Research Interests of CMPS Assistant Professors

2007-08

Astronomy

Alberto Bolatto

I pursue several lines of extragalactic research in the nearby and high-redshift universe, including studies of molecular gas and star formation in galaxies, galaxy kinematics and dark matter, molecular cloud structure, radio searches for atomic and molecular transitions at high redshift, and imaging and spectral surveys of nearby galaxies in the mid- and far-infrared. My research is geared toward understanding and characterizing the physical processes that determine the evolution of galaxies in the cosmological context.

To conduct this research I use telescopes that observe the light spectrum from optical to radio waves, and an array of techniques that include imaging, interferometry, and spectroscopy --- an experimentalist cannot have the luxury of ignoring any wavelength regime. My current projects include the Spitzer Survey of the Small Magellanic Cloud and its spectral continuation (S3MC/S4MC), which perform imaging and spectroscopy of the Small Magellanic Cloud in the mid- and far-infrared using NASA's Spitzer Space Telescope, galaxy surveys in molecular gas using the Combined Array for Research in Millimeter-wave Astronomy (CARMA) interferometer, and surveys of interstellar lines using the giant Greenbank Telescope to measure the value of fundamental physical constants in the early universe.

Massimo Ricotti

My research focuses on cosmology and the early evolution of cosmic structures, when stars, black holes and galaxies first appeared in the Universe. My work is mostly theoretical and often involves the use of large scale computer simulations. My main interest is understanding the formation and evolution of the first galaxies and how their formation is regulated by the radiation emitted by the first stars and black holes. Pursuing this interest has lead me to investigate the distribution of the dark matter in galaxies, the cosmological origin of dwarf galaxies and globular clusters observed in our cosmic neighborhood. I have also studied the evolution of the low density gas that permeates the space between galaxies - the intergalactic medium - including models to explain the observed temperature and ionization of the intergalactic medium and the sources of radiation responsible for this evolution, such as X-rays from the first black holes, ultraviolet radiation from massive stars and globular clusters. Recently I have worked on the astrophysical implications of the existence of primordial black holes. Primordial black holes are exotic objects that may form well before stars and galaxies from the gravitational collapse of "radiation" and are possible dark matter candidates.

Atmospheric & Oceanic Science

Daniel Kirk-Davidoff

Daniel Kirk-Davidoff is a climate dynamicist with interests in paleoclimate modeling, satellite climate monitoring, the use of satellite data to improve climate models. He uses a range of climate models, from simple two-dimensional models to coupled climate models, to explore the dynamical basis for such fundamental aspects of climate as the pole-to-equator temperature difference, and the mean tropopause height, to understand the interaction of surface topography and roughness with climate, and to generate and test hypotheses about the connections and feedbacks among tropospheric dynamics, stratospheric overturning, the stratospheric water vapor budget and polar stratospheric clouds. In addition, he design tests of global climate models fidelity to data that are directly relevant to the models' predictions of the sensitivity of the earth's climate to increasing greenhouse gas concentrations, and works to develop optimal observing strategies for climate monitoring satellites.

Computer Science and UMIACS

Amol Deshpande

My research is motivated by the challenges in managing and processing real-world data generated by distributed measurement infrastructures such as large-scale sensor networks. The data generated by such infrastructures is typically incomplete, imprecise, erroneous, and hence rarely usable as it is. Further, the data is typically generated continuously at very high rates and must be processed in real-time. To solve these problems, my students and I are developing a system called "MauveDB" that aims to make it easier for users to apply statistical or probabilistic models to streaming data and query the outputs of such modeling using declarative interfaces. By choosing an appropriate statistical model to be applied to the data, MauveDB can be used to remove noise and errors from noisy data, to infer missing values or hidden attributes, to identify failures and anomalies, and to forecast future states of the system. In addition, we are developing models and tools for representing and querying uncertain, probabilistic data inside a relational database system. To handle the large volumes of streaming data efficiently, we are developing adaptive query processing techniques that can dynamically change query plans during execution in response to changing data and environment characteristics; we are also looking at ways to exploit multiprocessor and multicore parallelism for efficient query execution over streaming data. Finally, we are working on theoretical bounds and practical energy-efficient algorithms for data acquisition, target monitoring, and distributed data compression in wireless sensor networks.

Jeffrey Foster

Jeff Foster received his Ph.D. in Computer Science from the University of California, Berkeley, and he received B.S. and M.Eng. degrees from Cornell University, also in Computer Science. He is a recipient of the 2004 NSF CAREER award and a member of DARPA's Computer Science Study Group (2007). Jeff's research focuses on programming languages with applications to software engineering. Jeff has developed numerous tools for reasoning about the quality and security of software. Among others, recent contributions include a system to check type safety of programs written in multiple languages; a new approach for showing that network protocol implementations match their specification; a scalable analysis for finding data races in multi-threaded C programs; and type qualifier systems for C and Java, which have been applied to a wide variety of problems, including finding security vulnerabilities in C programs and detecting deadlocks in the Linux kernel.

Lise Getoor

My main research areas are machine learning, reasoning under uncertainty and data mining. I am interested in applying statistical learning techniques to structured data (such as networks and graphs). This is a key component emerging area of statistical relational learning, which combines both statistical and logical representations and applies them to tasks such as link analysis, entity identification, information extraction, and ontology alignment. In addition to the theoretical and algorithmic foundations of statistical relational learning, I am investigating applications of these models to problems in social networks, biological networks and sensor networks. Other areas of interest include information visualization and database management.

Francois Guimbretière

The goal of my research is to bring the ease of use of pen and paper interactions to computer interfaces. Pen and paper are an extremely versatile tool used extensively by knowledge workers when sketching new concepts, exploring a design space by quickly sketching several variations, brainstorming during a meeting or simply proofreading documents. Pen and paper interactions are rapid, fluid, and almost transparent to the user. Unfortunately, work captured on paper is often difficult to transfer back into the digital world where powerful computational resources are accessible. Through my work, I have demonstrated that the ease of use of pen and paper interactions and access to digital resources can be smoothly bridged. Blending hardware prototypes, software implementations, I have proposed novel pen interfaces for a wide variety of digital surfaces, including large wall-sized displays such as the Stanford Interactive Mural, portable notepad-sized systems such as tablet PCs, and pen-sized systems such as digital pens which can record and process strokes made on a special pre-printed paper. My work establishes a unified framework for pen computing applicable to mixed paper-digital settings as well as a wide variety of future digital interactive surfaces such as "digital wall paper" or electronic paper (e-paper), an area I am starting to explore. More information can be found at http://www.cs.umd.edu/~francois.

Michael W. Hicks

Michael W. Hicks' research focuses on using programming languages and analyses to improve the security, availability, and reliability of software.

For the last several years he has developed several analyses and transformations that permit software to be updated while it runs, to fix bugs and security flaws, and to add new features. With his students, he developed Ginseng, a compiler and runtime system for C based on these ideas. His group has used Ginseng to successfully update several popular open source programs with dynamic patches based on three years' worth of actual releases.

He has worked on several tools and languages toward improving the quality of C programs. He is a core designer and implementor of Cyclone, a safe C-like language for building systems software, with a focus on support for safe and efficient manual memory management to complement garbage collection. He also co-developed Locksmith, a static analysis tool for automatically proving the absence of data races in multi-threaded C programs. Most recently he co-developed C-Mod, a wrapper for the C compiler and linker that enforces safe practices for modular programming in C.

He has recently begun to look at compiler and language-based solutions to software security problems. He is working on language-based techniques to ensure web-based applications enforce confidentiality and integrity policies by carefully considering administrative models. He is also looking at how to monitor operating system kernel integrity to detect malicious modifications. His approach is to develop checkable properties that focus on attacker goals and not on particular attack vectors.

Jonathan Katz

My research interests lie broadly in the areas of cryptography, security for distributed systems, and theoretical computer science. A primary goal of my research is to apply cryptographic techniques and principles to develop provably-secure solutions to real-world security problems. Some representative recent projects include:

- The design and analysis of efficient cryptographic algorithms which maintain security even after the exposure of secret keys.
- Development and formal analysis of trust inference protocols in distributed systems, using tools from game theory, distributed algorithms, and cryptography.
- Exploring the use of biometric data for secure remote authentication.
- Investigating theoretical limits (both in terms of efficiency as well as feasibility) of secure two-party and multi-party computation.

Carleton Kingsford

I develop computational techniques to analyze the large and increasing amount of available biological data. The complexity and size of this information requires new computational techniques to make biological discoveries, and thus this is a fruitful domain for the development of new computer science. Over the last several years, I have worked on a broad range of problems in computational biology. Colleagues and I have developed methods based on linear and integer programming to optimally position the side chains of proteins in three-dimensional space. We have investigated how bacterial genomes are organized, giving several algorithms to detect important patterns within DNA, and also describing the creation and deletion of overlapping genes. In addition, by analyzing many whole genomes, we have helped to track the westward movement of avian influenza. Processing high-throughput data in these areas requires new tools extending proven techniques such as combinatorial optimization, statistical methods, and machine learning. A central goal for many of these projects was faster algorithms and heuristics to make computationally prohibitive studies possible.

Mihai Pop

Mihai Pop's research focuses on the development of bioinformatics tools for the analysis of data generated through high-throughput experimental techniques, in particular the use of novel sequencing technologies to answering biological questions. The amount of biological data available to scientists is growing at an ever increasing pace, requiring new computational tools to manage and analyze this information. One of the main thrusts of Dr. Pop's research is the development of new algorithms and software to assist in the decoding of the DNA of organisms, especially in the context of the rapid advances being made in the development of new sequencing technologies. Currently he is collaborating with scientists from the Naval Medical Research Center to develop assembly software for pyrosequencing data, helping to sequence pathogenic bacteria and their near-neighbors as a tool for understanding the mechanisms of pathogenicity. In addition, Dr. Pop is studying computational approaches to understanding the bacterial communities that inhabit our bodies and our environment, building upon experience obtained during his participation in the first large-scale study of the microbial populations present in the human gut. The tools developed in his lab are disseminated to the scientific community through the AMOS project, an open-source software package for genome assembly and analysis.

Vibha Sazawal

In my research, I strive to understand and improve the technical decision-making performed by software engineers as they build and maintain software. I am also interested in helping software engineers connect design decisions to code.

In a past research project I invented design snippets, partial design representations that are extracted from source code. These design representations are intended to help software engineers make design decisions during software evolution and maintenance tasks. Design snippets are co-displayed in the context of units of code (e.g., files); by eliding design details unrelated to the unit of interest, design snippets can be effectively used by software engineers as they view and edit units of code. Design snippets are intended to support specific software design principles. My prototype, the Design Snippets Tool, focuses on design principles related to one important software property: ease of change.

Another project is about information-hiding URLs. Many common elements of URLs do not adhere to the principle of information hiding. For example, filename extensions and parameter names can reveal volatile implementation details. As a result, when website implementations change, links between pages break. Bookmarks and code that generates URLs often break as well. An information-hiding URL uses an alias to identify a web resource and appends parameter values into the hierarchical structure of the URL. If a programmer follows certain conventions, such as providing default values for parameters, a link defined using an information-hiding URL will not break even if certain details about the page have changed.

Neil Spring

Neil's research seeks to develop techniques to detect and correct faults in the Internet. With these techniques, developers can build smarter applications that can tolerate failures, people can make better decisions about replacing or upgrading hardware, and students can learn to the design of robust networks. As wireless network devices become cheap and plentiful, ordinary users become network administrators, which means that the tools of the network administrator must become unambiguous and easy. His self-diagnostic network protocols instrument and report their performance and pathologies so that applications can better adapt to partial connectivity. Sufficiently poor connectivity should be blamed on devices, service providers, wireless interference, or whatever feature interferes with proper communication, yet to do so requires actively instrumenting ongoing communication with self-diagnostic protocols.

Neil also researches the design of future network protocols. Internet connectivity is increasingly shaped by policies: for example, that certain traffic should not transit certain links, that unauthorized clients should not be able to contact important databases, that voice-over-IP traffic should be given priority, or that some applications should be prohibited. Yet, holding users and networks accountable was one of the last goals in the design of the Internet. In the

Postmodern Internetwork Architecture, these policies on packet transmission are made explicit, so that authorization and accountability are easier to express, verify, and debug. Providing mechanisms to hold users and networks accountable is the subject of his continued research.

More information can be found at: http://www.cs.umd.edu/~nspring/research.html

Geology

Andrew Campbell

My research is aimed at a better understanding of the chemistry, structure, and evolution of planetary interiors, especially Earth's. Our knowledge of how planets are made and how they work is limited by our knowledge of material properties and chemical reactions at the appropriate pressures and temperatures. In the Laboratory for Mineral Physics, my students and I perform experiments that replicate the high pressure, high temperature conditions of the Earth's deep interior – reaching pressures above 1 million atmospheres and temperatures exceeding 3000 K. In addition to these laboratory-based studies, we make regular use of synchrotron x-ray facilities to probe the condition of our samples under these extreme conditions.

Currently I am focused on two subjects: phase diagrams of Earth- forming materials (mostly silicate rocks and iron-rich metals), and improving thermodynamic evaluation of redox reactions in the deep Earth through equation of state studies at high pressures. Our studies on melting and other phase transitions in iron alloys are improving estimates of the temperatures and compositions in Earth's core, which is a partially molten iron alloy. This constraint on the temperature profile is essential to understanding the internal planetary motions that ultimately drive plate tectonics, earthquakes, and volcanism. My recent investigations into high pressure redox reactions are providing much-needed insight into the chemical potential of oxygen in the deep Earth; this thermodynamic parameter is of fundamental importance to the chemistry and mineralogy of the planet's interior. To make these and similar studies possible, I have been a pioneer in several experimental methods in high-pressure research, including for example a recent invention for mapping the temperature distributions in laser-heated samples.

Saswata Hier-Majumder

I am interested in studying dynamics of multiphase material in the deep interior of the Earth and planets.

In the deep interior of the earth, magma travels through interconnected networks of tubules and sheets embedded in a viscous rock matrix. The shape and distribution of these micrometer-sized tubules and sheets, the smallest building blocks of a melt network, influence the transport and storage of magma over length scales of up to several hundred kilometers. One area of our active research is to identify processes that can influence paths of magma transport in the mantle by controlling the microscale geometry of the melt network. For example, intense deformation of the matrix squeezes melt out of isolated pockets into connected sheets, thus facilitating magma transport in the large scale. Another related problem is retention and storage of magma. Beneath mid-oceanic ridges and within plume conduits, buoyant magma rises in discrete pulses through the matrix. Capillary action on matrix grain boundaries tend to retain melts from these pulses in a way similar to a damp sponge retaining a small amount of water. Finally, reactive mass exchange between the silicate minerals and the magma alters the composition of the magma, especially by altering the concentration of the radiogenic elements. In a collaborative effort with researchers from the University of Tokyo, we are developing a technique to predict the chemical nature of the deep interior of the Earth by observing the chemical composition of young midocean ridge basalts.

Physical properties of partially molten rocks depend on factors such as the volume fraction of melt, the ratio of viscosities between the matrix grains and the melt, and the melt geometry. Laboratory experiments indicate that changes in one or all of these parameters can cause orders of magnitude changes in physical properties such as shear viscosity and shear wave velocity. One area of our active research involves developing a theoretical framework for understanding and quantifying the relation between these physical properties and the governing factors. We are developing a code that calculates physical properties of two-phase particulate flow based on boundary integral equations of viscous flow. The new Altix 1300 Geophysics cluster, Stokeslet, will be dedicated to perform this calculation, and compare the reults with laboratory measurements.

Aaron Martin

My research focuses on tectonics – the study of the evolution of Earth's outermost solid layer, the lithosphere, and its interactions with the underlying asthenosphere and overlying hydrosphere. Within this broad subject, I concentrate on regions of the continents where two lithospheric plates collide, producing characteristic features such as volcanic arcs, high plateaus, and mountain belts. The location of my main research interest to date has been the Himalaya, the fold and thrust belt produced by the ongoing collision between India and Asia that began 55 million years ago. In the Himalaya, as in other mountain belts, I work to integrate diverse types of geologic data to better understand the construction, preservation, and destruction of the thrust belt. Further, I seek to quantify the effects of these tectonic processes on other Earth systems such as the chemistry of the oceans and climate (both on time scales of millions of years). One example of this integration is my work resolving the long-standing problem of locating the position of an important Himalayan fault known as the Main Central thrust. Using both examination of microscopic relationships between minerals and isotopic characterization of the rocks on either side of the fault, I showed that the Main Central thrust in central Nepal is in fact farther south than usually mapped on the basis of the appearance of the rocks in the field. This revised location, combined with the field-based recognition of several new faults, has broad implications for understanding other types of geologic data from the Himalaya. These data include the spatial relationships between fault locations, steep topography, and high elevations as well as the relationships between faults and areas of high erosion rates. Such data and relationships permit better understanding of the tectonic processes important in the Himalaya. I have also answered similar questions in an extensional setting in southeast Arizona. An emerging area of interest is the central Appalachian Mountains in Maryland, Pennsylvania, Virginia, and West Virginia.

Laurent Montesi

The Earth is unique in the Solar System in that it harbors life and it displays plate tectonics, a global deformation style in which the strong outer layer of the earth interior, known as the lithosphere, is divided into rigid plates that move with respect to each other. Plate tectonics requires weak plate boundaries and strong plate interiors. Dr Montési's research aims at quantifying how weak plate boundaries are and identifying the origin of their reduced strength.

To answer this challenge, he merges rigorous mechanical analyses and geological observations. His research addresses the formation of ductile shear zones, their effect on postseismic deformation, mantle flow at mid-ocean ridges and subduction zones, extraction of magma from the Earth's interior, origin of deformation patterns on Earth and other planets. The following are two featured example projects.

Ductile shear zones are geological structures that extend earthquake-producing faults like the San Andreas Fault at depth. While a key component of plate boundary, they are impossible to access directly and therefore, their mechanics are poorly understood. Dr Montesi models the chemical and microstructural evolution of the rocks that form ductile shear zones and determine the rheology of the resulting rocks. Then, he tests if this rheology is reasonable using geodetic data on transient deformation episodes that follow major earthquakes.

In other environments, especially mid-ocean ridges, weakening may be associated with the presence of melt at depth. Dr. Montési uses a combination of, and models of magma migration through the Earth's interior to predict how much magma is present underneath mid-ocean ridge and uses geochemical data, seafloor morphology. Specifically, he studies the slowest mid-ocean ridges, where the least among of melting is expected, and areas where ridges intersect other plate boundaries. Three-dimensional flow effects in such settings allow for more accurate testing of the mechanical models he develops.

Sarah Penniston-Dorland

I am interested in learning about the interactions between fluids and rocks at high temperatures through the study of the record chemically reactive fluids leave behind in metamorphic and igneous rocks. My students and I collect field data along with mineralogical, chemical, isotopic, and textural data and apply the concepts of equilibrium thermodynamics and mass transport to answer questions of mass transfer, fluid sources, and mechanisms and pathways of fluid flow in a variety of geologic settings. Current questions under investigation include: What are the sources of fluid and what elements are mobilized by fluid flow (studies in regionally metamorphosed rocks of east-central Vermont and in volcanic arc-related rocks in the Sierra Nevada mountains)? Can cooling time of a metasedimentary diapir be constrained using exchange of stable isotopes (oxygen and lithium) at the contact between magma and country rock (Bushveld Complex, South Africa)? Can the amount and processes of interaction between a mafic magma and surrounding late Archean/Paleoproterozoic country rock be constrained and related to platinum-group element ore formation using multiple sulfur isotopes (Bushveld Complex, South Africa)? What is the fate of fluid emanating from a subducting slab? Does it interact with high-grade metamorphic blocks in the mantle shear zone above the slab, imparting some of its chemical and isotopic signature to those blocks (Franciscan Complex, California)? Can the effects of dehydration and fluid flow in serpentinites be constrained in a contact metamorphic aureole using lithium isotopes (Bergell aureole, Italy)?

Wenlu Zhu

My primary research interest is to understand fluid transport processes in the Earth's crust and mantle, and their geological implications. Using experimental and theoretical approaches, I study the relationship between permeability and pore structure in a wide range of geomaterials, including sedimentary rocks (with applications to convergent margins, where tsunami generating earthquakes occur), partially molten rocks beneath mid-ocean ridges and deep sea hydrothermal vent deposits where unusual chemosynthetic microbial thrives. Better understanding of permeability-porosity relationship will provide critical constraints in studying the effect of pore fluid, including water, CO2, and melt on the mechanical and geochemical properties of various tectonic regions.

Mathematics

Wojciech Czaja

My research deals with, both, theoretical and applied aspects of harmonic analysis. These include the theory of wavelets and Gabor systems, time-frequency and time-scale methods for characterizations of pseudodifferential operators, as well studies of functional and geometric properties of wave packets of Cordoba and Fefferman. What all of the aforementioned systems have in common is that they represent various ways of efficiently decomposing the phase space. As such, they are, in particular, subject to different forms of the uncertainty principle.

Recently, I have worked on two different applications of the above theories. One deals with the image analysis of changes in autofluorescence images in AMD progression (a collaboration with NIH), where time-frequency techniques for feature detection, image enhancement, and sparse representation of data are used. The second project is focused on the development of wavelet techniques based on diffusion kernels for the purpose of dimensionality reduction and feature classification in hyperspectral satellite images (work sponsored by NGA).

Leonid Koralov

I have been working on various problems in the areas of random transport, random media, dynamical systems, and statistical physics.

One class of problems concerns the motion in random flows. Based on a probabilistic description of the local properties of the flow,
one wishes to predict the long-time properties of the trajectories of particles or describe the behavior of sets of particles carried by the flow. Besides pure mathematics, such problems arise in oceanography and theory of turbulence. Their analysis requires various methods at the interface of probability theory and dynamical systems.

Another class of problems concerns random perturbations of dynamical systems. We strive to describe the effective behavior of various systems where the contribution from a small random perturbation can be 'averaged out'.

Other problems concern the study of the asymptotic properties of solutions to certain parabolic equations. These problems belong to the areas of Statistical Physics, Theory of

Random processes and Theory of Partial Differential Equations.

Kasso Okoudjou

My research interests lie in the general area of harmonic analysis, with a particular emphasis on time-frequency and wavelet analysis, frame theory, pseudodifferential operators, and analysis and differential equations on fractals. More specifically, I have been interested in a comprehensive study of various Banach spaces of functions, or distributions by investigating the interplay between the smoothness and the regularity of these distributions on the one hand, and their time-frequency concentration on the other hand. The theory of frame which has many applications in engineering, provides with some of the tools used in such investigation. Frames are basis-like objects used in particular to characterize various functions spaces. Such characterizations are very important in approximation theory, and are also widely used in signal processing. Another aspect of my research deals with a time-frequency analysis of multilinear pseudodifferential operators and Fourier multipliers in the realm of the so-called modulation spaces. These spaces arise naturally in many applications such as wireless communications, seismic data image processing, and appear as substitutes to settle continuity properties of certain operators that are known to be unbounded on other classical spaces. The last aspect of my research is centered around the developing area of analysis and differential equations on fractals. In particular, I have been interested in investigating analogs of the Heisenberg uncertainty principle, and the Schrodinger equations on a class of fractals that includes the Sierpinski Gasket.

Kartik Prasanna

My research area is number theory, more specifically the theory of automorphic forms, periods and cycles on Shimura varieties and special values of L-functions. A basic problem in number theory is to find integer or rational solutions to equations with rational coefficients. Over the course of the last half-century, it was realized that one can often associate to an equation, a function called an L-function whose properties should hold very interesting arithmetic information about the solutions to the original equation. This expectation is made precise in the very deep and difficult conjectures of Birch and Swinnerton-Dyer and of Beilinson, Bloch and Kato. My research is primarily concerned with the study of the behaviour of L-functions at special points with a view to gaining a better understanding of these conjectures. One useful tool in this is the study of certain geometric objects called Shimura varieties. Shimura varieties have a very intricate structure, and one has available on them a rich supply of functions (automorphic forms), integrals (periods) and other geometric sub-objects (cycles). Thus my research stands at the crossroads of algebraic geometry and the theory of automorphic forms but with specific applications to number-theoretic problems.

Mathematics and IPST

Dionisios Margetis

Dionisios Margetis carries out research in the broader area of applied analysis and mathematical modeling, at the boundaries of mathematics with physics, materials science and biology. His primary goal is to describe analytically phenomena that are observed in physical experiments across length and time scales, from the atomistic to the continuum. His approach relies on asymptotic analysis, partial differential equations and integral equations. In connection to materials science, his research focuses on epitaxial growth and the modeling of small (nano-)

devices. He is concerned with the derivation and analysis of continuum models for the morphological evolution of crystal surfaces by accounting for the kinetics and fluctuations of microscopic defects. In connection to quantum physics, he works on:
(i) a macroscopic description of behavior of atoms at extremely low temperatures ("Bose-Einstein condensation"); and
(ii) aspects of quantum computing and decoherence, where computations are performed via the scattering of massive particles and photons. In electromagnetic theory, his primary interests are wave propagation near material boundaries and antenna theory. Most recently, he has been working on the coupling of the mechanics of biological membranes with chemical signaling pathways in cells. He earned a doctorate degree in applied physics at Harvard in 1999, and he worked as a lecturer of applied mathematics at Harvard and MIT.

Physics

Kevork Abazajian

Prof. Abazajian's research is the fields of particle cosmology and astrophysics. Specifically, they have included topics of neutrino physics in the early universe, including standard and non-standard neutrino properties effects on primordial nucleosynthesis and the cosmological matter distribution. This has included the calculations of the production and detection methods for a dark matter candidate that is in the neutrino sector of particle physics, the sterile neutrino. In addition, Prof. Abazajian has developed methods of using information from galaxy clustering measurements in the the Sloan Digital Sky Survey to determine cosmological parameters as well as galaxy clustering properties. Related work has included the precision measurement of cosmological statistics with large scale numerical simulations.

Kaustubh Agashe

Kaustubh Agashe's research is in the field of theoretical particle physics. Agashe works on ideas going beyond the standard model (SM) of particle physics, a theory developed over the past couple of decades which accounts for the interactions of the elementary particles. Such extensions of the SM are motivated to solve many of the problems of the SM such as existence of enormous mass hierarchies or the nature of dark matter of the universe. Agashe is interested in both building models along these lines and also their phenomenology, i.e., connecting these ideas to experiments. Specifically, his work has focused on two such extensions of the SM: supersymmetry (SUSY), which is a symmetry relating particles whose spins differ by 1/2 unit, and the existence of extra spacetime dimensions.

Agashe's recent work has been on the framework of a "warped" extra dimension. Agashe and his collaborators have shown that this idea solves many of the puzzles of nature: it provides an explanation for the mass hierarchies and a candidate for dark matter and also unifies the three forces of the SM. Hence, this framework is a worthy competitor to the more popular idea of SUSY which also enjoys some of the same successes. Currently, Agashe is working on making predictions for this framework which can be tested in ongoing and upcoming experiments, especially the large hadron collider (LHC) which will be operational at the CERN laboratory in Europe in a few years.

Paulo Bedaque

My main line of research is the study of one of the four fundamental forces of Nature:

the strong nuclear force. The strong force is responsible for the binding of quarks and gluons into protons and neutrons and for the force that binds protons and neutrons into atomic nuclei. The fundamental theory describing the strong interaction (Quantum Chromodynamics or QCD for short) has been known for over 30 years, but its equations are, in most cases, intractable. I have studied methods to extract information from the QCD equations in a variety of settings: highly compressed matter as found at the core of neutron stars, the mechanism of nuclear binding, the behavior of light strongly interacting particles, etc … .The methods used include analytical approximations based on field theory techniques as well as large scale computation.

Zackaria Chacko

My research interests are focused on finding new theories of physics beyond the Standard Model that could potentially be discovered in current and upcoming experiments. Specifically, I work on supersymmetry, extra dimensions, composite Higgs models, grand unification, neutrino physics, cosmology and also on possible modifications of Einstein gravity.

Victor Galitskiy

My general area of expertise is theoretical condensed matter physics. I am particularly interested in the fields of spin transport in semiconductors and superconductivity: (i) Spintronics is an emergent, fast developing field in which the spin degree of freedom is exploited to create novel electronic devices. The spin-orbit interaction provides a bridge between spin and charge properties and allows one to manipulate spins in a controlled and reliable way. In my research group, we have been working to develop a theoretical background to understand spin diffusion in disordered spin-orbit coupled semiconductors and explain a number of recent amazing spin transport experiments. Our recent theoretical results include the derivation and solution of a general spin diffusion equation for a two-dimensional semiconductor and the theoretical prediction about novel spin-carrying edge states; (ii) Another important thrust of my current research is related to fluctuation phenomena in superconductors. Over the last decade, a whole range of novel superconducting quantum detectors and elements for quantum computing have been proposed and some of these proposed devices have already been realized in laboratories. Of particular interest are sensitive quantum detectors, which utilize the singular effect of fluctuations in superconducting systems. One of the main goals of my superconductivity research is to provide a theoretical background for the development of new experimental devices based on the fluctuation transport in superconductors. Just above the transition, a superconducting system is extremely sensitive to the slightest changes in temperature due to fluctuations and this singular behavior may be utilized to detect parameter variations, which are unobservable otherwise. My recent results include a theory of quantum superconducting fluctuations as well as a theory of mesoscopic disorder fluctuation effects in an anisotropic gap superconductor. The latter results may explain some important aspects of the pseudogap phase in high-temperature superconductors, which is one of the key puzzles in modern condensed matter physics.

Michelle Girvan

My research operates at the intersection of statistical physics, computer science, and nonlinear dynamics and has applications to interdisciplinary problems in social, biological, and technological systems. Namely, my work falls within the fields of complex networks and social physics. Much of the work is theoretical, but I have been increasingly interested in using empirical data and sociological experiments to inform and validate mathematical models. Realizing that many complex systems cannot be well understood without explicitly taking into account how their components are connected can give us new insights into hard problems. My research addresses interdisciplinary, network-related problems by tackling broad theoretical issues, like the optimal deconstruction of complex networks and the detection of communities in overlapping networks, and then applying these insights toward the understanding of problems like social network construction, contagion processes, norm formation, and community fission.

Many of my current and developing research projects fall under the umbrella of social physics. Broadly speaking, social physics can be described as the search for fundamental laws and principles that characterize human behavior and result in collective social phenomena. Included in this field are topics such as the dynamics of complex social networks (which is how some of the above work ties in here), robustness of social processes, econophysics, the scaling of social systems, and the evolution of social organization. Each of these subtopics represents a union of what we call a social physics perspective with approaches from other fields.

Carter Hall

My current research interest is neutrinos, which are the most mysterious of the fundamental particles known to man. First observed in the 1950's, neutrinos were believed to be massless for over forty years. In the last decade, however, a variety of experiments have conclusively shown that neutrinos exhibit behavior which can only be attributed to a tiny neutrino mass. These experiments have measured the differences in the masses of the three neutrinos, but are unable to tell us about the absolute size of the neutrino mass scale. I collaborate with other researchers in the US, Canada, Switzerland, and Russia, on an experiment called the Enriched Xenon Observatory (EXO), which has the potential to measure the absolute neutrino mass scale, a basic property of the universe.

EXO will also address a second important issue in neutrino physics: the question of the charge of the neutrino. Neutrinos have long been known to be electrically neutral, but it is possible that they carry a new type of charge known as lepton number. Lepton number, if it exists, would be carried by neutrinos, and the total lepton number of the universe would remain unchanged for all time. Quantum field theory tells us that such a quantity, known as a conserved quantum number, is related to the symmetry properties of the universe, and characterizing such symmetries is one of the highest priorities of fundamental physics.

Interestingly, many theories predict that neutrinos will not carry lepton number, and therefore the neutrino and the anti-neutrino are exactly the same particle. If these theories are correct, then the EXO experiment should observe a new type of radioactive decay known as "neutrinoless double beta decay". EXO will monitor vessel containing 200 kg of liquid xenon, searching for the signature that a single xenon nucleus has undergone this decay. EXO will begin taking data this year, and is expected to be the world's most sensitive experiment of its kind.

Kara Hoffman

Kara Hoffman is a particle physicist whose past work has included detector design and dataanalysis on large collider physics collaborations, as well as research and development for the next generation of accelerators. She has recently turned her attention toward astrophysical sources of high energy particles. These sources are capable of accelerating particles to energies far beyond those attained at man made accelerators here on earth, although their exact nature remains a mystery. Neutrinos just might be the ideal messengers to identify these enigmatic sources of high energy cosmic rays since they interact only weakly and thus can reach us undeflected through regions of space that would be opaque to the other types of radiation that these sources emit. Because neutrinos interactions are rare, it requires a large detector to capture sufficient statistics to identify these distant point sources. The particle astrophysics group at the University of Maryland, which is lead by Hoffman, along with Greg Sullivan and Jordan Goodman, is playing a major role in building the world's largest neutrino observatory, IceCube, a cubic kilometer scale detector in the clear deep ice beneath the South Pole. Hoffman traveled to the South Pole in January 06 to participate in the construction. More than one quarter of the detector is now complete, and taking data. As the leader of the muon group, Dr. Hoffman is spearheading the collaboration wide effort to analyze data from this groundbreaking instrument. John Pretz, a University of Maryland student, was awarded the first Ph.D. based entirely on IceCube data.

In addition to her work on IceCube, Hoffman and her students are also building prototype instrumentation for an even larger neutrino detector array, to be built as a follow on to IceCube. This array would employ a novel technique based on the Askaryan effect, where high energy particle showers interacting in the ice would produce broadband rf pulses. Because rf has a long attenuation length in cold ice, this technique could be used to instrument an even larger detector volume than IceCube with relatively sparse instrumentation. The first prototype modules were deployed at the South Pole in January 2007, and have already produced a wealth of data. Four additional modules will be installed in the coming austral summer.

Min Ouyang

Min Ouyang has carried out active research programs in the emerging fields of Nanoscience and Spintronics aimed at exploring new physics and applications based on the spin and charge degrees of freedom of electrons and nuclei within ordered nano-engineered architectures with an emphasis on following areas:

(1) Development of novel synthetic methodologies for novel classes of hybrid organic-inorganic molecular- and nano- structures.

(2) Investigation of fundamental basis for plasmonics, phonon dynamics, spin-charge interactions and spin transport within nanostructured systems with new experimental techniques such as femtosecond optical spectroscopy, magnetotransport and low temperature scanning probe microscopy.
(3) Realization of new functional nanoelectronic and nanospintronic devices, and development of novel technologies for bio- imaging.

Dr. Ouyang's recent works include: (i) Controlled synthesis, fundamental electron-phonon interactions, fundamental mechanical properties and molecular sensor applications of zero dimensional (0D) metal nanoparticles; (ii) Tuning spin coherence dynamics of semiconductor qubits by high pressure technique; (iii) Controlled synthesis and characterization of one dimensional (1D) carbon nanotubes, semiconductor nanowires, and their heterojunctions that provided the general concepts of the growth of 1D superlattices; (iv) Exploration of fundamental electronic properties of single-walled carbon nanotubes (SWNTs) by both experiment and theory, including direct determination of atomic structures and electronic properties of intramolecular SWNTs junctions which have important implications for applications of these junctions in molecular electronics, first report on the intrinsic small energy gaps in "metallic" SWNTs that advances substantially our understanding of the electronic properties and potential application of carbon nanotubes, first experimental determination of energy dispersion of armchair SWNTs which open up opportunities to study the fundamental 1D band dispersion of individual SWNT, investigations on the local spin interactions between magnetic coordinate molecular complexes and the 2D (Au)/1D (nanotubes) electron gas and theoretical studies on the intrinsic electronic properties of SWNTs and their interactions with scanning tunneling microscope tips; (v) Investigation of spin dynamics and coherence in hybrid organic-inorganic condensed matter systems with a variety of femtosecond all optical spin resonance techniques, including spin dynamics in chemically synthesized nanostructures (such as quantum dots and quantum shells) and spin coherence transfer between molecularly bridged quantum dots, which solved the long-standing questions on how to efficiently establish and probe the spin communication between quantum dots.

Peter Shawhan

Peter Shawhan's research is aimed at obtaining new and unique information about massive astrophysical objects, such as black holes and neutron stars, from the faint gravitational echoes of their creation and interactions. Einstein's general theory of relativity predicts that such objects emit gravitational waves, which are distortions of the geometry of space-time that travel away from the source at the speed of light. These waves alternately stretch and squeeze all objects they encounter, but by such a tiny amount (perhaps one part in 10^{21} when they reach the Earth, stretching its diameter by an amount equal to the size of an atomic nucleus) that such waves have not yet been directly detected. Remarkably, years of instrumentation research and engineering—with their origin in the work of Joe Weber here at the University of Maryland in the 1960s—have now made it possible to detect such waves. A handful of large gravitational-wave detectors are now operating, led by the three detectors of the NSF-funded Laser Interferometer Gravitational-Wave Observatory (LIGO), and plans are in place to alternate data collection with detector upgrades over the next several years.

Dr. Shawhan has provided several important software components for operating and monitoring LIGO and the data that is collected, and is a key player in the data analysis effort which is carried out by the LIGO Scientific Collaboration (LSC). He is currently Co-Chair of the LSC working group devoted to searching for gravitational wave "bursts", a general class of short-duration signals with a wide range of possible forms. Detection of such gravitational-wave signals, especially if they can connected to other astronomical or astro-particle observations (optical, X-ray, gamma-ray, neutrino, etc.), will provide new insight into the astrophysical processes and can also test the properties of gravity itself in the extreme strong-field, nonlinear regime. Given the limited state of current knowledge about gravitational-wave sources, the rate of detectable signals is uncertain, but it is believed that detections will be made beginning sometime in the next several years.

Physics and IPST

Arthur La Porta

The main focus of my research is the manipulation of single biological molecules using both convention optical tweezers and a new variety of optical tweezers called the Optical Torque Wrench (OTW). The OTW technique allows the response of biological molecules to pN forces and pN-nm torques to be measured with nanometer precision. From a scientific standpoint, such information can be used to directly measure the energy landscape associated with conformation changes of a protein or nucleic acid structure, or can be used to determine the mechanism of motility of a molecular motor protein. A major scientific goal is to investigate the physical mechanisms by which the transmission of genetic information by nucleic acid based enzymes is regulated. From an engineering standpoint, this program will involve development of specialized techniques to create bio-functionalized handles which can be attached to target proteins, and may lead to the fabrication of nucleic acid or protein molecular probes that could be used to non-invasively probe remote environments.

Arpita Upadhyaya

My research seeks to understand how mechanical properties of cells and their constituents shape biological movement at various length scales – from single polymer filaments inside cells to multi-cellular tissues. Intracellular organelles, single cells and tissues are physical objects and must be subject to forces in the environment whenever there is motion or deformation. Forces arising from cytoskeletal polymerization and rearrangement are important in numerous biological contexts such as cell movement, cancer metastasis, the immune response, cell division, and large-scale collective movements of cells during development. The common theme that pervades these disparate cellular movements is the necessity of complex and dynamic mechanical interactions between the cell and its extracellular environment that are coordinated in space and time by physical and biochemical signals. The cell membrane, cytoskeletal polymers and other proteins collectively form a highly nonlinear, a daptive dynamical system that allows the cell to respond to its environment. I combine soft condensed matter physics with quantitative imaging, biochemical and genetic manipulation to uncover how signaling networks and physical properties of the cell and its surroundings control force generation in biological systems. In my newly established laboratory, I have set up state of the art imaging equipment including an optical microscope capable of total internal reflection to follow the dynamics of genetically expressed fluorescent proteins in cells. I use these high-resolution imaging techniques, coupled with mathematical modeling and micro and nano-manipulation to study the mechanics of cells as well as biopolymer networks.

IREAP

Oded Rabin

Dr. Rabin joined the MSE department and IREAP in Fall 07. His research program focuses on nanoscale structures and their interaction with their chemical and physical environment. The lab will develop synthetic strategies to make nanoparticles, nanowires, and nano-structured thin films. In addition to the investigation of the unusual properties of these structures, studies will focus on how molecular entities can be used to tune and regulate the physical properties of the nanostructures, leading to new methods for chemical sensing and device fabrication. Other areas of interest include (1) advanced materials for thermoelectric energy generation, (2) applications of nanoparticles as biomarkers for imaging, diagnosis, and repair, (3) porous anodic alumina scaffolds, and (4) molecular and nanoparticle transport in microfluidic devices.

Edo Waks

My research focuses on the optical and electronic properties of semiconductor quantum dots and photonic crystal structures. Quantum dots are nanoscale heterostructures that exhibit a discrete energy spectrum analogous to that of an atom. For this reason, they are often referred to as *artificial atoms*. They can be easily coupled to photonic crystals, which are periodic materials that guide and confine light at the scale of an optical wavelength. Photonic crystals can create an optical interface between individual quantum dots to form complex integrated devices. They can also be used to engineer optical micro-cavities with ultra-small mode volumes that significantly enhance atom-light interactions. We are interested in using such devices to implement quantum information processing, as well as to develop ultra-compact opto-electronic components.

Semiconductor quantum information processing: The unique properties of quantum mechanics enable us to perform computational tasks thought to be impossible from the perspective of classical physics. Two important examples are quantum computation, which enables exponentially faster computational algorithms, and quantum cryptography, which provides unconditionally secure cryptographic codes. To achieve these remarkable applications, we must be able to store and coherently manipulate quantum information in real physical systems. Our research group is exploring the properties of semiconductor quantum dots for storing quantum information. These quantum dots can be interconnected using photonic crystals in order to develop a scalable and compact quantum processor on a semiconductor chip.

Ultra-compact opto-electronic devices: Quantum dots are useful as bright emitters for a broad range of opto-electronic applications. By coupling them to photonic crystal micro-cavities we can strongly modify their emission properties to generate nonlinear optical effects at low light levels. We are studying methods to exploit these nonlinearities to develop useful devices such as all optical switches, low threshold lasers, and chemical and biological sensors with single particle sensitivity.