Enduring Quests – Daring Visions

NASA - Astrophysics Division Roadmap

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OUR CHARTER

http://science.nasa.gov/media/medialibrary/2013/02/22/secure-Astrophysics_Roadmap_Team_Charter-final.pdf

This Road Map will:

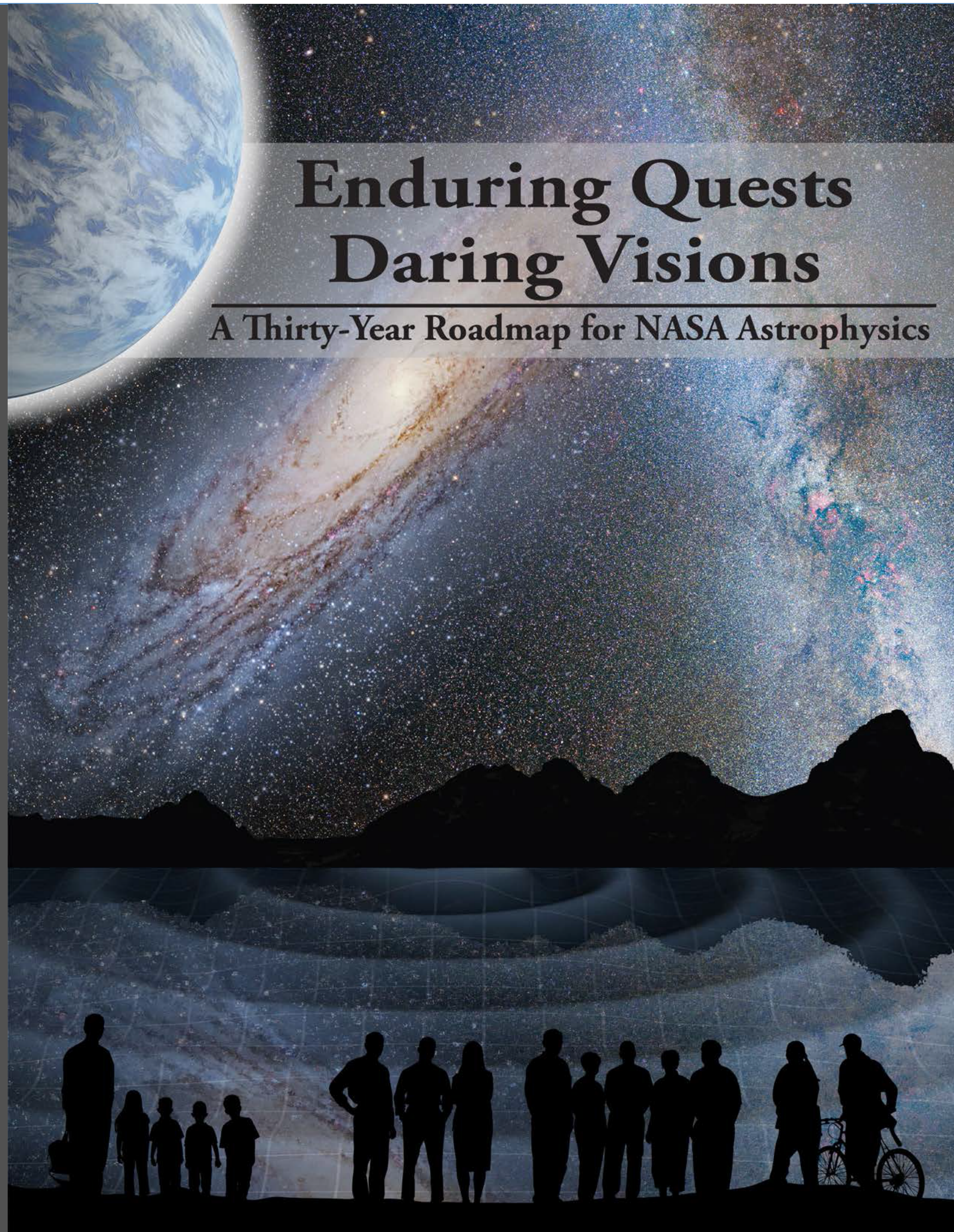
- present a compelling, 30-year vision
- take the Astro2010 decadal survey as the starting point and build upon it
- be science based, with notional missions
- be developed by task force of the Astrophysics Subcommittee (APS)
- take into account community input solicited Town Hall meetings and other potential calls for input
- be delivered to APS

Note that the roadmap

- is ***not*** a mini-decadal survey with recommendations and priorities
- is ***not*** an implementation plan
- ***is*** a long-range vision document with options, possibilities and visionary futures

OUR SCHEDULE

- **Report** to the APS Chair at least monthly or more often as the team deems desirable, and to the entire APS at regular meetings
  - *Reported to the two APS regular meetings during the past 8 months; frequent interactions with the APS Chair*
- **Deliver** an interim report with high-level themes, to the APS in time for approval by the APS by August 30, 2013
  - *Delivered July 17, 2013*
- **Deliver** their final report to the APS in time for approval for the APS, by December 16, 2013
  - *Delivered November 10, 2013*
- **Disband** once their final report has been approved and accepted by the APS
  - *The final report delivery is currently planned for December 20, 2013 – the team requests, therefore, that they are disbanded at that time and no sooner.*


Enduring Quests
Daring Visions
A Thirty-Year Roadmap for NASA Astrophysics

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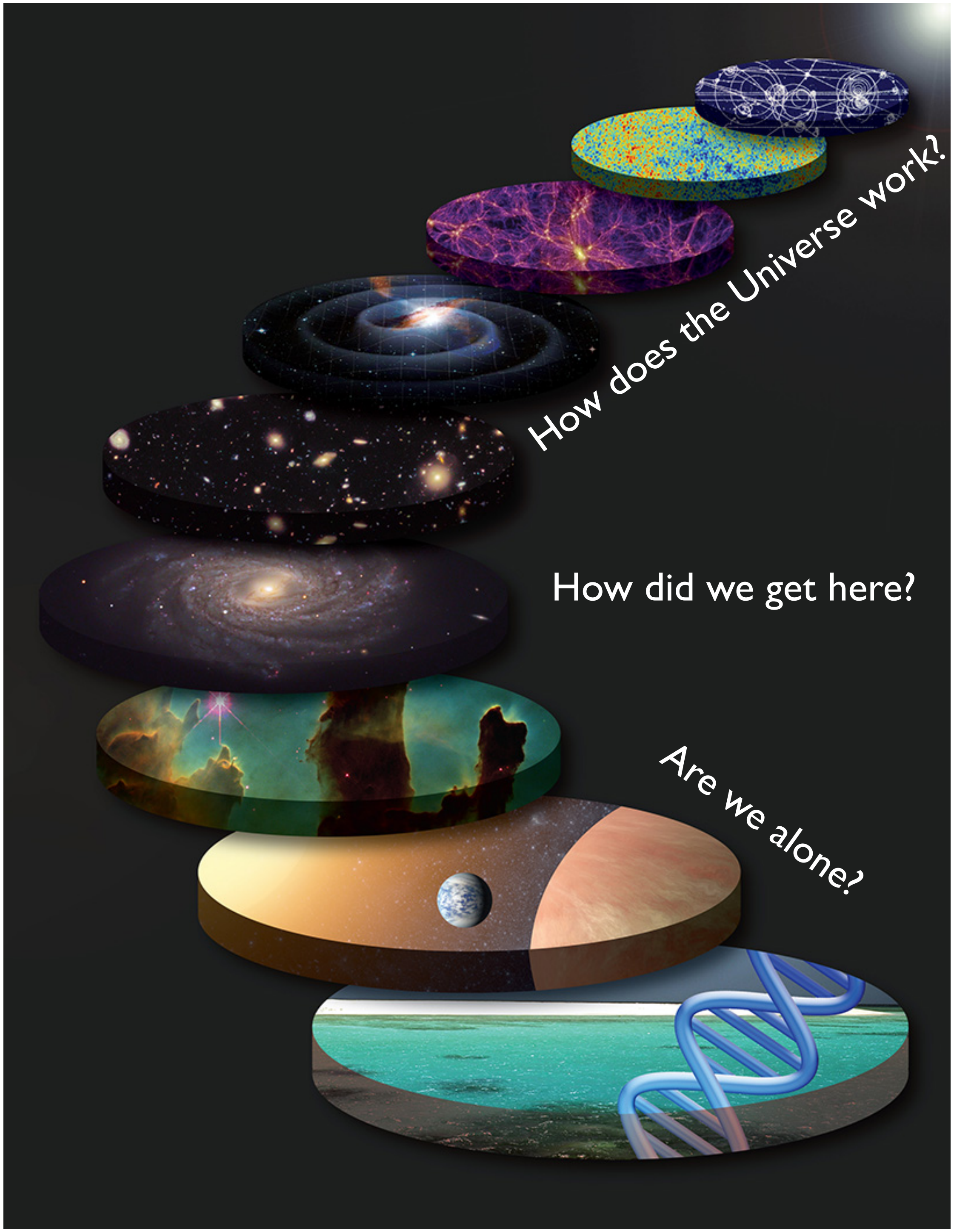
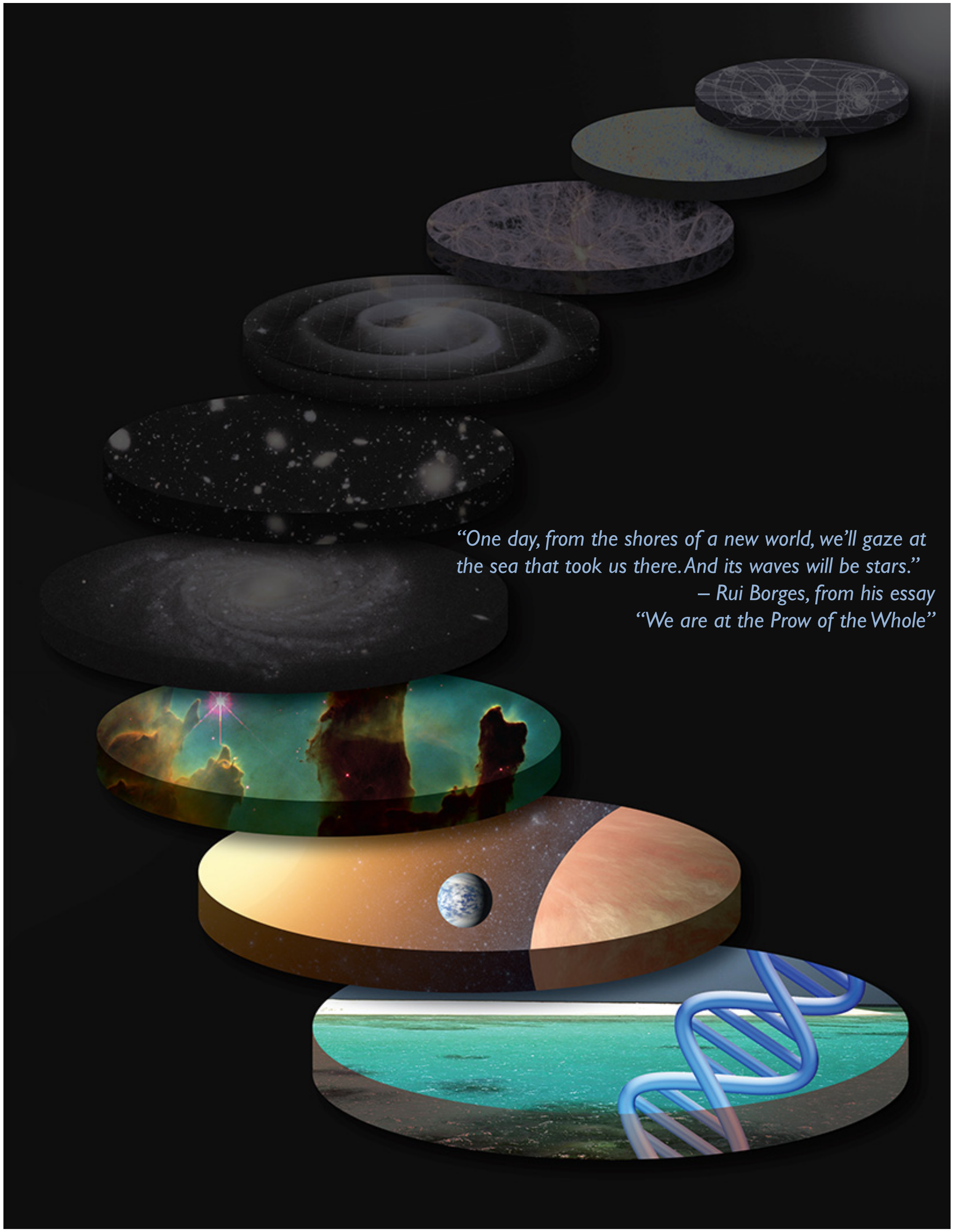


- Probe the inflationary era
- Map Cosmic Microwave Background
- Chart Large Scale Structure
- Map extreme spacetime
- Map galaxy assembly
- Detail galactic chemo-dynamics
- Characterize planetary systems
- Find exo-Earths
- Search for life

Are we alone?

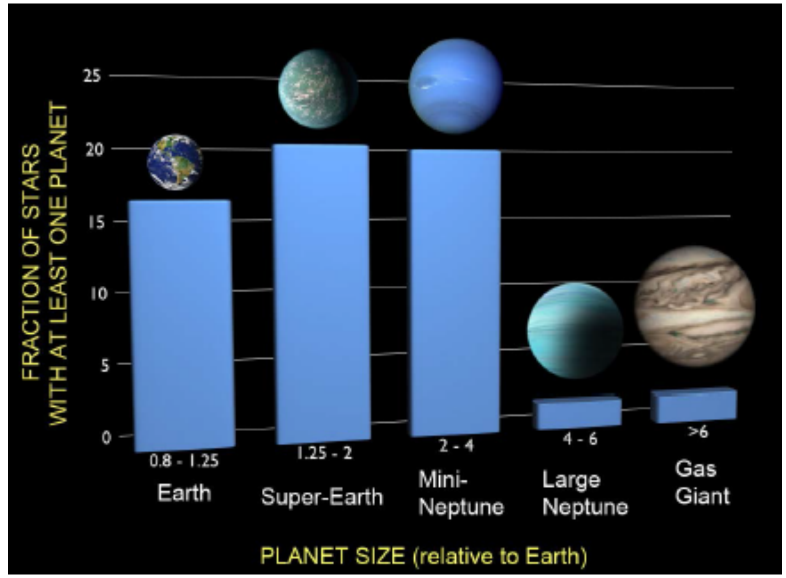


- Catalog the full diversity of planetary systems
- Perform detailed characterization of a broad sample of exoplanets
- Study nearby exoEarths in detail, and identify habitable climates and evidence for life on these worlds

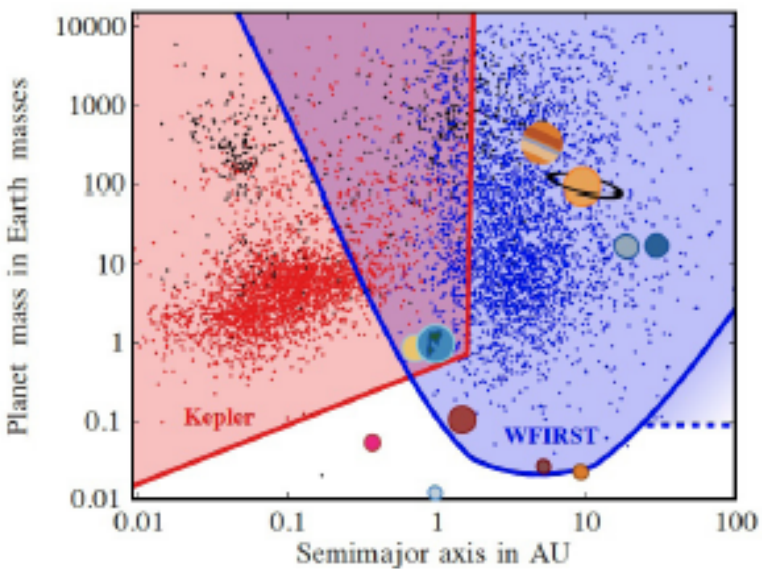
The exoplanet Zoo

Complete the census of exoplanets

Ground-based surveys have revealed many exotic types of planets, including Hot Jupiters and Super-Earths.



Kepler has fully surveyed the population of "hot" and "warm" planets, and has measured the fraction of stars hosting exoEarths, η_{EARTH}~20%. *TESS* and the next generation ELTs will explore the population of exoEarths around red dwarfs.



WFIRST-AFTA will complete the *Kepler* census by measuring the frequency of "cold" outer planets using two techniques: gravitational microlensing, and high-contrast direct imaging using an internal coronagraph.

What are exoplanets like?

Comparative planetology

Current Exoplanet motley crew:
Super Earths
Mini-Neptunes
Hot Jupiters
Super-Jupiters
ExoEarths

Comparative planetology requires:

- *planet sizes*: in fainter, distant systems (*Kepler*), and in nearby, bright stars (*TESS*)
- *planet masses* (current and future ground-based RV)
- *planet spectra* (*HST*, *Spitzer*, *JWST*, *WFIRST-AFTA*, *LUVOIR Surveyor*)

JWST will provide high-precision time-resolved spectra for transiting planets discovered from the ground, *Kepler*, and *TESS*, possibly including planets close to exoEarth sizes orbiting low mass stars.

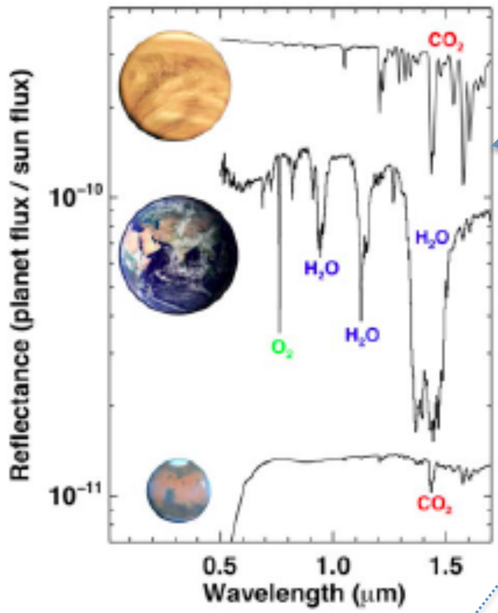
WFIRST-AFTA-coronagraph will survey dozens of the nearest stars for Jupiters and Saturns, and characterize a subset of the discoveries.

LUVOIR Surveyor will discover and characterize the atmospheres of a diversity of exoplanets orbiting nearby stars, and identify exoEarths with potentially habitable climates.

***Kepler*+ *TESS* + *JWST* + *WFIRST-AFTA* + *LUVOIR Surveyor* will enable extensive comparative planetology and identify exoEarths (η_{EARTH})**

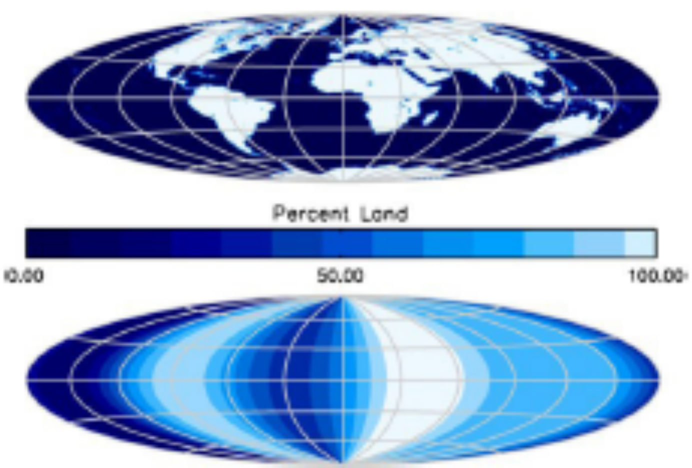
The search for life

Pale Blue Dots

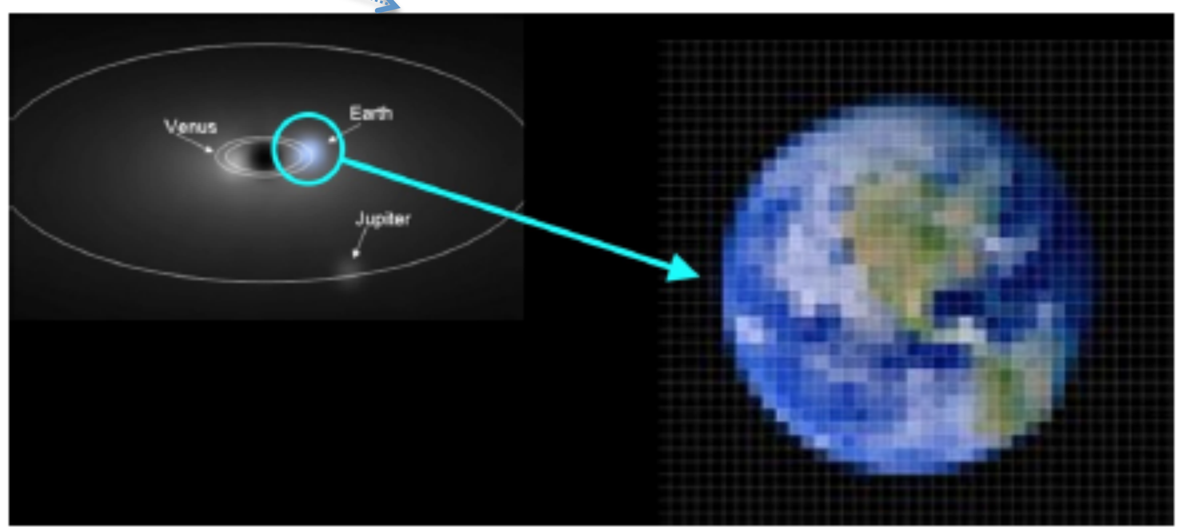


Step 1: Measure the frequency of potentially habitable planets.

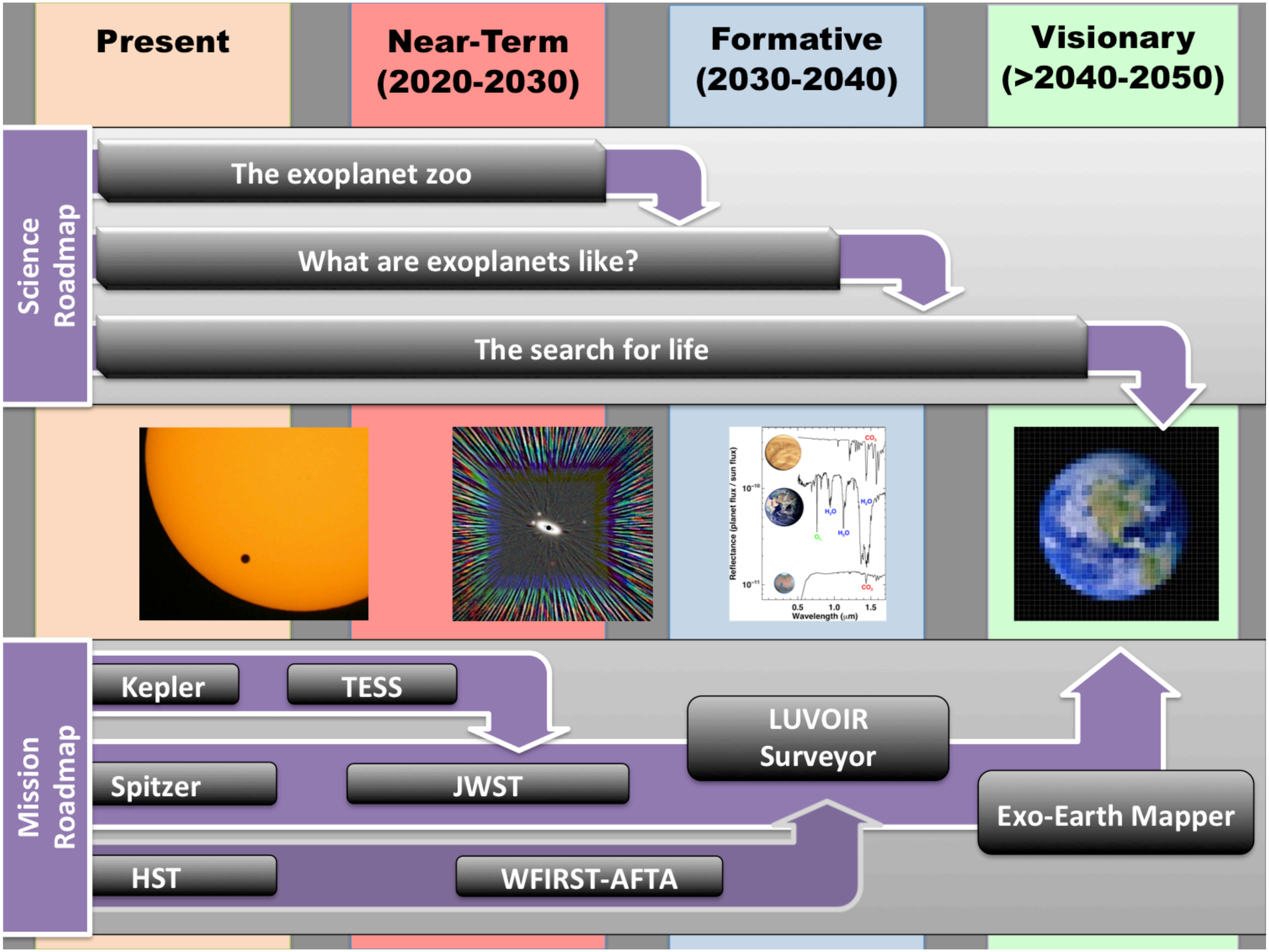
Step 2: Identify nearby potentially habitable planets and characterize these in great detail:



Step 3: Identify and map the most promising ExoEarths.



Activities by Era



How did we get here?

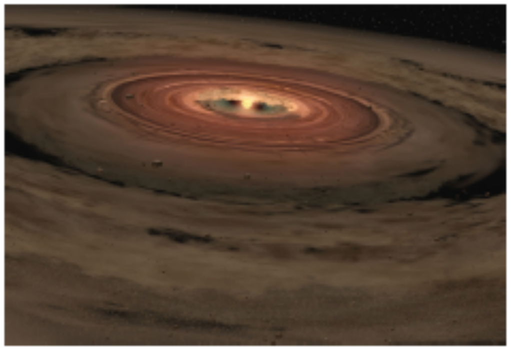
Map newborn stellar and planetary systems across the Milky Way

Decode the assembly of our Milky Way galaxy

Characterize the detailed nature of the Universe's first galaxies and the subsequent growth of all galaxy components over cosmic history

Stellar Life Cycles

Evolution of the elements



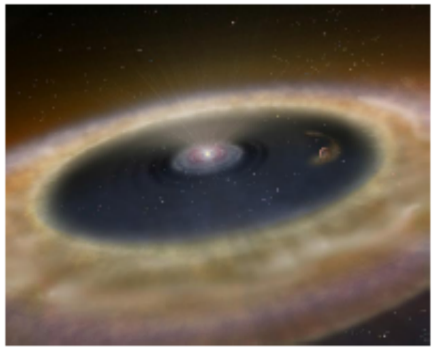


Chart 1000s of stellar nurseries

ALMA: molecular clouds and dust, planets via protoplanetary disk gaps

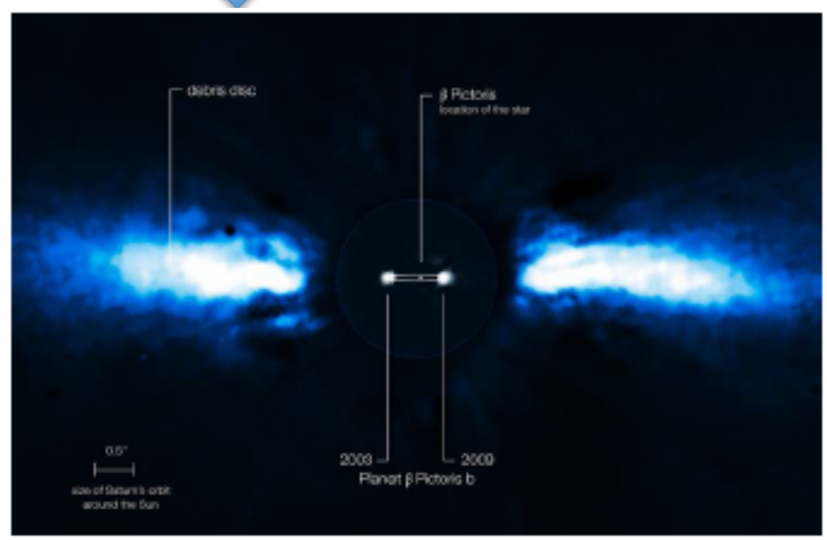
JWST, ELTs: search for rocky planets at inner regions

FIR Surveyor: map the distribution of water

LUVOIR Surveyor: characterize warm dust / inner regions of debris disk

Stellar Feedback

- Study SN-induced feedback with the *X-ray Surveyor*
- Establish stellar Initial Mass Function (IMF) over all mass scales & environments
- Understand conditions for particle acceleration



Archaeology of MW & its Neighbors

Study the fossil records

Our Milky Way

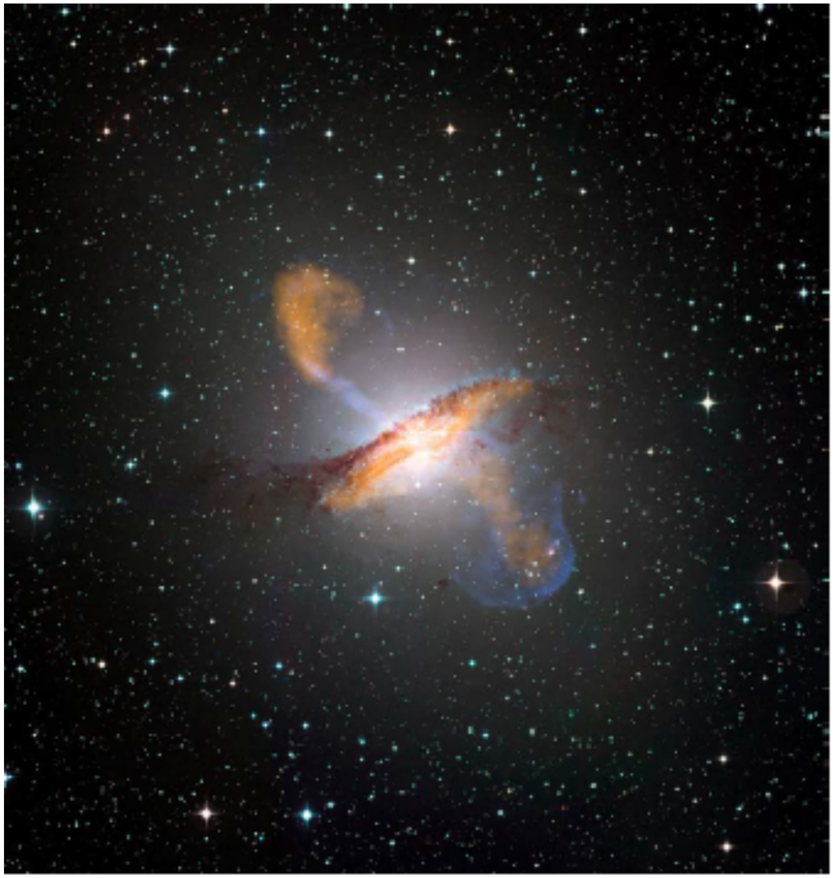
- Establish a census of the MW structure and stellar populations (*LSST, WFIRST-AFTA*)
- Fully characterize the MW relics: streams, clusters, halo stars, bulge, dwarf spheroidals (dSphs) (*LSST, WFIRST-AFTA, GAIA, ELTs, LUVOIR Surveyor*)
- Measure the MW mass from 3-D velocities of distant halo tracers
- Test DM models from 3-D velocities for stars in all dSphs (*JWST, LUVOIR Surveyor*)

Our Neighbors

- Resolve the entire Hubble sequence & measure the surface brightness, Star Formation History, radial velocities, ages, halo shapes of hundreds of galaxies (*ELTs, JWST, WFIRST-AFTA*)
- Characterize spatial and kinematic substructure
- Measure chemical abundance gradients
- Establish tests of high-resolution simulations of galaxy formation
- Measure the line of sight absorption of cool, warm & hot gas

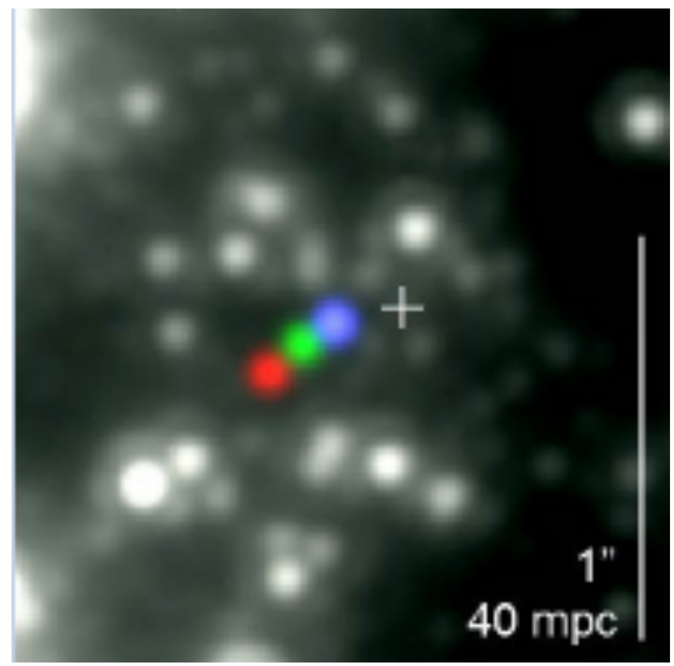
The history of galaxies

Monsters in the middle



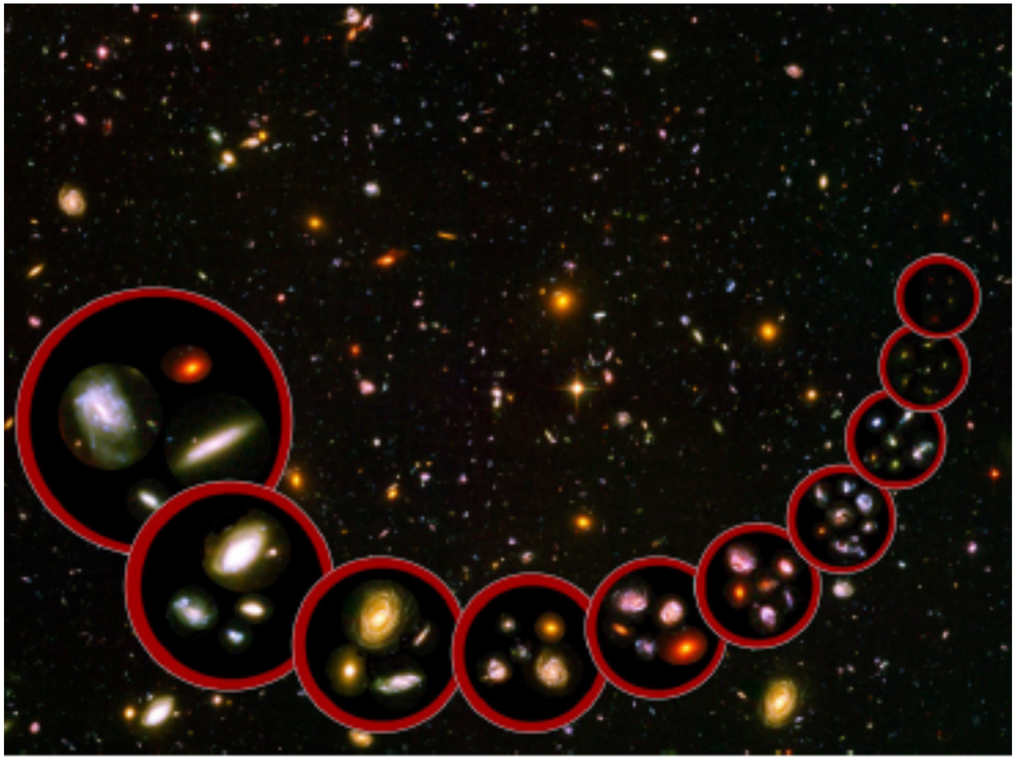
AGN Feedback

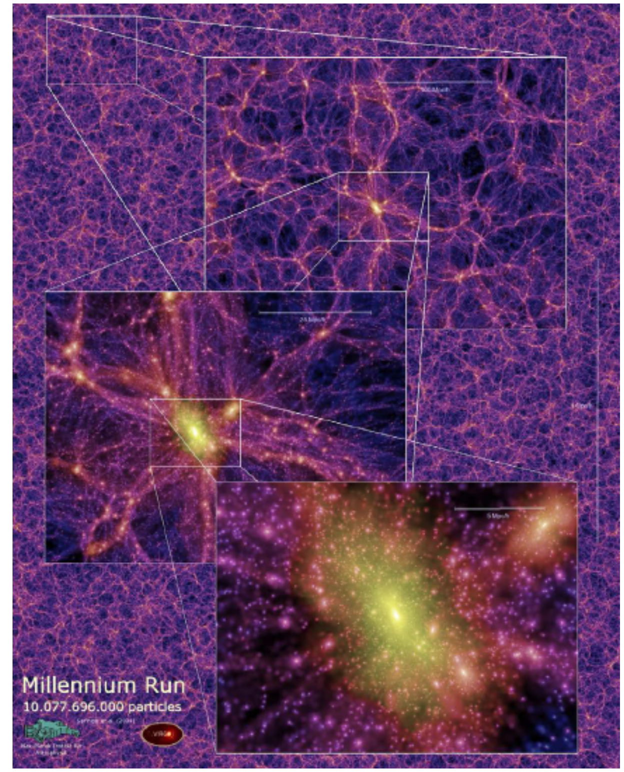
• Determine modes of galaxy-SMBH growth: "what the monster ate"
• Measure distribution of SMBH spins and masses in cosmic time: "how it ate it"
• Synergy progression: ALMA, *JWST, LUVOIR Surveyor, X-ray Surveyor* and *BH Mapper, Gravitational Wave Surveyor* and *Mapper*



The history of galaxies

Manufacturing and Assembly





- Characterize the physical nature of the first galaxies – Measure buildup of metals since z~15
- Understand the effect of dark energy on galaxy assembly
- Map the distribution, dynamics & chemistry of gaseous galactic halos
- Map the cosmic web: measure the cold, warm and hot baryon mass budget in galaxies, galaxy clusters, and IGM
- Detect the emergence of structure during the Dark Ages (z~10-20) via 21-cm observations
- Synergies: ALMA, *VLA, SKA, LSST, JWST, WFIRST-AFTA, FIR, X-ray,* and *LUVOIR Surveyors, Cosmic Dawn Mapper*

Activities by Era

Near-Term Era

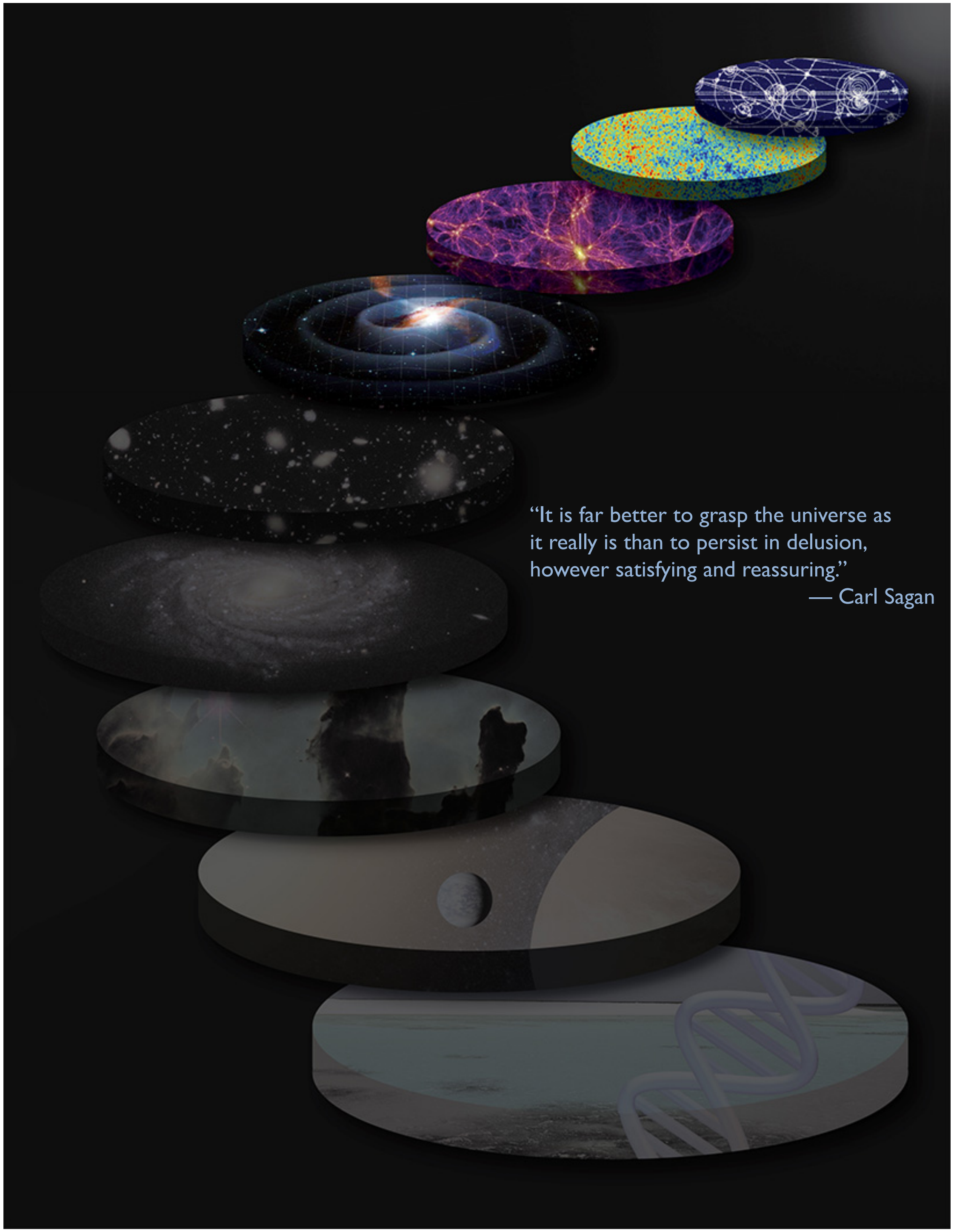
- Chart Stellar Nurseries
- Establish inventory of MW's populations and satellite galaxies (dSphs)
- Measure BH masses in nearby galaxies – hunt for first seed BHs
- Image light from first galaxies in the Universe

Formative Era

- Map the chemical-dynamical evolution of all nearby planetary systems
- Characterize the Archaeology of the MW – Measure SF histories for all galaxy types
- Measure the stellar IMF in all scales and environments
- Measure BH masses and spins in the local Universe
- Study the sites of violent star formation in early proto-galaxies
- Record the gravitational waves that signal mergers of BHs
- Measure properties of the first stars in the Universe
- Measure the process of reionization in the early Universe

Visionary Era

- Inventory all types of BHs in the MW and nearby galaxies
- Measure BH spins across the Universe and the feedback energy released at the Cosmic Dawn
- Study the surfaces of the most distant stars in the MW
- Image the accretion discs of nearby BHs
- Pinpoint the sites of BH mergers across the Universe



How does the Universe work?

Probe the imprints of the Big Bang to shed light on the origin of our Universe

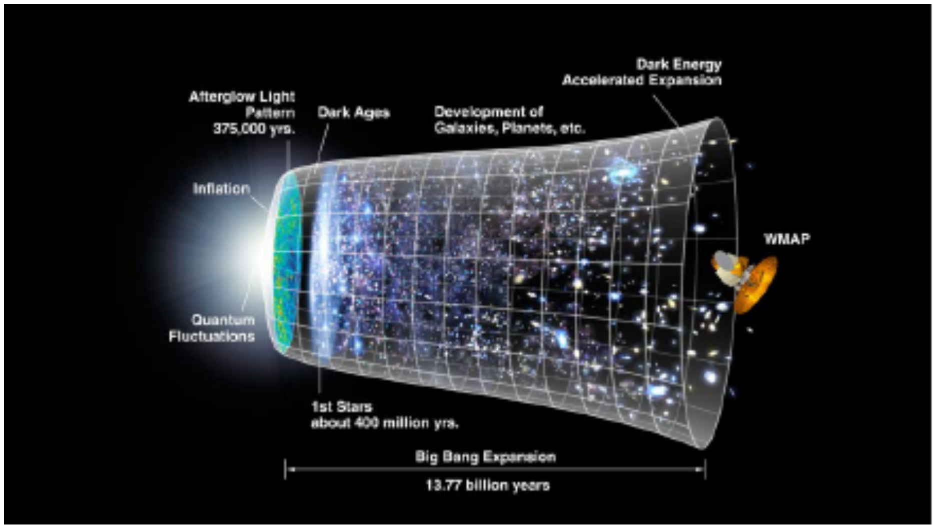
Pin down the forms of matter and energy that govern the expansion and fate of our Universe

Open a new window on the cosmos by measuring ripples of spacetime

Explore the extremes of gravity and matter, from the horizons of black holes to the edge of the Universe, to test the limits of our fundamental physics laws

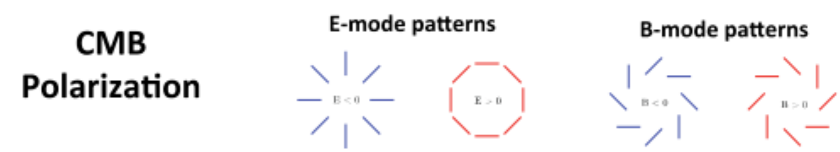
The origin and fate of the Universe

The Big Bang



• Map the CMB to cosmic variance limits using primordial GW signature (B-mode polarization) to derive powerful constraints on the inflationary epoch (*CMB Polarization Surveyor*)

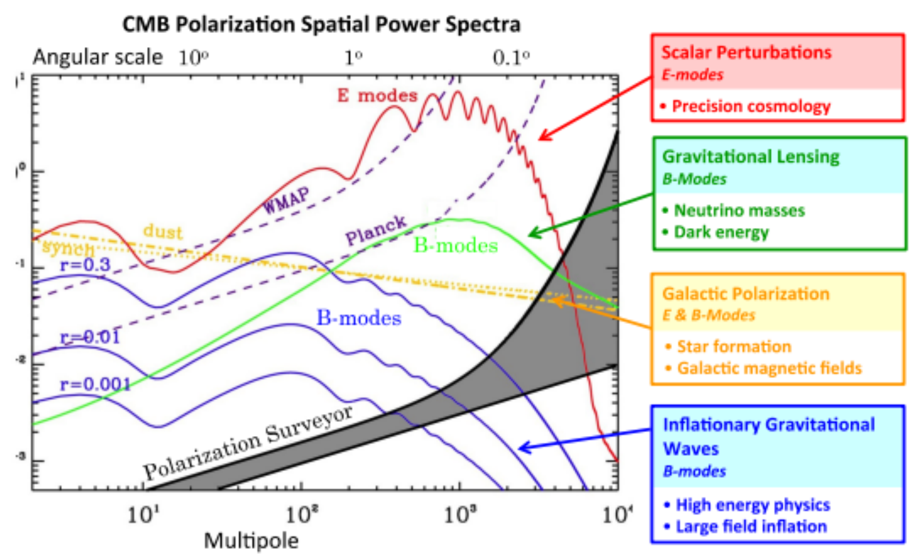
• Probe the thermal history of the Universe by measuring imprints of relics & recombination on CMB blackbody spectrum (*CMB Polarization Surveyor*)



• Constrain theories of cosmic acceleration with *WFIRST-AFTA, LSST, Euclid*

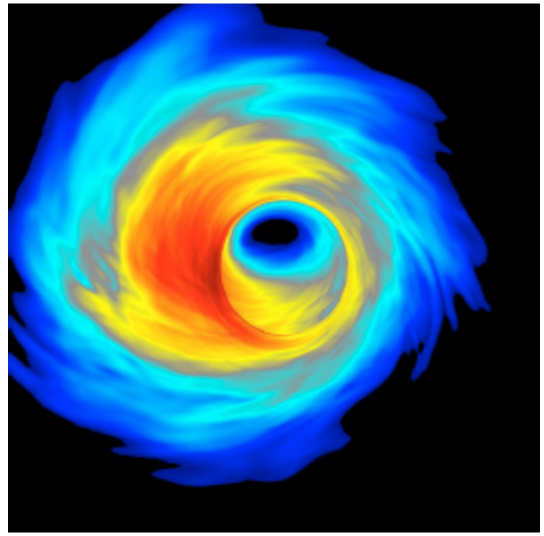
• Measure the cosmological constant to determine the fate of our Universe

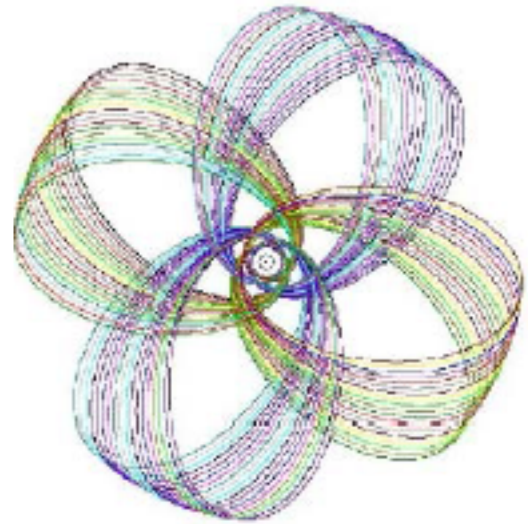
• Detect the emergence of structure during the Dark Ages (z~10-20) via 21-cm observations (*Cosmic Dawn Mapper*)



The extremes of Nature

Black Holes



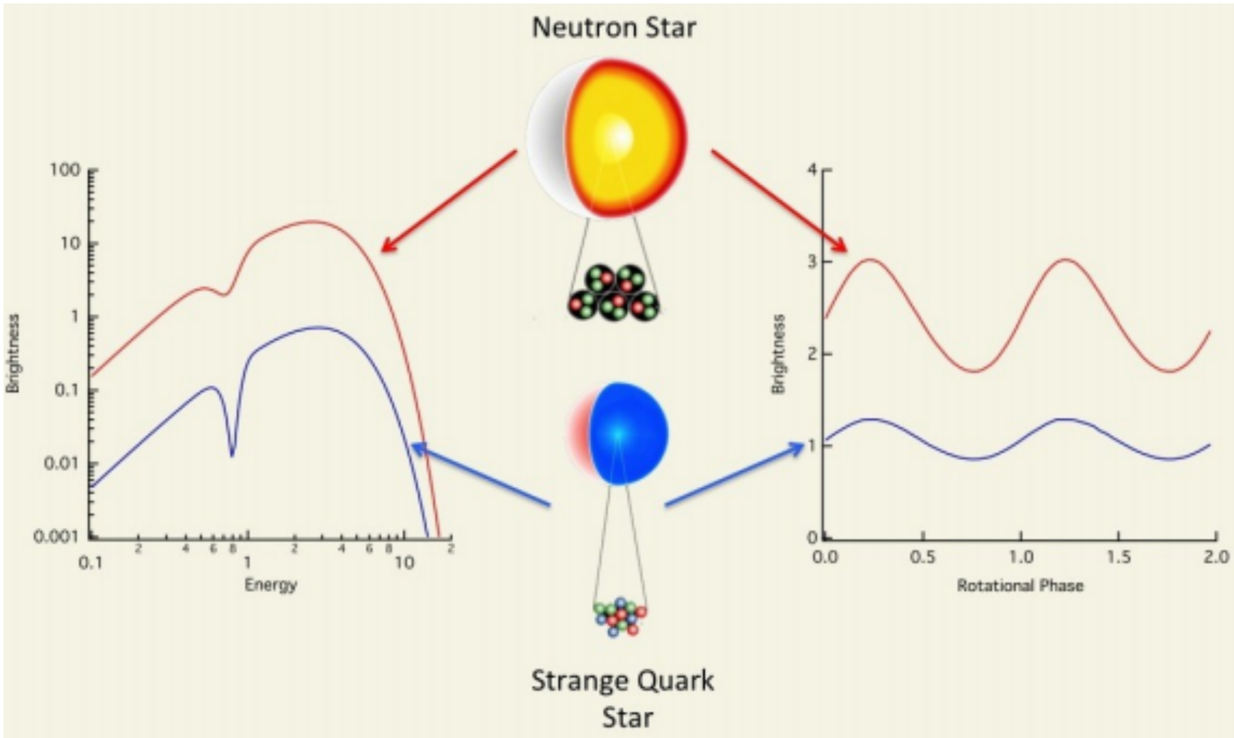


Understand the accretion-driven engines

• Measure BH masses and spins (accretion diagnostics and mergers) (*X-ray, GW Surveyors*)
• Direct imaging (sub-microarcsecond) of powerful accretion flows around SMBH and the launching regions of jets; ultimate tests of accretion models (*BH Mapper*)
• Test strong-field GR and map spacetime around SMBHs via GW from Extreme Mass Inspirals and merging SMBHs (*GW Surveyor)*

The extremes of Nature

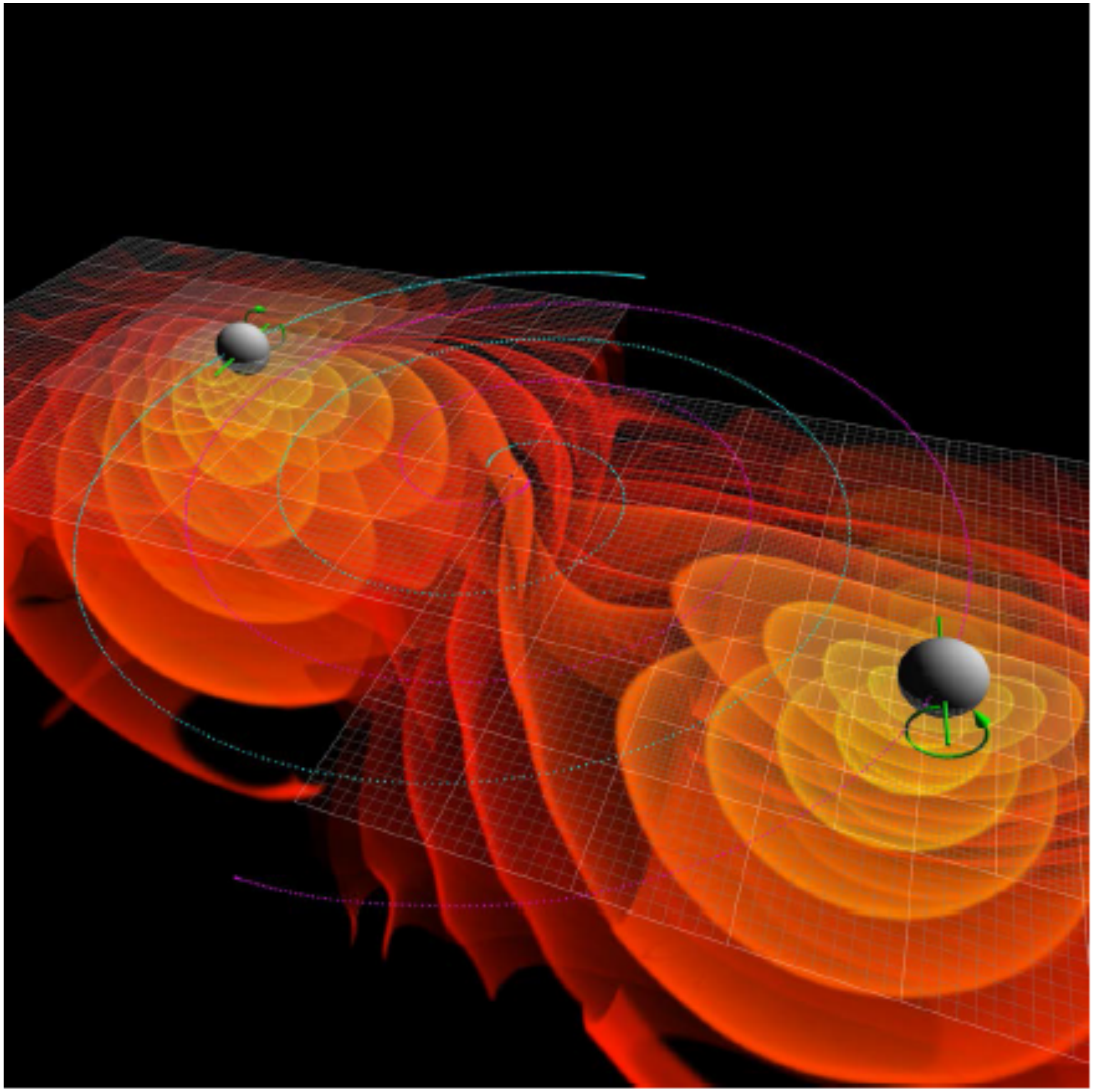
Neutron stars



• Determine the composition and interactions of particles at the NS cores - constrain the equation of state of NS (*NICER, X-ray Surveyor*)

Listening to the Cosmos

The Gravitational Wave window



- Track BH mergers across all of cosmic time
- Probe exotic phenomena – great potential for surprises
- Direct detection of primordial GWs; listening to inflation
- Chart the expansion history of Universe with GW standard sirens (*Gravitational Wave Surveyor* and *Mapper*)

Activities by Era

Near-Term Era

- Complete characterization of CMB anisotropies
- Improve precision measurements of the Hubble constant
- Probe the origin of cosmic acceleration
- Constrain the equation of state of neutron stars

Formative Era

- Measure the CMB polarization to cosmic variance limits
- Make high precision determinations of NS properties
- Measure BH spins and test GR predictions for BH Spacetimes
- Map BH Spacetimes with EMRIs
- Measure BH mergers throughout the Universe and WD binaries throughout the MW
- Search for new phenomena – sources of gravitational waves

Visionary Era

- Measure early matter clustering with 21-cm: define the range of the reionization Era
- Measure the cosmic expansion history using standard sirens
- Image the innermost regions of SMBH accretion discs
- Directly detect the background of GW from the inflationary epoch

Public Engagement
Connecting through Astronomy

Astronomy has a unique ability to capture the imagination of the public and inspire the next generation of explorers. Ensuring that NASA data are easily accessible and scientific discoveries are effectively communicated is our highest priority.

The continuum of Astronomy Learners

Engage the widest audience possible to share in the discovery process using new technologies and methods conducive to learning in a variety of settings

The cornerstone of communicating Astronomy: unique data

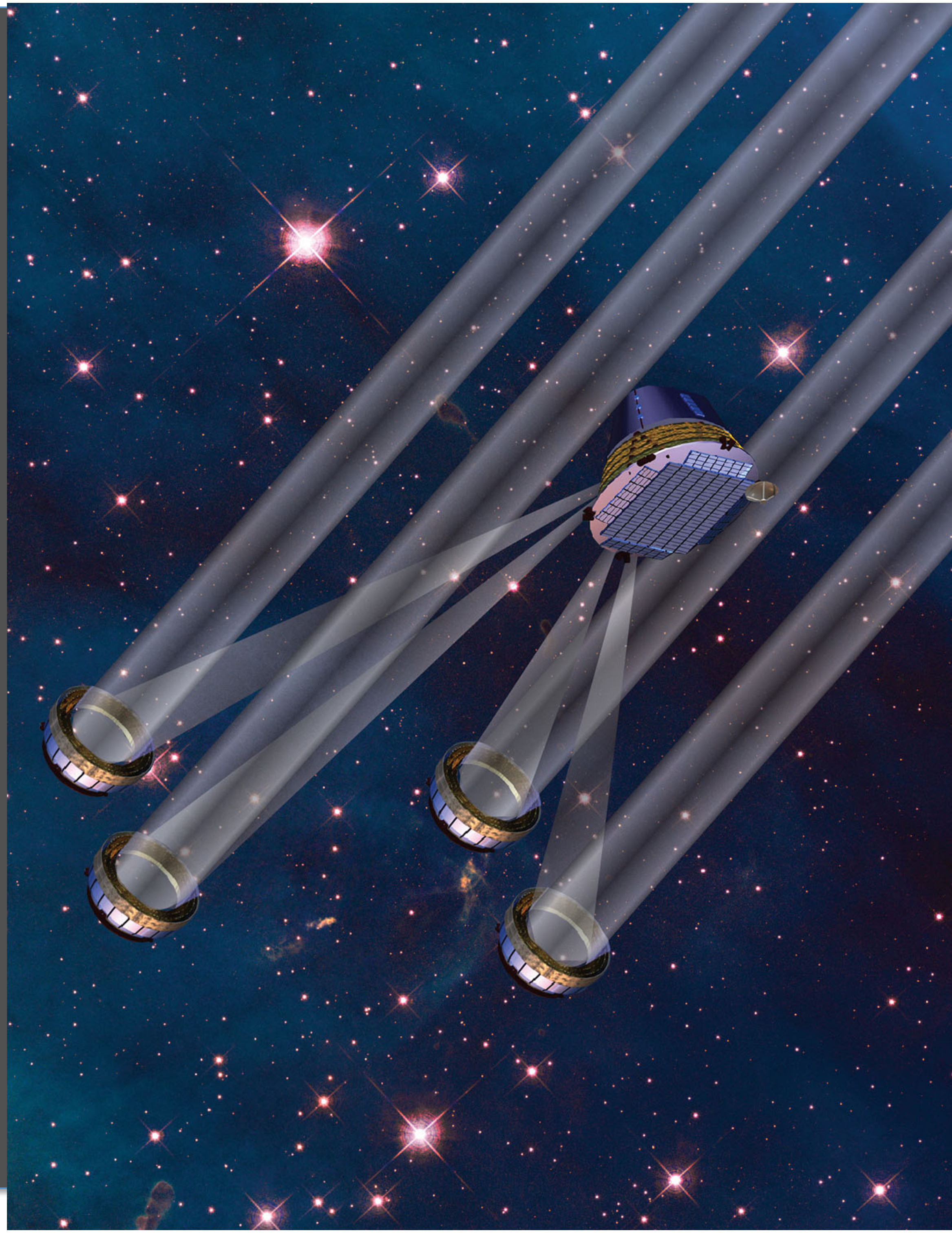
Ensure accessibility to NASA data via online archives – enhance and support citizen science (Galaxy Zoo, Planet Hunters…)

Audiences: From online to one-to-one

• New models of science communication – social media (Twitter, Facebook). Nasa.gov has averaged 11.5 million visits per month from February through September 2013, with 5.25 million unique visitors per month for the same period.
• Promote in-person experiences between scientists and the public.
• Maintain close ties between missions/scientists and the EPO professionals that develop teacher and classroom materials

Diversity and inclusion: Critical for STEM success

• Increase engagement with underrepresented populations in a focused and coordinated effort



Realizing the vision: notional missions and technologies

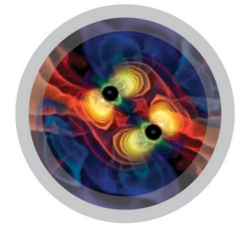
Formative Era: 5 Surveyors

Visionary Era: 4 Mappers

Probe-scale missions such as:

- Measure the BB spectrum distortions in the CMB
- Map the Universe's hydrogen clouds with a 21 cm lunar orbiter from the far side of the moon
- Monitor energetic transients with X- and gamma-ray telescopes
- Measure X- and gamma-ray polarization

Formative Era: Gravitational Wave Surveyor



Peak sensitivity: mHz range – enables detection of

- BH mergers across the Universe
- stellar remnant captures by galactic BHs up to z~1
- thousands of compact binaries in the MW

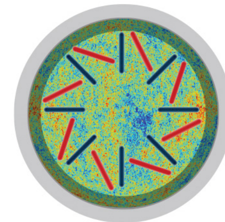
Technological needs:

- Precision microthrusters
- Frequency stabilized lasers
- High rigidity telescope assemblies & optical benches
- Precision gravitational sensors
- High cadence phase meters

Currently LISA Pathfinder is scheduled to launch at 2015

Suggested configuration: 3 spacecraft flying in triangular configuration

Formative Era: CMB Polarization Surveyor



Peak sensitivity: 1- 2 mm range –few arcmin angular resolution requires 1-4m aperture telescope. It enables characterization of

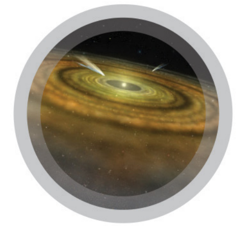
- E-mode polarization to cosmic variance limits
- B-mode polarization produced by gravitational lensing of the CMB

Technological needs:

• Large arrays (10^4) of superconducting detectors
• Component technologies: detector array readout electronics, large cryogenic optics systems, anti-reflection coatings, polarization modulators, optical filters, and sub-Kelvin cryogenic systems for the detector arrays

Large array technology is currently tested on balloon flights

Formative Era: Far-IR (FIR) Surveyor



30+m FIR (10 – 400 microns) interferometer enables

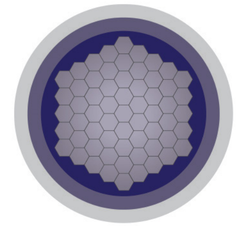
- multi-object spectroscopy
- imaging spectroscopy
- tomographic spectral line mapping

Technological needs:

- Segmented large single-aperture (10-20m) FIR telescopes
- Sub-Kelvin focal-plane coolers
- Space-qualified 4 K mechanical coolers
- Detector readout electronics
- Wide-field or multi-beam spectrometers

Formative Era: Large UV/Optical IR (LUVOIR) Surveyor

8-16m (~10 micron – 91 nm) with <10 mas resolution enables



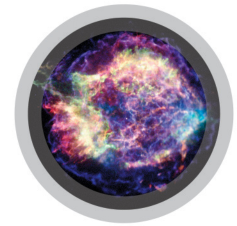
- wide field imaging across a broad spectral range
- high contrast imaging and spectroscopy of circumstellar environments
- single-object spectroscopy across a broad spectral range and resolution range
- multi-object spectroscopy of thousands of objects
- diffraction-limited spatially-resolved spectroscopy
- astrometry of nearby bright stars and fainter stars

Technological needs:

- Segmented technology development
- Robotic assembly
- Wavefront accuracy and stability
- High-reflectivity coating
- Large format high-sensitivity detectors from IR to UV
- Starlight suppression systems

Formative Era: X-ray Surveyor

>~ 3m^2 collecting area (0.1 -10 keV) with <1 arcsec resolution, 5’ FOV, and high spectral resolution enables



- hot intergalactic gas surrounding clusters of galaxies
- accretion regions surrounding BHs
- studies of plasma states and interactions, motions, and substructure

Technological needs:

- Large number production of very thin shells
- Active axial figure control via e.g., piezoelectric or magnetorestrictive methods, or coating techniques
- Development of low-stress coatings that still meet the requirements of low surface roughness and high bulk density
- Mounting, alignment and bonding for thin shell optics
- Metrology, Calibration and Verification
- Large microcalorimeter arrays
- Readout

Visionary Era

Gravitational Wave Mapper

Two or more widely separated detectors significantly increases the angular resolution particularly if the peak sensitivity is moved to higher frequencies (~ 0.1Hz). The overall sensitivity of the instrument is increased by using more powerful lasers, larger telescopes and improved gravitational reference sensors.

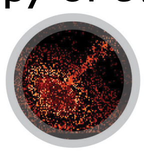
Cosmic Dawn Mapper

Array of thousands of radio antennas (λ=2-20m) separated from meters to tens of meters on the far side of the Moon, to be shielded from all the radio noise produced on Earth.

Exo-Earth Mapper

A large optical/near-IR space-based interferometer with a goal of a 30x30 element map of an Earth at optical wavelengths (0.3 to 1 micron), with the planet at a distance of 10 parsecs (33 light-years). A total collecting area of around 500m^2 (~20, 6m units separated by ~370km) will provide R ~ 100 spectroscopy of every spatial element within a day of exposure time.

Black Hole Mapper



An X-ray interferometer with (sub)microarcsecond resolution would allow us see the shadow of the event horizon in our Galactic Center and the giant elliptical galaxy M87, strongly complementing studies in the mm-band and testing one of the most fundamental predictions of the GR theory of BHs. X-ray interferometry poses significant technical challenges.

Cross-Cutting, game changing technologies

New technology: mirrors, on-orbit fabrication, assembly

The key to bigger and better space telescopes may rely on assembling and testing telescopes on-orbit, from subcomponents produced on Earth, and perhaps in the visionary period, from actually producing many components in space using so-called "smart materials" and advanced robotics and possibly astronauts.

3-D printing was invented ~30 years ago. Today 3-D printers are being used to manufacture a wide range of products from human transplants to firearms and even houses.

One could imagine, e.g., a lunar fabrication facility where giant telescope mirror support structures were printed and launched with a water reservoir and a small amount of metal.

Interferometry

Challenges:

- precision laser metrology
- formation flying
- beam combination, possibly with delay lines
- aperture synthesis techniques: beam combiner optimization, data analysis techniques

Daring visions

- Sense the ripples in Gravity out to the edge of our Universe
- Chart the warped space of a Black Hole and reveal how they power the greatest outflows of energy in the Cosmos
- Tell the complete the story of galaxies – from quantum fluctuations through first light to the present day
- Reconstruct the complete star formation, structural and chemical history of our Milky Way and its neighbors
- Map the Surface of an Earth-like planet
- Find evidence of life beyond the solar system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	Formative Era					Visionary Era			
	GW Surveyor	CMB-pol Surveyor	Mid-IR /FIR Surveyor	LUVOIR Surveyor	X-ray Surveyor	GW Mapper	Cosmic Dawn Mapper	ExoEarth Mapper	Black Hole Mapper
Demographics of planetary systems			S	P				P	
Characterizing other worlds			S	P				P	
Our nearest neighbors and the search for life				P				P	
The origins of stars and planets			P	P				P	
The Milky Way and its neighbors			P	P	P		P	S	P
The history of galaxies	P		P	P	P	P	P	S	P
The origin and fate of the Universe	S	P		P	P	P	P		
Extremes of matter and energy	P	S			P	P			P
Ripples of spacetime	P					P			

NOTE: P and S, stand for Primary and Secondary science goals, respectively.

6.5 Technology Summary

	Formative Era					Visionary Era			
	GW Surveyor	CMB-pol Surveyor	Mid-IR /FIR Surveyor	LUVOIR Surveyor	X-ray Surveyor	GW Mapper	Cosmic Dawn Mapper	ExoEarth Mapper	Black Hole Mapper
Large format detectors			•	•	•				
Formation flying	•					•		•	•
Interferometry: precision metrology	•					•	•	•	•
Interferometry: beam combination							•	•	•
High contrast imaging techniques				•				•	
Optics deployment and assembly			•	•			•	•	
Broadband Coatings				•					
X-ray optics					•				•
Long wavelength detector arrays		•					•		
Short wavelength detector arrays					•				•
High-energy-resolution detectors			•	?	•				•