Field Dark Matter and the Stochastic Gravitational Wave Background from Inflation: New Cosmological Constraints and Detectability

We consider an alternative to WIMP cold dark matter (CDM), ultralight bosonic dark matter ($m \geq 10^{-22}$ eV) described by a complex scalar field (SFDM), of which the comoving particle number density is conserved after particle production during standard reheating ($w=p/\rho=0$). In a ΛSFDM universe, SFDM starts relativistic, evolving from stiff ($w=1$) to radiation-like ($w=1/3$), before becoming nonrelativistic at late times ($w=0$). Thus, before the familiar radiation-dominated phase, there is an even earlier phase of stiff-SFDM-domination, during which the expansion rate is higher than in ΛCDM. The transitions between these phases, determined by SFDM particle mass m, and coupling strength λ, of a quartic self-interaction, are therefore constrained by cosmological observables, particularly N_{eff}, the effective number of neutrino species during BBN, and z_{eq}, the redshift of matter-radiation equality. Furthermore, since the homogeneous energy density contributed by the stochastic gravitational wave background (SGWB) from inflation is amplified during the stiff phase, relative to the other components, the SGWB can contribute a radiation-like component large enough to affect these observables. This same amplification makes possible detection of this SGWB at high frequencies by current laser interferometer experiments, e.g., aLIGO/Virgo, eLISA. For SFDM particle parameters that satisfy these cosmological constraints, the amplified SGWB is detectable by aLIGO, for values of tensor-to-scalar ratio r currently allowed by CMB polarization measurements, for a broad range of possible reheat temperatures T_{re}. For a given r, if SFDM parameters marginally satisfy cosmological constraints (maximizing total SGWB energy density), the SGWB is maximally detectable when modes that reenter the horizon when reheating ends have frequencies in the 10-50 Hz aLIGO band today. For example, if r=0.01, the maximally detectable model for $(\lambda/(mc^2)^2, m)=(10^{-18}$ $eV^{-1}cm^3$, 8×10^{-20} eV) has $T_{re}=10^4$ GeV, for which we predict aLIGO O1 run detection with SNR ~10. Nondetection by aLIGO O1 would provide a new cosmological constraint on SFDM. A wider range of SFDM parameters and T_{re} should be accessible to aLIGO/Virgo O5, which may detect this unique signature of SFDM.

Author(s): Bohua Li[1], Paul R. Shapiro[1], Tanja Rindler-Daller[2]
Institution(s): *1. The University of Texas at Austin, 2. University of Vienna*

418.05D – Using Galaxy Simulations to Examine Dark Matter in the Solar Neighborhood with Implications for Direct Detection

Experiments aiming for the direct detection of dark matter have made great progress in recent years in exploring the WIMP mass - cross section parameter space. These experimental results are highly dependent on the assumed dark matter velocity distribution. I will show results comparing the conventional Maxwell-Boltzmann distribution to the dark matter velocity distribution in the Solar neighborhood from both dark matter-only simulations and simulations which include dark matter, gas, and stellar physics. It is well established that dark matter-only simulations do not support the Maxwell-Boltzmann assumption. I show that the inclusion of gas and stellar physics alters the dark matter velocity distribution in simulated Milky Way analogue galaxies. Further, I will examine the dependence of the dark matter velocity distribution on halo mass and resolution. The impact of observed differences between these distributions on selected direct detection results will be shown. I will also discuss the origins of the differences between the velocity distributions.

Author(s): Jonathan D Sloane[1]
Institution(s): *1. Rutgers, The State University of New Jersey*

418.06 – Decaying sterile neutrino dark matter in the Local Group

The detection of a 3.55 keV X-ray line in clusters of galaxies and the Andromeda and Milky Way galaxies, while contentious, can be explained by the decay of resonantly-produced 7.1 keV sterile neutrinos. If the X-ray line is confirmed to be the result of dark matter decay, then it is the first non-gravitational signal of dark matter and groundbreaking evidence of physics beyond the standard model. We use simulations that accurately model the dark matter distribution of the Local Group in realistic sterile neutrino cosmologies to study the dark matter interpretation of the X-ray flux. We present the sterile neutrino dark matter models that are consistent with the observed M31 flux profile and discuss the predictions of these models for X-ray observations of classical Milky Way dwarf galaxies. We discuss how these results relate to Lyman-alpha forest constraints of sterile neutrino models and predictions for satellite galaxy counts in future surveys, which may be able to rule out 7.1 keV sterile neutrinos as a dark matter candidate.

Author(s): Brandon Bozek[2], Michael Boylan-Kolchin[2], Shunsaku Horiuchi4, Shea Garrison-Kimmel[1], Kevork Abazajian3, James Bullock3
Institution(s): *1. California Institute of Technology, 2. The University of Texas at Austin, 3. University of California, Irvine, 4. Virginia Tech*

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419 – Star Formation II

419.01 – Probing the EBL evolution at high redshifts using 22 GRBs detected with the Fermi-LAT

The extragalactic background light (EBL) is the collective emission of all the stars and galaxies over the history of the universe. The most efficient method to study the EBL is through the imprint it leaves via photon-photon annihilation in the spectra of distant gamma-ray sources. Here we present a combined analysis of a sample of 22 Gamma Ray Bursts (GRBs) detected by Fermi Large Area Telescope. GRBs are short-lived, bright, high-energy sources detected up to very high redshifts. This allows us to probe the EBL at much higher redshifts than before. We report the first constrain on the EBL when the Universe was one fourth of its present age (z=1.8). This will be discussed in the context of the generation of the UV-optical background and the star-formation activity of the Universe.

Author(s): Abhishek Amitbhai Desai[1], Marco Ajello[1], Nicola Omodei[2], Dieter Hartmann[1]
Institution(s): *1. Clemson University, 2. Stanford University*
Contributing team(s): Fermi-LAT collaboration

419.02 – Five-Steps Star Formation Histories across M51: Hybrid FUV+IR Star Formation Rates and the Contribution of Older Stars to the IR Emission

Galaxies are products of gigayears of evolution and therefore have complex star formation histories (SFHs). Modeling star formation rate (SFR) as a flexible function of cosmic time is crucial to disentangle the contributions from stellar populations of different ages and best describe complex SFHs from current UV-to-IR spectral energy distributions (SEDs). We present a novel approach modeling SFHs as a number of steps in time, maximizing the information obtained from these SEDs and minimizing degeneracies. Our model includes a variable attenuation curve and stellar metallicity. For this work, we adopted SFH bins with lookback times of 0-10Myr, 10-100Myr, 100Myr-1Gyr, 1-5Gyr, and 5-13Gyr, resulting in SFHs with five steps. Our resolved analysis across the nearby Whirlpool spiral galaxy, M51, shows that the three first bins (ages less than 1 Gyr) can be well recovered separated, but the other two have much-increased uncertainties, being only upper limits in the outskirts of the galaxy. No significant difference was found if the recent SFR is averaged over the last 10Myr or over the last 100Myr, suggesting SFR did not vary significantly in the last 100 Myr. A considerable SFR increase can be seen in the 100Myr-1Gyr bin, with relative intensities varying across the galaxy. The recovered intrinsic FUV is, as expected, directly proportional to the SFR averaged over the last 100 Myr and allows us to test the hybrid SFR traced by combining the observed FUV and a broadband intensity in the mid- or far-IR. We have also tested hybrid SFR tracers of the form Lobs(FUV) + a_{corr} × Lobs(lambda_IR), deriving correction factors (a_{corr}) for various wavelengths and found they all increase with specific star formation rate (sSFR). This indicates a significant IR contribution from stars older than 100 Myr, not associated with the recent SFR. We then empirically decomposed the full IR SED into a component related to the recent SFR and another not associated with it. We derived comparable IR emission coming from each component. Quite distinct IR SEDs shapes are recovered for each component.

Author(s): Rafael T. Eufrasio[2], Bret Lehmer[2], Andreas Zezas3, Ann E. Hornschemeier[1]
Institution(s): *1. NASA Goddard Space Flight Center, 2. University of Arkansas, 3. University of Crete*

419.03D – Star Formation in Edge-on Galaxies and its Relation to Radio Continuum Halos

We study the radio continuum emission in edge-on galaxies from the Continuum Halos in Nearby Galaxies -- an EVLA Survey (CHANG-ES), with a particular focus on the question of the correlation of radio synchroton halos with the star formation rate distribution across the galaxy disks. To determine the star formation rates we analyze the application of various SFR calibration methods, in particular those involving Hα and 24 µm emission for the galaxies in the sample. We test consistency of the published SFR calibrations by predicting thermal radio continuum maps that are compared with the observed radio data and with the derived spectral index maps, both before and after removal of the predicted thermal maps. In addition to published calibrations of the SFR from Hα and 24 µm data, we explore different mixtures of Hα and 24 µm maps that may be more applicable in the case of an edge-on galaxy perspective. We also discuss the correlation between the luminosity, morphology, and spectral indices of radio synchrotron halos with the distribution of SF in the galactic disks, and explore the connection with extra-planar diffuse ionized gas obtained from sensitive Hα images with the ARC 3.5m telescope for the entire sample. This research is supported by the National Science Foundation under Grant No 1650681 and AST - 1615594.

Author(s): Carlos J. Vargas[2], Silvia Carolina Mora Partiarroyo[1], Philip Schmidt[1], Rene A.M. Walterbos[2], Judith Irwin3, Daniel Wang5, Richard J. Rand[6], Yelena Stein4
Institution(s): *1. Max Planck Institute for Radio Astronomy, 2. New Mexico State University, 3. Queen's University, 4. Ruhr University Bochum, 5. University of Massachusetts Amherst, 6. University of New Mexico*
Contributing team(s): CHANG-ES

419.04 – Are We Correctly Measuring Star-Formation Rates?

Integrating our knowledge of star formation (SF) traced by observations at different wavelengths is essential for correctly interpreting and comparing SF activity in a variety of systems and environments. This study compares extinction-corrected, integrated ultraviolet (UV) emission from resolved galaxies with color–magnitude diagram (CMD) based star-formation rates (SFRs) derived from resolved stellar populations and CMD fitting techniques in 19 nearby starburst and post-starburst dwarf galaxies. The data sets are from the panchromatic *Starburst Irregular Dwarf Survey (STARBIRDS)* and include deep legacy GALEX UV imaging, Hubble Space Telescope optical imaging, and Spitzer MIPS imaging. For the majority of the sample, the integrated near-UV fluxes predicted from the CMD-based SFRs—using four different models—agree with the measured, extinction corrected, integrated near-UV fluxes from GALEX images, but the far-UV (FUV) predicted fluxes do not. Furthermore, we find a systematic deviation between the SFRs based on integrated FUV luminosities and existing scaling relations, and the SFRs based on the resolved stellar populations. This offset is not driven by different SF timescales, variations in SFRs, UV attenuation, nor stochastic effects. This first comparison between CMD-based SFRs and an integrated FUV emission SFR indicator suggests that the most likely cause of the discrepancy is the theoretical FUV–SFR calibration from stellar evolutionary libraries and/or stellar atmospheric models. We present an empirical calibration of the FUV-based SFR relation for dwarf galaxies, with uncertainties, which is ~53% larger than previous relations. These results have signficant implications for measuring FUV-based SFRs of high-redshift galaxies.

Author(s): Kristen B. McQuinn[2], Evan D. Skillman[2], Andrew E. Dolphin[1], Noah P. Mitchell3
Institution(s): *1. Raytheon Company, 2. Univ. of Minnesota, 3. University of Chicago*

419.05D – Swift/UVOT Measurements of the UV Dust Extinction Curve and the Recent Star Formation History of the SMC and M33

The Swift Ultraviolet/Optical Telescope (UVOT) is uniquely suited to study star formation and dust extinction in nearby galaxies. I will discuss results from the Small Magellanic Cloud (SMC) and M33, for which we have unprecedented observations in three near-UV bands from 1700-3000Å at 2.5" resolution. We combine our UV imaging with archival optical and infrared data to model the spectral energy distributions of individual regions of each galaxy, simultaneously fitting for the dust extinction curve properties, total dust, stellar mass, and age. We have created the first-ever maps of the UV dust extinction curve, which show previously-unconfirmed spatial variation: both the slope and 2175Å bump vary considerably over the face of both the SMC and M33. I will discuss the implications of these results on studies of star formation and galaxy evolution at both low and high redshift.

Author(s): Lea M. Z. Hagen[2], Michael Siegel[2], Erik A. Hoversten[2], Caryl Gronwall[2], Stefan Immler[1], Angelica Vargas[2]
Institution(s): *1. NASA/GSFC, 2. Penn State*

419.06 – Tracing magnetic fields and identifying star formation with velocity gradients

We are presenting a new technique of tracing magnetic fields utilizing Doppler broadened spectral lines. We demonstrate that for subAlfvenic turbulence, i.e. for regions with turbulence velocities less than Alfven speed, the velocity gradients (VGs) are well aligned with magnetic fields both in 3D data cubes and in synthetic observations. For the latter case the VGs are calculated using velocity centroids and their alignment with the projected magnetic field is studied. We demonstraed this by comparing the HI data with the PLANCK polarization maps. We conclude that velocity gradients present a new promissing way of studying magnetic fields in diffuse media. We also explored the properties of VGs in dense gas and found that starting with a particular density threshold value the VGs tend to be perpendicular to magnetic fields. We also compare the alignment of VGs and the density gradients (DGs) and find that these measures are well aligned in the absense of self-gravity, although in diffuse regions the VGs trace magnetic field better than the DGs. The advantage of VGs for tracing magnetic fields gets more obvious as the Mach number increases. Self-gravity acts differently on the VGs and the DGs. For self-gravitating regions the VGs and the DGs tend to get orthogonal to each other, revealing the the regions of ongoing star formation. This misalignment of the VGs and DGs is also evident in synthetic observations. We conclude that the VGs present
(a) a new promising way of tracing magnetic field in diffuse media,
(b) in combination with polarimety they reveal shocked gas,
(c) in combination with the DGs they reveal star forming regions.

Author(s): Alex Lazarian[1], DIEGO GONZALEZ CASANOVA [1], Ka Ho YUEN[1]
Institution(s): *1. Univ. of Wisconsin*

419.07 – Observations of the Zeeman effect in Class I methanol masers

We present observations of the Zeeman effect in Class I methanol maser sources toward high mass star forming regions. Toward DR21(OH), we have detected the Zeeman effect at 44 GHz in a 219 Jy/beam maser centered at an LSR velocity of 0.83 km/s, and we find $zB_\text{los} = 53.5 \pm 2.7$ Hz. If 44 GHz methanol masers are excited at 10^{7-8} cm^{-3}, then magnetic fields in DR21(OH) should be ~10 mG. Our detected zB_los would then imply that the Zeeman splitting factor for the 44 GHz methanol maser line should be ~5 Hz/mG. Such small values for z would not be surprising, since the methanol molecule is non-paramagnetic, like H2O. Since there are no direct measurements or calculations of the 44 GHz methanol maser Zeeman splitting factor to date, such empirical attempts could prove valuable in building a repository of measurements from which to gain an understanding of the magnitude of z.

Author(s): Anuj Pratim Sarma[1], Emmanuel Momjian[2]
Institution(s): *1. DePaul University, 2. National Radio Astronomy Observatory (NRAO)*

420 – Circumstellar & Debris Disks

420.01 – A New M Dwarf Debris Disk Candidate in a Young Moving Group Discovered with Disk Detective

The ongoing Disk Detective citizen science project has been identifying new debris disk candidates for over two years. We present an overview of the project and its current status, and discuss the newest result from this project: J080822.18-644357.3, a new candidate member of the young (~45 Myr) Carina association identified by the Bayesian analysis tool BANYAN II. This star, an M5.5V star with very strong infrared excess, would be the oldest M dwarf debris disk detected in a moving group if confirmed as a member. This discovery could thus be an important constraint on our understanding of M dwarf debris disk evolution.

Author(s): Steven M. Silverberg7, Marc J. Kuchner3, John P. Wisniewski7, Jonathan Gagne[1], Alissa Bans[8], Shambo Bhattacharjee[6], Thayne M. Currie4, John H. Debes5, Joseph R. Biggs[2], Milton Bosch[2], Katharina Doll[2], Hugo A. Durantini Luca[2], Alexandru Enachioaie[2], Phillip Griffith[2], Michiharu Hyogo[2], Fernanda Piniero[2]
Institution(s): *1. Carnegie Institution of Washington, 2. Disk Detective, 3. NASA's GSFC, 4. National Astronomical Observatory of Japan, 5. Space Telescope Science Institute, 6. University of Leeds, 7. University of Oklahoma, 8. Valparaiso University*
Contributing team(s): Disk Detective Collaboration

420.02D – Modeling gas–dust interactions in debris disks

The discovery of gas in debris disks has raised the question of whether gas–dust interactions can observably affect global disk structure. This has important implications for identifying planets in debris disks, as well as probing dust grain composition, which is key to understanding the habitability of planetary systems. In this dissertation talk, I present two-dimensional global hydrodynamical models of debris disks with gas and discuss the effects of the gas on the global distribution of the dust.

Author(s): Alex J.W. Richert3, Marc J. Kuchner2, Wladimir Lyra1
Institution(s): *1. California State University, Northridge, 2. NASA Goddard Space Flight Center, 3. The Pennsylvania State University*

420.03 – Modeling Mid-Infrared Polarization from Protoplanetary Disks and YSOs

Imaging polarimetry has demonstrated its potential to map magnetic fields in star formation regions. To interpret high-resolution, mid-infrared (mid-IR) observations obtained with present or forthcoming instruments, such as GTC/CanariCam and SOFIA/HAWC+, we have developed a new package of codes to model mid-IR polarization from protoplanetary disks and YSOs. Based on RADMC-3D and DDSCAT, our package is the first of its kind that takes into account all polarization mechanisms known to be present in the mid-IR, including dichroic absorption, dichroic emission, and scattering. Mid-IR polarization arising from a disk or YSO depends on dust properties (e.g., the size distribution, shape, and composition), magnetic field configurations, and the geometry of the disk and/or envelope, all of which can be customized in our model. We have created synthetic maps of mid-IR linear polarization for a series of fiducial disk and YSO models to compare with observations. In general, we find 1) that emissive polarization arising from aligned dust grains in disk magnetic fields is at the level of a few percent and lower than previous expectations, and 2) that micron-sized dust particles are required to reproduce the observed level of polarization from dust scattering in the mid-IR for a typical Herbig Ae/Be disk. The research was support in part by NSF awards AST -0903672, AST-0908624, and AST-1515331 to CMT.

Author(s): Han Zhang2, Eric Pantin1, Dan Li2, Charles M. Telesco2
Institution(s): *1. Service d'Astrophysique CEA , 2. University of Florida*

420.04 – In Outburst, the Seeds of Planet Formation

Young stars form new planetary systems during the collapse of a giant cloud of gas and dust. Tiny dust particles and gas parcels collide and stick together, growing slowly into planetary cores and then full-size planets. But is this process a steady and slow one, or are there bumps in the road to planet construction? In 1936, the young star FU Orionis (FU Ori) became 100 times brighter in only a few short months. Although astronomers didn't realize at the time, FU Ori was undergoing a "burst" of accretion -- nearly 20 Jupiters worth of material have fallen in during the past 80 years. This sustained flow is a large fraction of the entire measureable disk mass (both gas and dust) surrounding FU Ori. What changes did this increased brightness wreak upon FU Ori's disk, and what implications would it have for any planets that might have formed or form later? Unlike most observed young stars, FU Ori and its (~ 10) brethren with similar behavior show no evidence of crystalline dust grains like forsterite (peridot), and the temperatures at an Earth-equivalent distance would have risen from room temperature to a scalding 1000 degrees Kelvin. We present a study with SOFIA/FORCAST combined with our previous study with Spitzer/IRS, the first multi-epoch infrared spectroscopic study of an FUor, as it appeared in 2004 and 2016. First, the continuum (the energy emitted by viscous heating in the disk) has decreased by ~ 13%. The silicate dust remains unchanged. We conclude that the accretion rate of material in the innermost portion of the disk has been slowly reducing, perhaps combined with overall cooling, and is not being resupplied on this timescale.

Author(s): Joel D. Green1
Institution(s): *1. Space Telescope Science Institute*

420.05 – Evidence for Magnetically Driven Protoplanetary Disk Winds

We present Keck high resolution (~7km/s) optical spectra from a sample of 32 pre-main sequence T-Tauri stars in Taurus-Auriga plus TW Hya. We focus on low-excitation forbidden emission lines like the [O I] 6300 Å and 5577 Å lines, whose high-velocity component, with blueshifts between ~30 – 150 km/s, is known to trace fast outflowing material in the form of jets (e.g. Hartigan et al. 1995). The origin of the low-velocity component (LVC), with blueshifts on the order of ~5 km/s, has been long debated. We demonstrate that the LVC can be described by a combination of a broad and a narrow line emitting region. We show that the broad line emitting region is very common, arises within ~0.5 AU from the star, and shows the expected disk wind signature, i.e. larger blueshifts associated with narrower lines and lower disc inclinations. Such winds must be magnetically driven given that the emitting region is well inside the gravitational potential well of the central star. The origin of the narrow line emitting region remains difficult to assess, in particular we cannot exclude that it traces a thermally driven (photoevaporative) wind. Disk winds, both thermally and magnetically driven, might play a major role in the evolution and eventual dispersal of protoplanetary material, which has implications for solar system architectures and planet formation more generally. Hence, it is critical to determine the rate at which mass is lost via disk winds.

Author(s): Molly Simon5, Ilaria Pascucci5, Suzan Edwards4, Wanda Feng1, Elisabetta Rigliaco2, Uma Gorti3, David J. Hollenbach3, James Tuttle Keane5
Institution(s): *1. Arizona State University, 2. ETH Zurich, 3. SETI, 4. Smith College, 5. University of Arizona*

420.06 – Probing the debris disks of nearby stars with Fermi-LAT

Many nearby stars are known to host circumstellar debris disks, similar to our Sun's asteroid and Kuiper belts, that are believed to be the birthplace of extrasolar planets. The asteroids in these debris disks passively emit gamma radiation resulting from interactions with cosmic rays from their host star, as previously observed from measurements of the gamma ray albedo of the Moon. We present the results of applying a point source analysis to four of these nearby debris disks using the past nearly-eight years of data taken by the Fermi Gamma-ray Space Telescope. Through this analysis, we obtain upper limits on the gamma ray flux from these debris disks that provide constraints on the physical parameters of the disk.

Author(s): Alexander Riley2, Louis Strigari1
Institution(s): *1. Texas A&M University, 2. University of Texas at Dallas*

420.07 – Pushing the limits of high contrast with STIS/BAR5

The Hubble Space Telescope (HST)/Space Telescope Imaging Spectrograph (STIS) contains the only currently operating coronagraph in space that is not trained on the sun. We demonstrate the high contrast capabilities of the newly commissioned BAR5 occulter. We discuss the latest procedures in obtaining high contrast imaging of circumstellar disks and faint point sources with STIS and present results from a recent calibration program that demonstrates better than 10^{-6} point-source contrast at sub-arcsecond inner working angles, and better than 10^{-5} point-source contrast beyond 0.25′′. These results are obtained by a combination of sub-pixel grid dithers, multiple spacecraft orientations, and post-processing. Some of these same techniques will be employed by future coronagraphic missions. We present sample science cases for high contrast imaging in the visible with these newly demonstrated capabilities.

Author(s): John H. Debes2, Bin Ren1
Institution(s): *1. Johns Hopkins University, 2. STScI*

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421 – Astronomy Picture of the Day: Creative Uses in the Classroom & Beyond

Do you use APOD in your class? In addition to finding relevant astronomy images, teachers around the world leverage APOD to help educate their students and the public in creative and engaging ways. The session will start with a "behind the scenes" look of how the popular Astronomy Picture of the Day (APOD; main NASA address http://apod.nasa.gov/) is created and the most spectacular APODs of 2016 will be reviewed. Next, speakers will share their APOD-related resources and how they use APOD with their classes and in public outreach. After the presentations, the floor will be opened so audience members can share their experiences with using APOD in their own activities, make general comments, ask questions, and provide criticisms. If you are curious about APOD, use APOD in your classroom, want ideas for using APOD in your classroom or for outreach, want to know how to get APOD to promote your astronomy outreach activity, or would like to make suggestions for changing APOD, this session is your chance to provide direct feedback.

421.01 – Can My Image Appear on APOD?: How APOD Really Works

The Astronomy Picture of the Day (APOD) makes an effort to present and annotate the best astronomical images of our time. How "best" is defined in practice is debatable and will be discussed. However, if your image appears destined to appear in future astronomy textbooks, there is a good chance it will be highlighted on APOD. Perhaps the most ambitious goal of APOD is to bolster astronomy as a globally unifying medium, highlighting that all of humanity shares the night sky. Perhaps the least ambitious goal is to find enough time to prepare a reasonably interesting and error-free APOD for tomorrow. In practice, APOD has been cited by many teachers of astronomy as making educational images easily available to bolster their lectures and give a background understandable to their students. Feedback from teachers is therefore particularly encouraged.

Author(s): Robert J. Nemiroff[1], Jerry T. Bonnell[2]
Institution(s): *1. Michigan Technological Univ., 2. NASA's GSFC*

421.02 – Beyond APOD

There is more to APOD than APOD! Beyond APOD is a far-reaching network of social media and mirror sites, discussion threads and translations, collections and alternate ways to view APOD each day. The presenter will cover what's behind the last two links on the link bar at the bottom of every APOD page, *About APOD* and *Discuss,* the great resources available for educators, and some of the ways volunteers support APOD's mission.

Author(s): Alice Allen[1]
Institution(s): *1. Astrophysics Source Code Library*

421.03 – After APOD: From the Website to the Classroom and Beyond

Astronomy Picture of the Day (APOD) images may start on the apod.nasa.gov website, but their reach goes much further than the individual sitting at their computer screen. They provoke questions that then prompts the reader to email the authors; teachers use the images in their classrooms; students use them in their projects. This presentation will take a look at some of the work done using APOD images and text, including public outreach via middle school presentations and email communications, and academic uses beyond astronomy such as lesson plans on atmospheric refraction and even plagiarism, copyright and fair use.

Author(s): Teresa Wilson[1]
Institution(s): *1. Michigan Technological University*
Contributing team(s): APOD

421.04 – Spacetime Symphony: APOD and Gravitational Waves

In 1915, Albert Einstein published his General Theory of Relativity. In this theory, gravity is not a force, but a property of space and time in the presence of massive objects. A century later, on September 14, 2015, the Laser Interferometer Gravitational-wave Observatory (LIGO) received the first confirmed gravitational wave signals. Now known as GW150914, the event represents the coalescence of two distant black holes that were previously in mutual orbit. The LIGO-Virgo Scientific Collaboration planned a detailed social media strategy to publicize the February 11, 2016 press conference that announced this discovery. Astronomy Picture of the Day (APOD) was a major factor in disseminating the now iconic imagery that was developed, and the LVC worked closely with APOD to ensure that the secrecy would be maintained throughout the press embargo period. Due to the success of our efforts, we repeated the process for the AAS press conference that announced GW151226, the second confirmed gravitational wave event. We have also repurposed the APOD imagery for an online course for community college instructors, as well as in a poster that will be available through CPEPphysics.org (Contemporary Physics Education Project).

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Contributing team(s): LIGO-Virgo Scientific Collaboration

421.05 – Teaching Astronomy with Podcasts of the APOD

The APOD website provides many excellent astronomy photos that are used to enhance introductory astronomy classes. For nearly six years, podcasts have been used to enhance learning in introductory astronomy classes at Harrisburg Area Community College. Daily 3-5 minute podcasts have been created and made available through iTunes to students in these classes at no charge. Students are asked to subscribe to the podcast collections and are quizzed on the images discussed throughout the semester. Because the images often focus on current findings in astronomy, the students are given instruction on findings that will not appear in their textbooks for several years. The students also receive a taste of some topics that may not be covered or that are just touched upon because of time limits in the classes. The podcasts have been used successfully with both traditional and fully online classes. The use of the podcasts enhances mobile learning as students can download and listen to the podcasts on their smartphones or tablets at their convenience. The student response to the podcasts has been excellent with some students noting that they continue to follow the website and podcasts even after they have completed the class. With mobile learning expanding, this is an excellent way to reach students and encourage them to further research the various topics in astronomy that are covered in the APOD images.

Author(s): Robert M. Wagner[1]
Institution(s): *1. Harrisburg Area Community College*

421.06 – Fake! Astronomy picture forgeries and how to find them

With the advancement of technology, more digital images can be captured and manipulated than ever before in recorded history. Both the hardware and software developments have contributed to lowering the entry bar to photographers all over the world. Now anyone from amateur to professional astrophotographers with camera and computer has the ability to capture astronomical events. Unfortunately, the ease of access also brings with it manipulations and distortions from actual astronomy, allowing the creation of images that don't reflect reality. These "astronomical impossibilities" are being submitted regularly to APOD and occasionally make it through to the public, sometimes on purpose but sometimes not. But how do we know an image we see is a correct representation of the real world? What is "real" anyway?

Author(s): Matipon Tangmatitham[1]
Institution(s): *1. Michigan Technical University*
Contributing team(s): APOD Team

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422 – Plenary Talk: The 2017 Total Solar Eclipse: Through the Eyes of NASA, Alex Young (NASA GSFC)

422.01 – The 2017 Total Solar Eclipse: Through the Eyes of NASA

The August 21, 2017 eclipse will be the first time a total solar eclipse has traversed the Continental US since June 8th, 1918.

Anticipation and energy for this eclipse is off the charts! Over 500 million in North America alone will catch the eclipse in either partial or total phase. Parts of South America, Africa, and Europe will see a partial eclipse as well. NASA is planning to take full advantage of this unique celestial event as an education and public engagement opportunity by leveraging its extensive networks of partners, numerous social media platforms, broadcast media, and its significant unique space assets and people to bring the eclipse to America and the world as only NASA can.
This talk will outline NASA's education plans in some detail replicating our many Big Events successes including the 2012 Transit of Venus and the MSL/Curiosity landing and show how scientists and the public can get involved.

Author(s): C. Alex Young[1], Louis Mayo[2], Carolyn Ng[2], Troy Cline[2], Elaine Lewis[2], Shannon Reed[2], Asidesach Debebe[2], Bryan Stephenson[2], Sten Odenwald[2], Steele Hill3, Ernest Wright[1]
Institution(s): *1. NASA's GSFC, 2. NASA/GSFC/ADNET, 3. NASA/GSFC/WYLE*

423 – Plenary Talk: How Supermassive Black Hole Feedback Might Work, Megan Donahue (Michigan State University)

423.01 – How Supermassive Black Hole Feedback Might Work

How black holes regulate their own growth and the growth of their host galaxy is an unsolved problem in galaxy evolution. The problem is particularly acute in the centers of clusters of galaxies, where the largest and most massive galaxies in the universe are found. That is, coincidentally, also where the interaction between the black hole and the surrounding gas is the easiest to study because the gas is sufficiently hot and dense to emit X-rays. The massive central galaxies of clusters of galaxies (BCGs) exhibit striking patterns in their relationships between star formation, radio AGN activity, and the thermodynamic state of the hot, X-ray emitting intracluster gas (ICM) surrounding the galaxies. The AGN jets excavate giant, kpc-scale cavities in the hot gas, in principle, supplying enough heat to the ICM to replace energy lost to radiative cooling. Simulations suggest (by elimination) that AGN feedback must be required to explain the luminosity and colors of these galaxies, but cosmological simulations still struggle with modeling how AGN feedback works in detail. In clusters of galaxies with active AGN and star-forming BCGs, the AGN somehow regulates the gaseous atmosphere to be marginally critical, with a ratio of the cooling time to the free fall time of ~ 5-20. This behavior is also seen in elliptical galaxies, where the feedback is mostly coming from stars. I will discuss the observations that motivated this model. The precipitation model in BCGs is a class of models known as "preventative" feedback, regulated by jets in BCGs. Further, the complex behaviour seen in recent idealized simulations seem to follow emergent patterns predicted by this model, while reproducing the scatter and the time scales inferred from the observations. The link between the thermal instabilities and the depth of the gravitational potential may explain scaling laws such as the black hole mass-velocity dispersion relation, the galaxy mass-metallicity relation and the baryonic Tully-Fisher relation. I will discuss how future X-ray and UV telescopes could be used to test and inform this class of models.

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Authors Index