NASA's Physics of the Cosmos Program

Jamie Bock

California Institute of Technology

Chair of the Physics of the Cosmos Program Analysis Group

pcos.gsfc.nasa.gov

What is the Physics of the Cosmos Program?

NASA Astrophysics is organized into 3 broad science themes:

- **Exoplanet Exploration** ➡ **ExoPAG**
- **Cosmic Origins** ➡ **COPAG**
- **Physics of the Cosmos** ➡ **PhysPAG**

Physics of the Cosmos Program seeks to understand the nature of the Universe. What are its constituents? What are the laws that govern its birth and evolution?

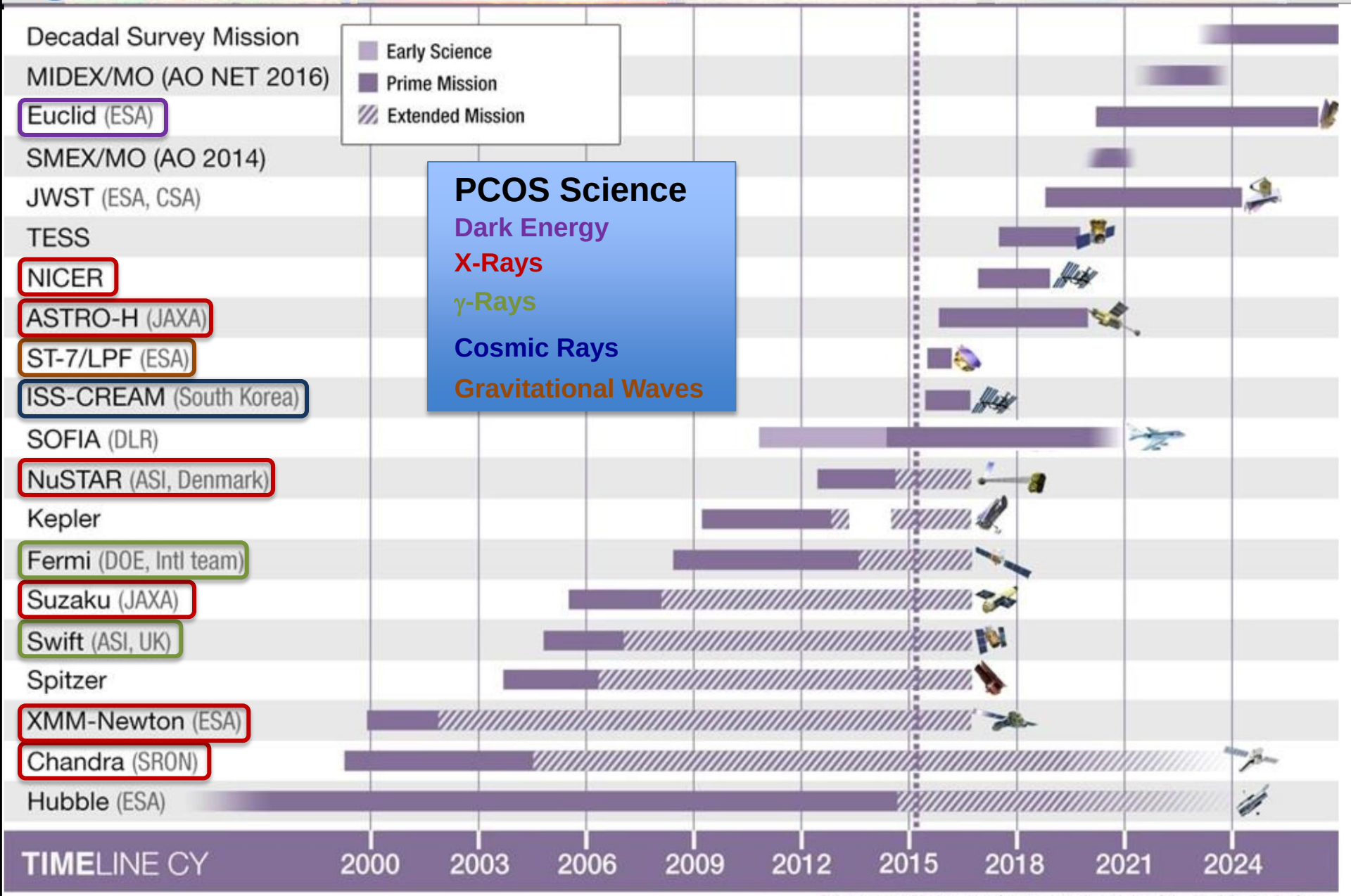
Dark Energy: Probe the nature of dark energy by studying the expansion rate of the universe and the growth of structure

Inflation: Test the theory of inflation by measuring the polarization of the Cosmic Microwave Background.

Black Holes & General Relativity: Probe the properties of black holes and test General Relativity in strong gravity environments using x-ray emission and gravitational waves

Behavior of Matter in Extreme Environments: Explore extreme astrophysical processes with Cosmic rays, X-rays and Gamma-rays

Missions in Operation and Construction



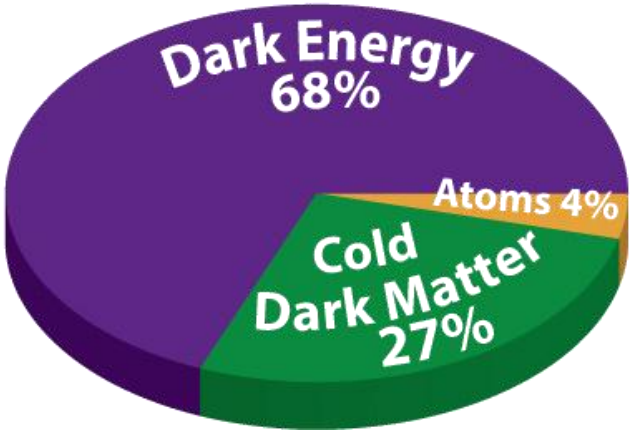
Dates beyond 2016 are contingent upon the results of the 2016 Senior Review

PhysPAG SIG Leaders

- **Five Science Interest Groups:** Cosmic Structure, Inflation Probe, Gamma Rays, Cosmic Rays, Gravitational Waves, X-Rays
- **PhysPAG Executive Committee membership:**
  - ***J. Bock, Chair, California Institute of Technology***
  - ***M. Bautz, Vice-Chair, MIT, X-rays***
  - R. Bean, Cornell University, Cosmic Structure
  - J. Bookbinder, SAO, X-Rays
  - ***J. Conklin, University of Florida, Gravitational Waves***
  - N. Cornish, Montana State, Gravitational Waves
  - ***O. Doré, NASA Jet Propulsion Laboratory, Cosmic Structure***
  - H. Krawczynski, Washington University St. Louis, Gamma Rays
  - ***M. McConnell, University New Hampshire, Gamma Rays***
  - A. Miller, Columbia University, Inflation
  - J. Nousek, Penn State, X-Rays
  - ***A. Olinto, University of Chicago, Cosmic Rays***
  - Eun-Suk Seo, University of Maryland, Cosmic Rays
  - ***E. Wollack, NASA Goddard Space Flight Center, Inflation***
- Rotating off in Dec 2015, Call for applications in Fall 2015

Speaking this session!

Physics of the Cosmos
Science Objectives



- **Expand our knowledge of dark energy**
- Precisely measure the cosmological parameters governing the evolution of the universe and test the inflation hypothesis of the Big Bang
- Test the validity of Einstein's General Theory of Relativity and investigate the nature of spacetime
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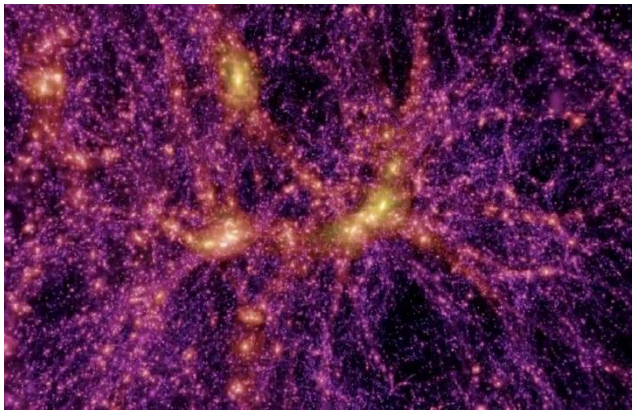
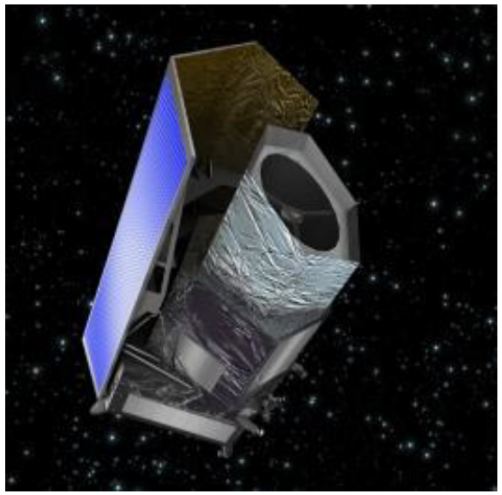


See talk by
Olivier Doré
Cosmic Structure SIG
in this session!

Euclid

A visible and near-infrared telescope to explore cosmic evolution

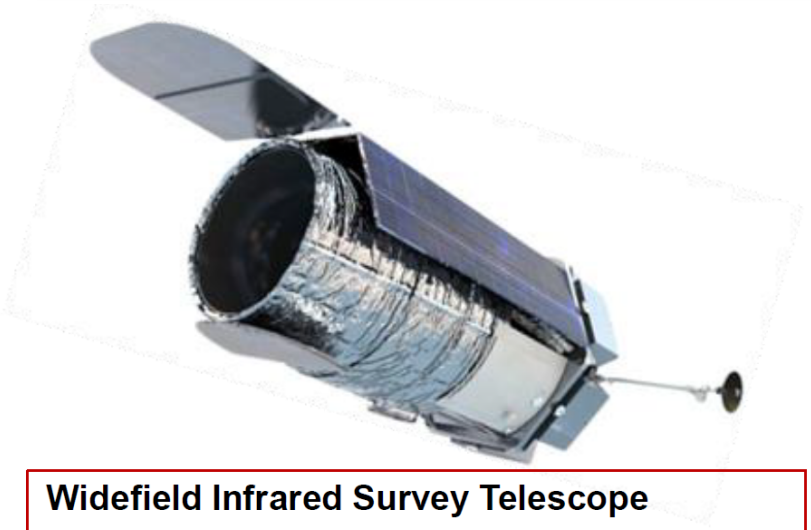


- **ESA Cosmic Vision 2015-2025 Mission**, M-Class with NASA participation.
- 1.2-m mirror, visible & near-IR images, spectra
- **Launch Date**: Mar 2020
- **Science Objectives**:
  - Euclid will look back 10 billion years into cosmic history.
  - Probe the history of cosmic expansion (influenced by dark energy and dark matter) and how gravity pulls galaxies together to form the largest structures.
  - The shapes of distant galaxies appear distorted because the gravity of dark matter bends their light (gravitational lensing). Measuring this distortion tells us how the largest structures were built up over cosmic time.
  - Measuring how strongly galaxies are clumped together tells us how gravity influences their motions, and how dark energy has affected the cosmic expansion.

CURRENT STATUS:

- Currently in implementation phase.
- ~50 U.S. scientists are members of the Euclid Science Team that will analyze the data, and make maps of the sky.
- NASA is providing the sensor assembly for the NISP instrument.
  - First experimental manufacturing run for the Euclid near-infrared detectors was completed in FY 2014 (ESA) and are currently being evaluated and characterized.
  - NASA has initiated the buy for the flight infrared detectors. First lot is complete with a better than expected yield, moving into hybridization phase and growing the second lot of layers. NASA will test and characterize the near-IR flight detectors.
  - Final proposal for detector contract received from Teledyne in February 2015.
- NASA is funding the ENSCI (Euclid NASA Science Center at IPAC). ENSCI will:
  - Support all segments of US community on Euclid to enhance science utilization
  - Integrate into Euclid Science Ground System provided by the Euclid consortium to gain/contribute expertise in pipelines

WFIRST / AFTA Widefield Infrared Survey Telescope with Astrophysics Focused Telescope Assets



Widefield Infrared Survey Telescope

Top priority of 2010 Decadal Survey

Science themes: Dark Energy, Exoplanets, Large Area Near Infrared Surveys

Mission: 2.4m widefield telescope at GEO, uses existing AFTA hardware to image 0.28 deg^2 at 0.8-2.0 μm

Instruments (design reference mission): Wide Field Instrument, Coronagraph Instrument

- FY15 Budget Request and Appropriation support pre-formulation of WFIRST/AFTA
- Plans support Agency/Administration decision for formulation to begin NET FY 2017, should funding be available.

http://wfirst.gsfc.nasa.gov/

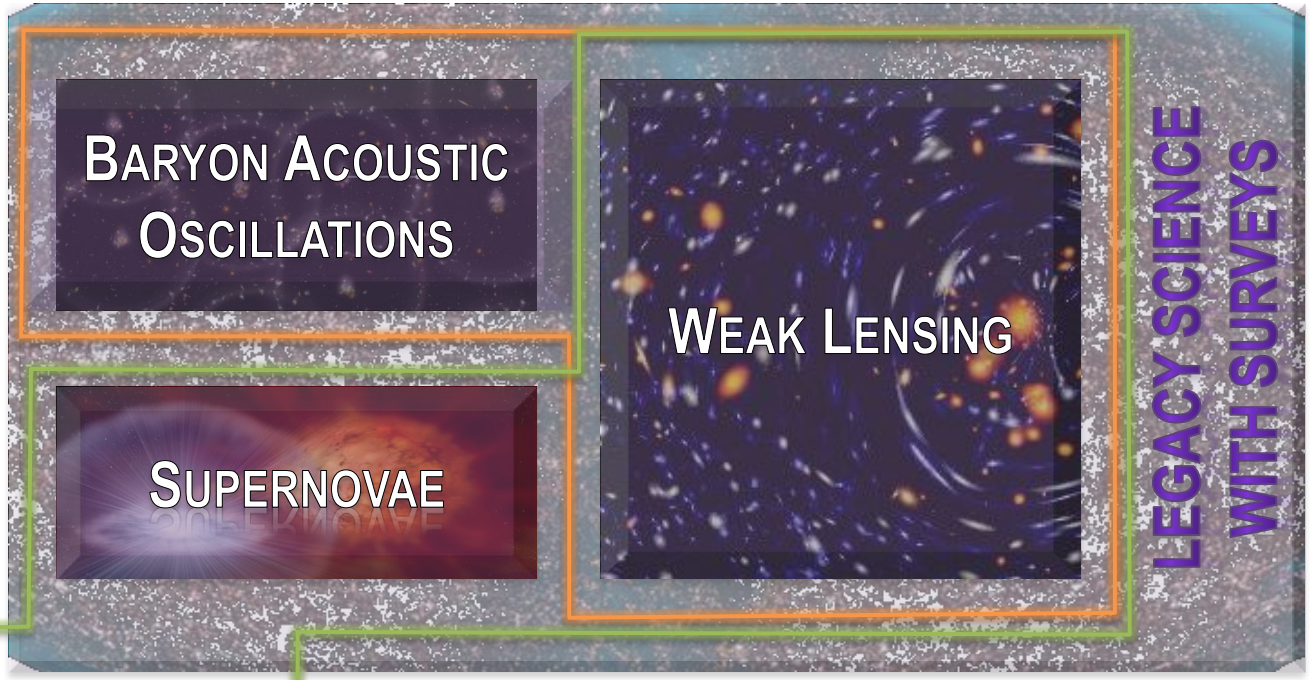
CURRENT STATUS:

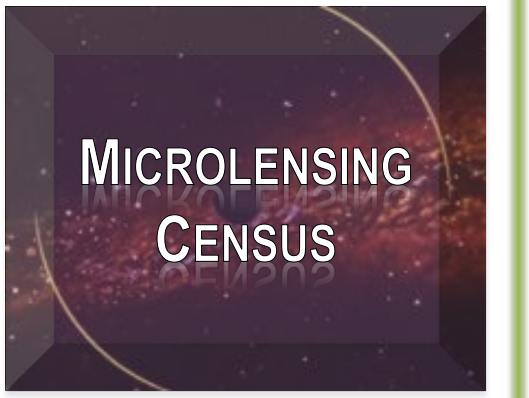
- May 2013, NASA Administrator Bolden directed study of WFIRST/AFTA and preserve option for FY17 new start if budget is available.
  - No decision expected before early CY 2016.
- Currently in pre-formulation phase.
  - Activities include technology development for detectors and coronagraph (with STMD), assessment of the 2.4m telescopes including risk mitigation, mission design trades, payload accommodation studies, and observatory performance simulations.
- Maturing key technologies by FY19.
  - H4RG infrared detectors for widefield imager.
  - Internal coronagraph for exoplanet characterization (two architectures identified December 2013; occulting mask coronagraph and phased induced amplitude apodization complex mask coronagraph).
- March 2014 NRC study on WFIRST/AFTA offers positive view of AFTA, with concerns about technology and cost risks.
- WFIRST Preparatory Science (WPS) funds ROSES proposals that are relevant to WFIRST's goals and WFIRST-specific simulations and models.
- SDT final report submitted January 31, 2015, and available online soon.

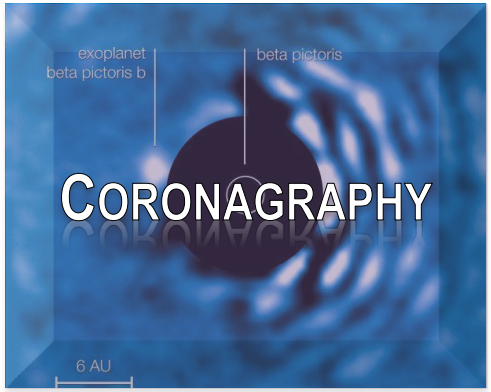
WFIRST-AFTA Dark Energy Science

complements Euclid

complements LSST







continues Great Observatory legacy

Physics of the Cosmos
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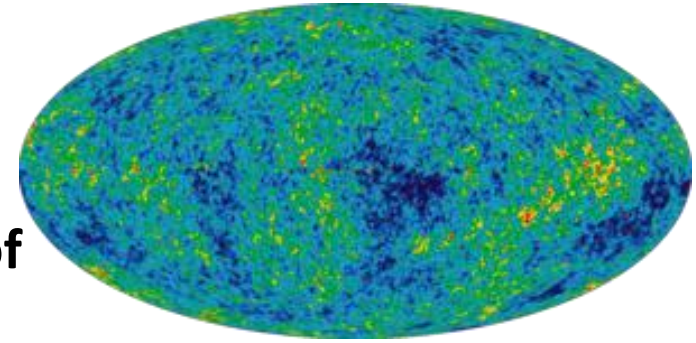
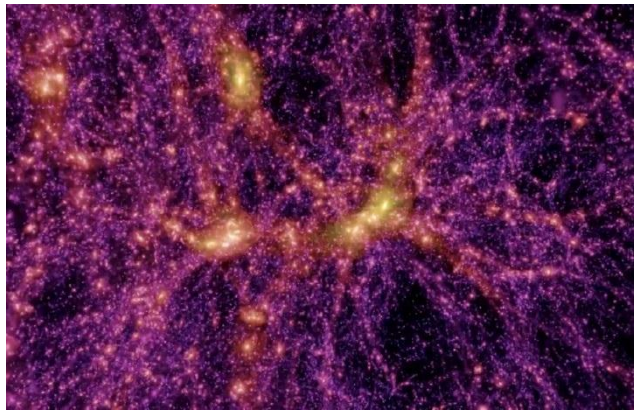
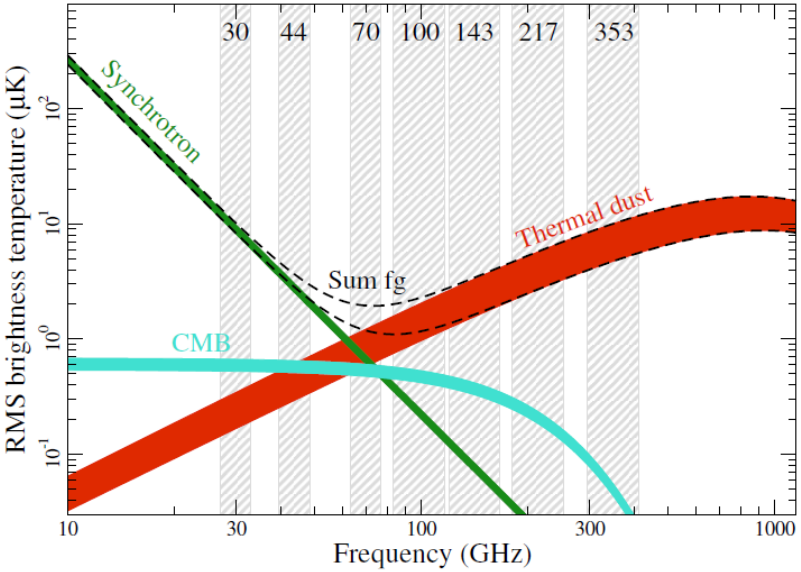


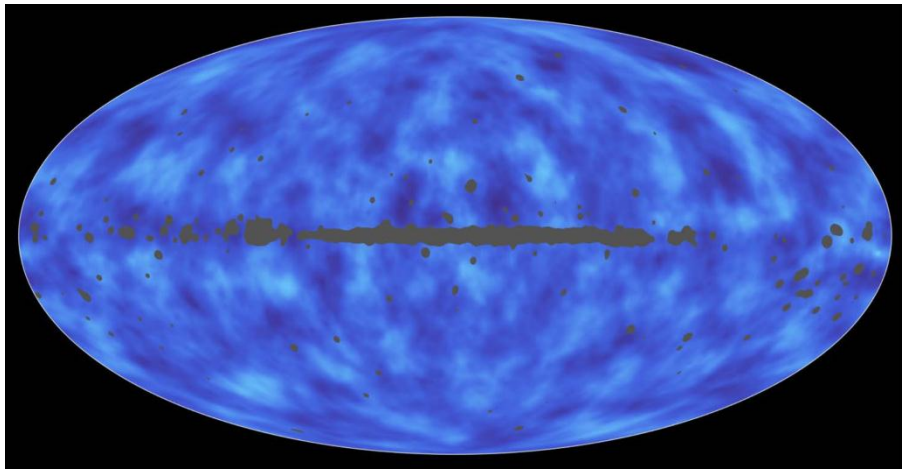


See talk by
Ed Wollack
Inflation SIG
in this session!

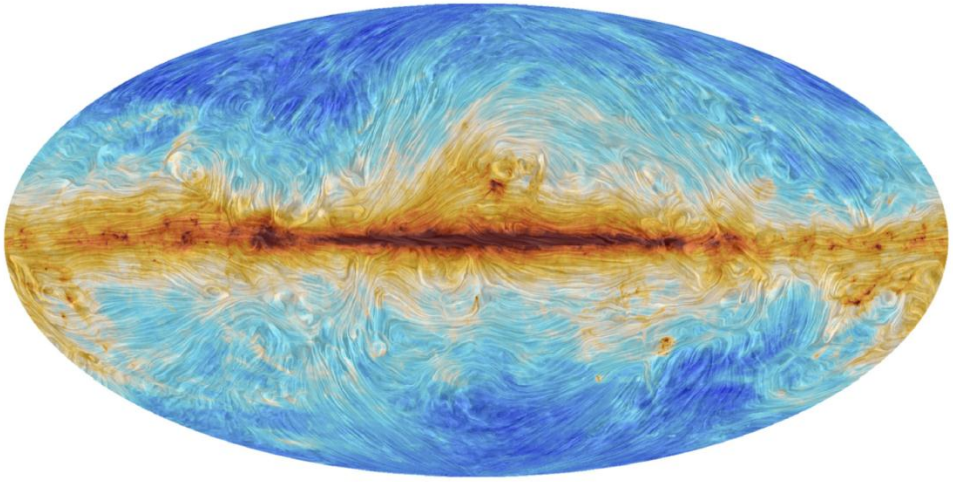
Legacy of Planck – Looking Towards the Future



All-sky polarized maps in 7 frequency bands



Gravitational potential derived from CMB lensing



Rendering of polarized Galactic dust emission

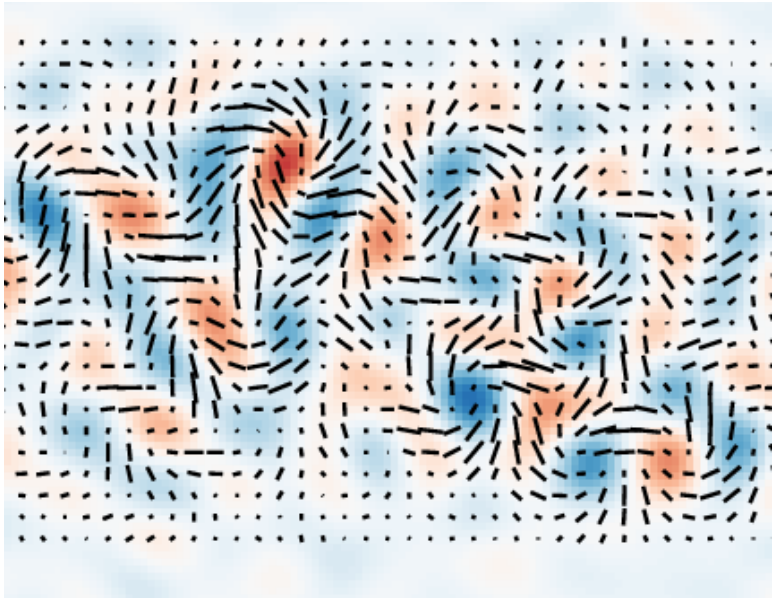
Planck detects lensing at 40σ!

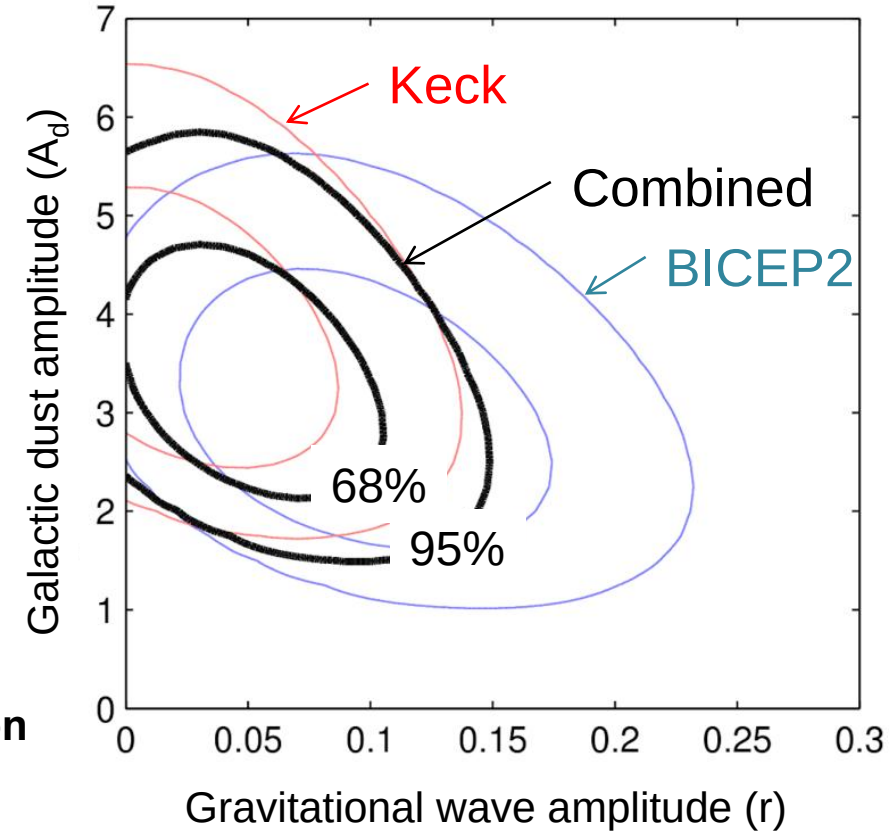
- mostly using CMB temperature data

B-mode polarization from lensing

- detected by BICEP2/Keck, SPT, ACT, and POLARBEAR
- ultimate tool to map the gravitational potential, large-scale structure

Inflation and the CMB





- **Signature of inflationary gravitational waves: degree-scale 'B-mode' polarization**
  - B-modes reported at 150 GHz by BICEP2
  - Consistent result from Keck Array in 2015
- **Dust subtraction with BICEP+Keck+Planck leaves a residual CMB signal at 1.5σ**
  - Upper limit on r < 0.12 (95 % conf.)
  - Note r=0 is not at likelihood peak
  - Errors increase from dust subtraction
- **Errors improving quickly with new data**
- **Regime r = 0.01 – 0.1 very interesting**
  - Tests slow-roll models
  - Will be mined in the next few years

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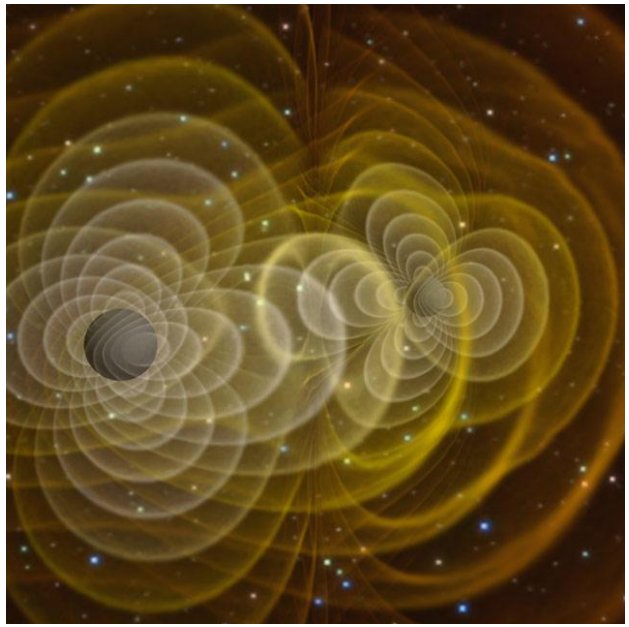
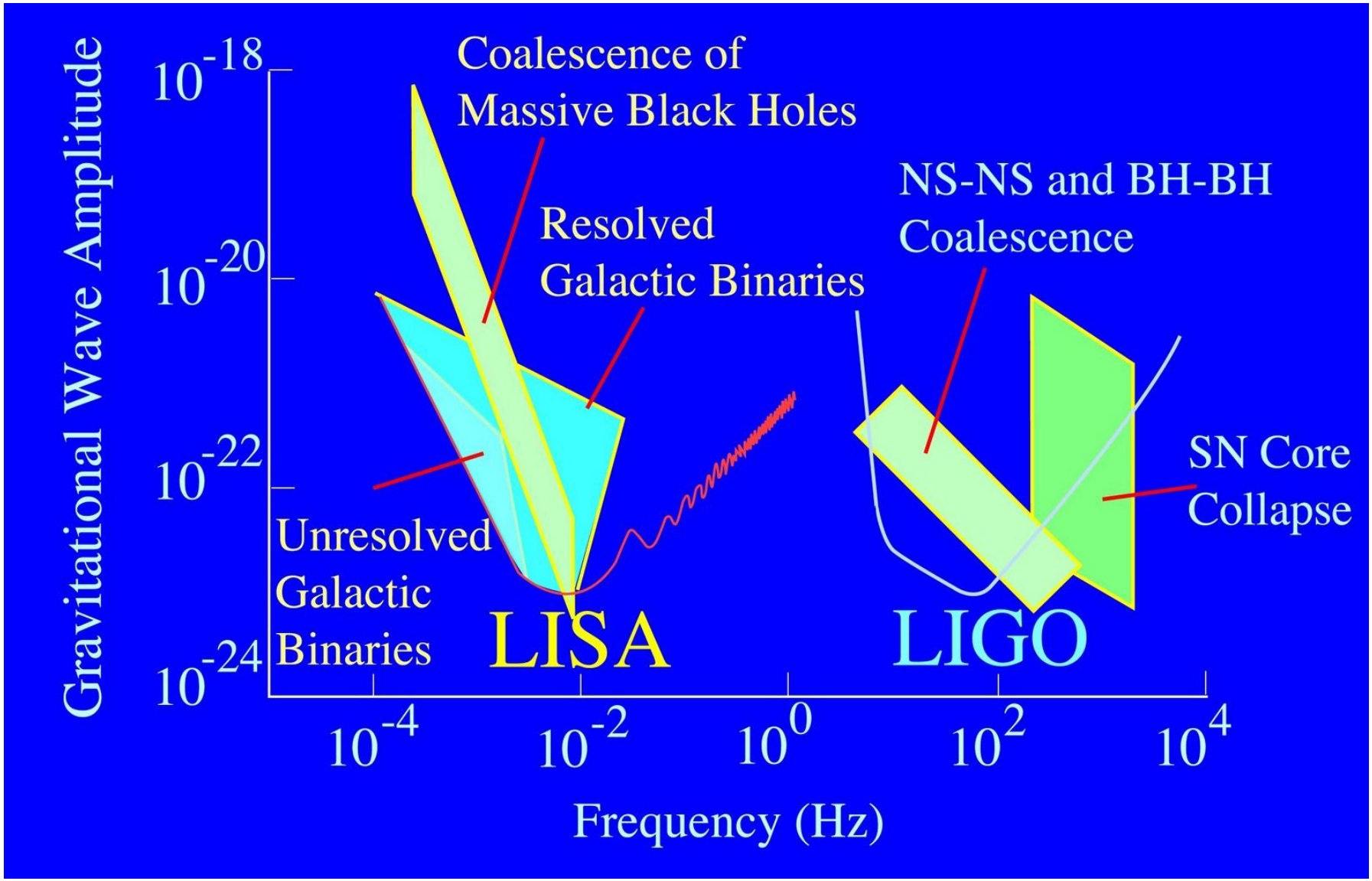
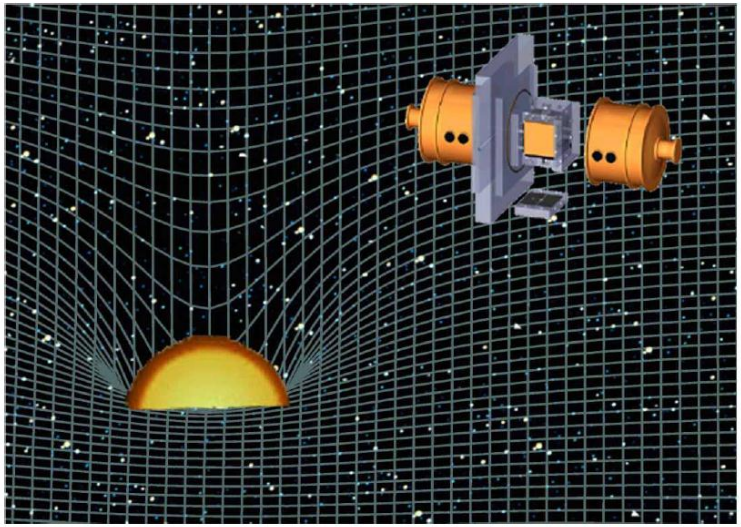


See talk by
John Conklin
Gravitational Wave SIG
in this session!

Space-Borne Gravitational Wave Observations



LISA Pathfinder Background



- ESA Mission with NASA Collaborating
- Project Category: 3 Risk Class: C
- DRS flies on the ESA LISA Pathfinder spacecraft
- Sun-Earth L1 halo orbit
- Drag-free satellite to offset solar pressure
- Payload delivery: July 2009 – COMPLETE
- Launch date: October 2, 2015
- Operational life: 2 months
- Data Analysis: 12 months

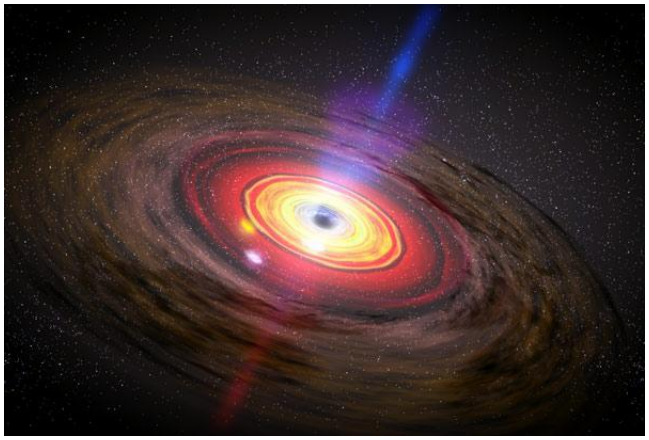
CURRENT STATUS:

- Ongoing tests at Airbus UK testbed
- Extended mission being discussed
- Spacecraft has shipped from Airbus to IABG for the environmental test - arrived in early March.
- NASA analysis team is supporting as needed.
- System level thermal vacuum test in April/May 2015
- System level acoustics and mass properties in May 2015
- Shipping in August to launch site

Evolved Laser Interferometer Space Antenna (eLISA)

- **A space-based gravitational wave observatory was recommended by Astro2010 as the third priority under large space missions**
- **NASA and ESA are discussing a potential NASA contribution to ESA L3**
  - ESA has selected eLISA for the L3 mission with a planned 2034 launch
- **Discussions between ESA and NASA are ongoing; the partnership *likely* will be subject to Astro2020 decadal approval**

Physics of the Cosmos
Science Objectives



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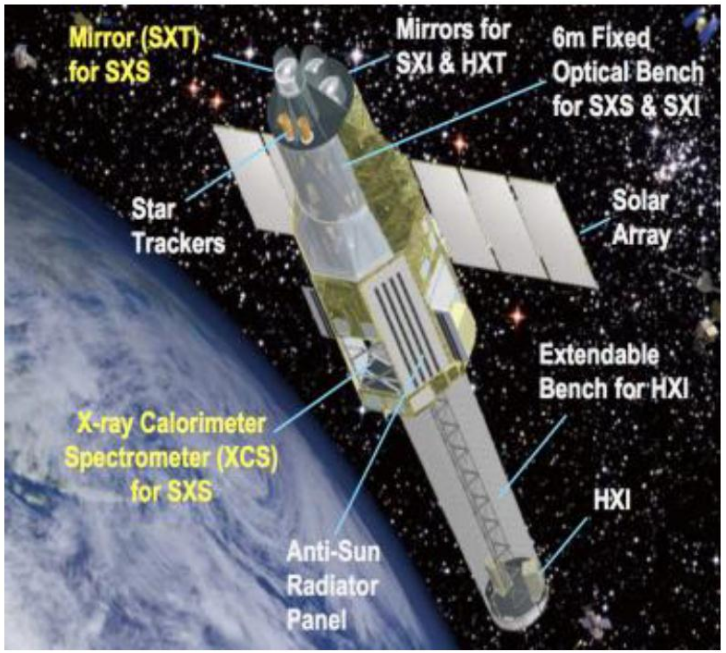
See talk by **Mark Bautz** ***X-Ray SIG*** in this session!

ASTRO-H

Soft X-ray Spectrometer and Soft X-ray Telescope Mirrors



- **Explorer Mission of Opportunity**
- **PI**: R. Kelley, Goddard Space Flight Center
- **Launch Date**: Nov 2015 on JAXA H-IIA
- **Science Objectives**: Study the physics of cosmic sources via high-resolution X-ray spectroscopy. The SXS will enable a wide range of physical measurements of sources ranging from stellar coronae to clusters of galaxies.
- **Operations**: Prime Mission is 3 years

CURRENT STATUS

The U.S. is providing instrument contributions to the JAXA ASTRO-H mission.

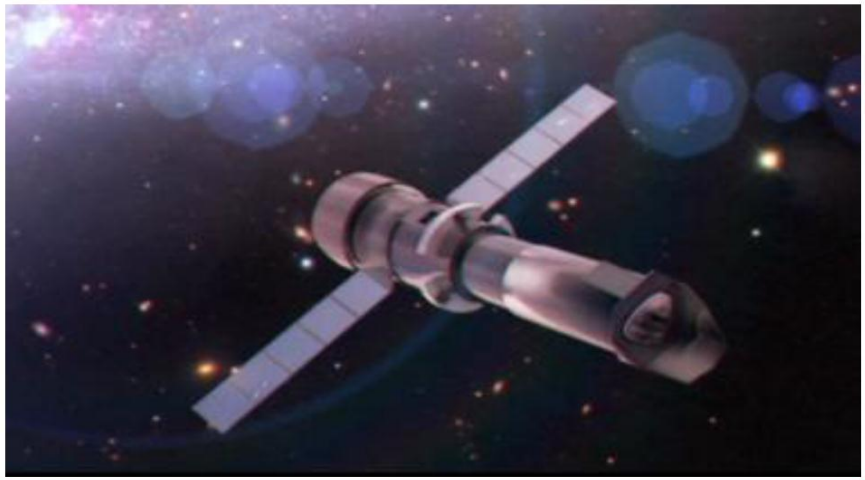
- Soft X-ray telescope mirrors (SXT-S and SXT-I) – Both delivered.
- Calorimeter Spectrometer Insert (CSI) – delivered and integrated in the FM Dewar and has successfully performed during all testing activities.
- Completed FM Dewar cryo performance testing in December with excellent results.
- Supporting additional dewar testing in preparation for integration onto spacecraft.

UPCOMING EVENTS:

- March 19-20 – Systems Integration review
- March 25 2015 - SXS dewar integration onto spacecraft
- Summer 2015 (TBD) – Start of spacecraft testing

Athena

Advanced Telescope for High Energy Astrophysics



- **Second ESA Cosmic Vision Large mission**
  - L-class with NASA/JAXA participation
  - Decadal Survey recommendation
  - Large X-ray mirror, X-IFU and WFI instruments
- **Launch Date:** 2028
- **Breakthrough Technologies**:
  - High Throughput, Wide FOV, High spectral resolution X-ray Astronomy
  - 10x Chandra area, 100x improved non-dispersive spectral resolution, 5x FOV.
- **Science Objectives**: The Hot and Energetic Universe: How does ordinary matter assemble into the large scale structures that we see today? How do black holes grow and shape the Universe?

CURRENT STATUS:

- Selected as 2nd Large mission in ESA Cosmic Visions Program
- Currently in 2 year Study Phase
- NASA and US community involved in Study Phase via membership on ESA-chartered Athena Science Study Team and Science Working Groups
- NASA budgeting for a $100M-$150M hardware contribution, plus a US GO program and a U.S. data center
- NASA and ESA are discussing possible NASA contributions, such as:
  - Sensor array to the X-ray Integral Field Unit
  - Portions of the X-ray Mirror
  - Contribution to science data center (U.S. node)
- NASA continues to invest in Athena technologies via SAT and directed investigations.

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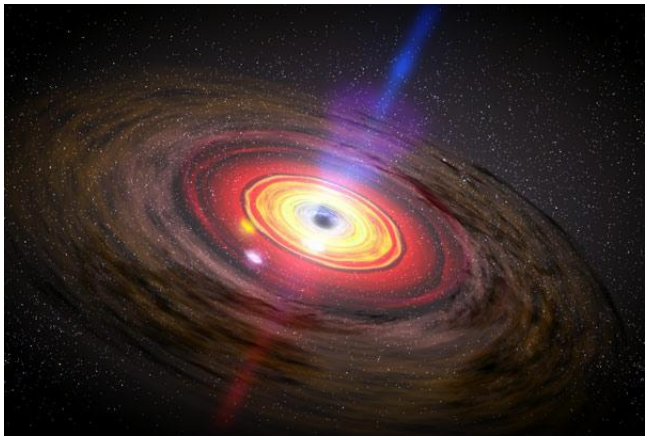
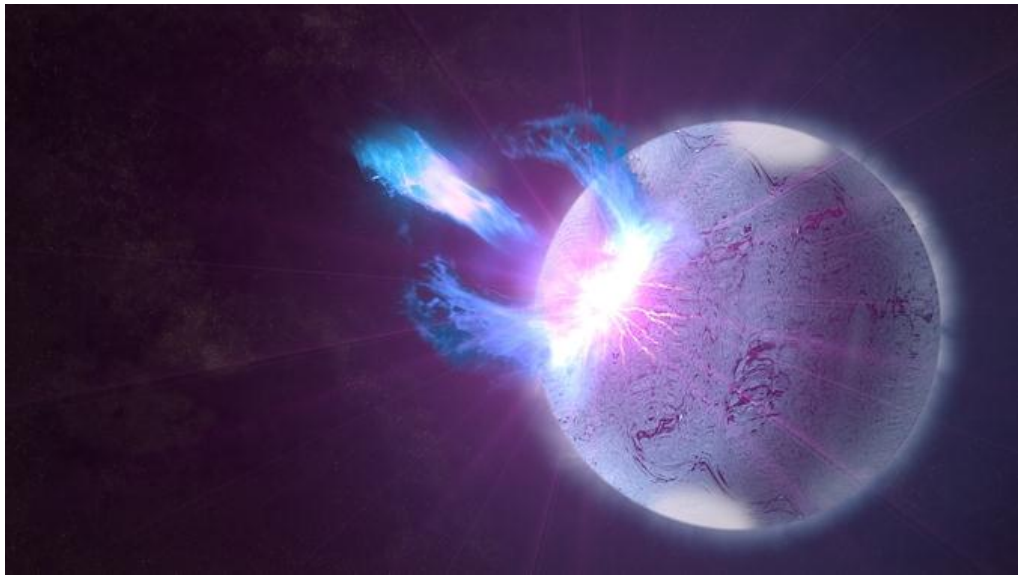


See talk by **Mark McConnell** ***γ-Ray SIG*** in this session!

See talk by **Angela Olinto** ***Cosmic-Ray SIG*** in this session!

Recent News from Fermi: Magnetar Storms

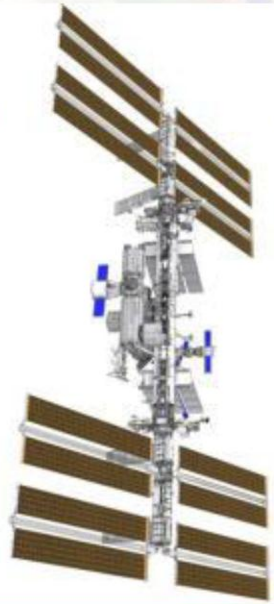
- Magnetars are highly magnetized neutron stars. Only 20 are currently known
- Bursting detected J1550–5418 in 2009. Bursts are smaller but more frequency than the rare giant flares
- Flare associated with surface quakes (mag 23 on the Richter scale!)
- Further analysis of Fermi data shows that bursts have characteristic frequencies
- Thought to be a result of strong coupling between the surface and the magnetic field

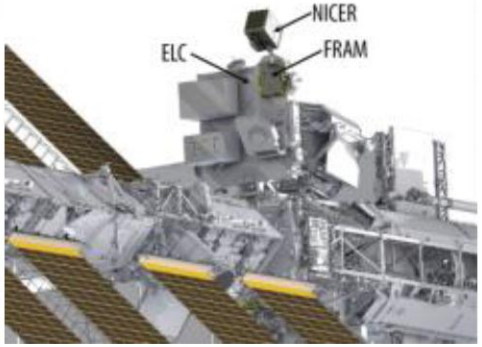


NICER

Neutron Star Interior Composition Explorer

Intl Space Station (ISS)

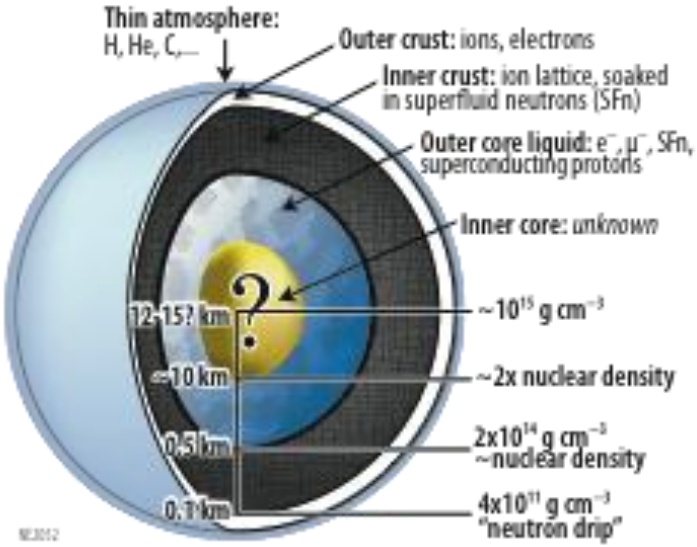




- **Explorer Mission of Opportunity**
- **PI:** Keith Gendreau, GSFC
- **Launch:** October 2016 on Space-X Falcon 9
- **Science Objectives:** Perform high-time-resolution and spectroscopic observations of neutron stars in the .2-12 keV energy range to study the physics of ultra-dense matter in the core of neutron stars.
- **Instrument:** X-ray Timing Instrument uses X-ray concentrators and detectors to detect X-ray photons and return energy and time of arrival.
- **Platform:** Located externally on the ISS, ExPRESS Logistics Carrier 2, Starboard 3 site
- **Operations:** Operated on a non-interference basis for 18 months
- **SEXTANT** for Pulsar navigation demo funded by NASA's Space Technology Mission Directorate

CURRENT STATUS:

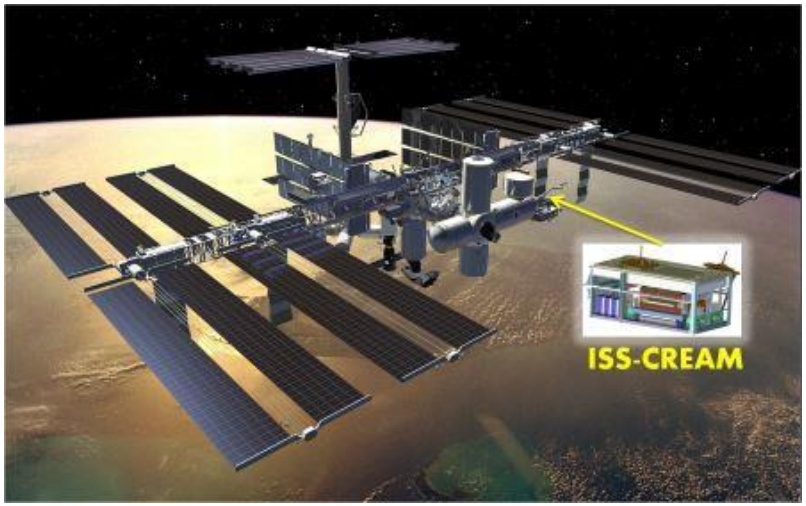
- Project successfully passed Critical design review (CDR) September 2014
- Design is maturing quickly; engineering test units of many subsystems have been developed and tested. Fabrication has started on the instrument optical bench, detector subassemblies, and pointing system, and electrical subsystem
- Integration of the x-ray timing instrument to start in March 2015, to support testing, beginning in June 2015

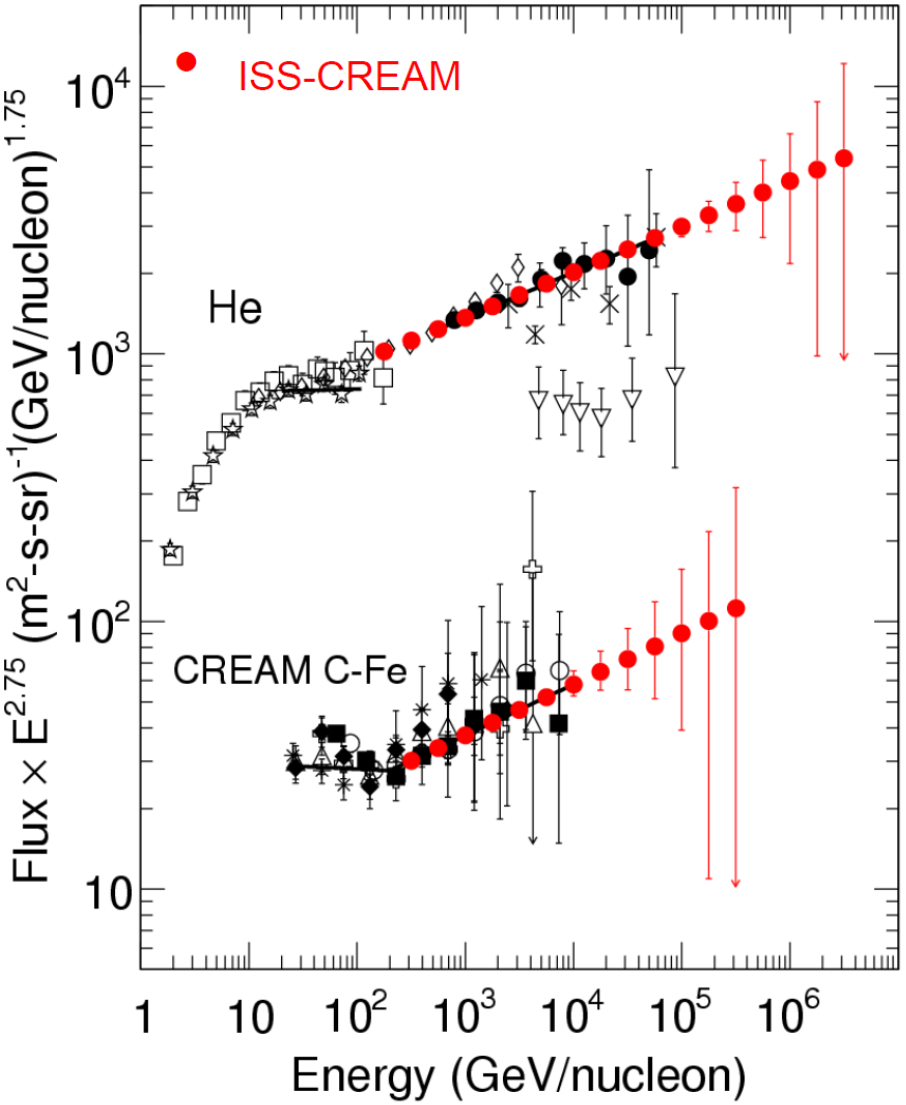


ISS-CREAM

Cosmic Ray Energetics And Mass for the International Space Station

- P.I.: Eun-suk Seo, Univ. of Maryland
- Measures the energy spectra from 10^{10} to $>10^{14}$ eV over the elemental range from protons to iron (Z = 1-26)
- Evolves from the CREAM balloon experiment.
- Extends reach of direct cosmic ray measurements to the highest energy possible to probe their origin
- Launch planned in 2015





How Can I Get Involved?

If you are interested and participate:
You are a NASA PhysPAG member

- **Visit pcos.gsfc.nasa.gov**
- **Sign up for email announcements, or for a Science Interest Group**
- **Participate in community discussions**

National Aeronautics and Space Administration

Physics of the Cosmos Newsletter

August 2014 Vol. 4 No. 2

Summer 2014 PCOS Update

Mansoor Ahmed, *PCOS Program Manager*
Ann Hornschemeier, *PCOS Program Chief Scientist*

Since February 2014, progress has continued on a number of fronts in the PCOS portfolio. Chief among these are the next steps in defining a U.S. role in the European Space Agency (ESA) L2 and L3 opportunities. Following the June 2014 announcement by ESA of the selection of the L2 mission Athena we are now referring to this mission by name and are pleased to have selected, via an open community call in early July 2014, a U.S. representative to the Athena Science Study Team (SST).

Contents

Please read Robert Petre's article on Athena which includes the full list of members of the ESA-selected SST. Conversations with ESA concerning L3 are at a much earlier stage and we ex-

(continued on page 2)

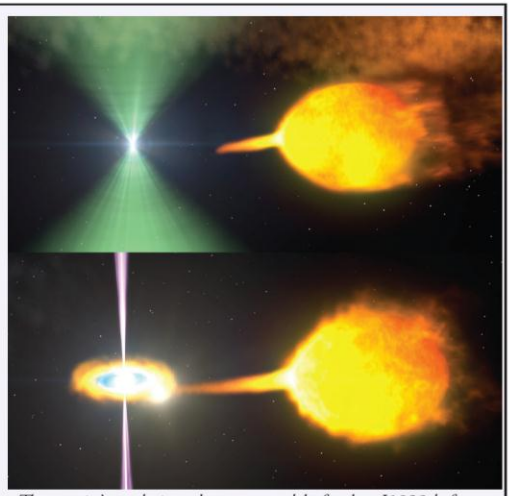
NASA's Fermi Finds A "Transformer" Pulsar

In late June 2013, an exceptional binary containing a rapidly spinning neutron star underwent a dramatic change in behavior never before observed. The pulsar's radio beacon vanished, while at the same time the system brightened fivefold in gamma rays, the most powerful form of light, according to measurements by NASA's Fermi Gamma-ray Space Telescope.

The binary pairs a 1.7-millisecond pulsar named PSR J1023+0038—J1023 for short—with a star containing about one-fifth the mass of the sun. The stars complete an orbit in only 4.8 hours, which places them so close together that the pulsar will gradually evaporate its companion.

For J1023, the dramatic changes seem to reflect an erratic interaction with its companion star, according to a recent study by an international team led by Ben Stappers at the University of Manchester in England.

The stars are close enough that a stream of gas flows from the sun-like star toward the pulsar. The pulsar's rapid rotation and intense magnetic field are responsible for both the radio beam and a powerful outflow of high-energy particles. When the radio beam is detectable, the pulsar wind blows back the companion's gas stream, preventing it from approaching too closely. But when the flow from the companion surges, the gas is able to reach toward the pulsar and establish an accretion disk.



These artist's renderings show one model of pulsar J1023 before (top) and after (bottom) its radio beacon (green) vanished. Normally, the pulsar's wind staves off the companion's gas stream. When the stream surges, an accretion disk forms and gamma-ray particle jets (magenta) obscure the radio beam. Image Credit: NASA's Goddard Space Flight Center

Gas in the disk becomes compressed and heated, reaching temperatures hot enough to emit X-rays. Next, material along the inner edge of the disk quickly loses orbital energy and descends toward the pulsar. When it falls to an altitude of about 50 miles (80 km), processes involved in creating the radio beam are either shut down or, more likely, obscured.

Read the full article at **http://www.nasa.gov/content/goddard/nasas-fermi-finds-a-transformer-pulsar/** and published paper **Stappers et al. ApJ, Vol. 790, p. 39** at **http://adsabs.harvard.edu/abs/2014ApJ...790...39S**

Current PCOS Activities:
Preparing Large Missions for 2020 Decadal

Identify a small set (~3-4) of large mission concepts to study

- **The community has invested considerable resources in discussing notional classes of mission concepts for consideration as large missions following JWST and WFIRST and in parallel with the ESA-led missions Euclid, Athena, and L3.**
  - The 2010 Decadal Survey, *New Worlds New Horizons in Astronomy and Astrophysics*.
  - The 2014 Astrophysics Visionary Roadmap, *Enduring Quests, Daring Visions*.
- **NASA has drawn an initial small set of 4 candidate mission concepts from the missions discussed in these strategic documents.**
- **The Astrophysics PAGs are to solicit community input for the purpose of commenting on the small set, including adding or subtracting large mission concepts; each PAG will submit a report regarding the small set of large mission concepts for consideration by the NAC Astrophysics Subcommittee.**
- **At its Fall 2015 meeting, the NAC Astrophysics Subcommittee will consider the three PAG reports and submit a report to NASA on the small set of large mission concepts for study.**
- **NASA will then decide which large mission concepts will be studied as input for the 2020 Decadal Survey.**

Current PCOS Activities
Preparing Large Missions for 2020 Decadal

- **Far-Infrared Surveyor**
  - 4-6 m filled cold aperture
  - 10 m segmented cold aperture
  - High sensitivity spectrometers, wide-field imagers
- **Habitable Exoplanet Imaging Mission**
  - 4-8 m monolith
  - 10^{-10} contrast with coronograph or starshade
  - Camera, IFU spectrometer
- **UV/Optical/IR Surveyor**
  - 8-16 m aperture
  - UV, optical and near-IR coverage
  - Suite of imagers and spectrometers
  - Possibly has a coronograph
- **X-Ray Surveyor**
  - Angular resolution < 1", 5' FOV
  - 3 sq. meter effective aperture
  - High resolution (~1000) spectroscopy over a broad band
  - 0.1 – 10 keV

- **The ESA Athena is regarded as a mission in progress for the 2020s**
- **The ESA L3 gravitational wave mission is regarded as a mission in progress for the 2030s**
- **The Inflation Probe is regarded as a smaller mission class (a "probe" mission)**
- **Probe mission studies are planned as the following step**

Large Mission PhysPAG Themes*

- **Far-Infrared Surveyor**
  - How and when did the first supermassive black holes form?
  - Evolution of galaxies and their supermassive black holes
  - Multi-messenger studies with GW events
  - Technology synergies with Inflation Probe and X-ray detectors and optics
  - Intensity mapping measurements of large-scale structure
- **Habitable Exoplanet Imaging Mission**
- **UV/Optical/IR Surveyor**
  - Evolution of galaxies and their supermassive black holes
  - Understand the physics of supernovae and feedback on evolution of galaxies
  - Understand the physical state, composition and kinematics of baryons in the cosmic web
  - Multi-messenger studies with GW events
  - Follow-on studies of large-scale structure measurements
- **X-Ray Surveyor**
  - How and when did the first supermassive blackholes form?
  - Evolution of galaxies and their supermassive black holes
  - Test strong GR by probing behavior of matter in the vicinity of supermassive black holes
  - Measure the spin distribution of supermassive black holes in the local Universe
  - Determine the properties of matter at the highest densities and pressures in neutron stars
  - Understand the physics of supernovae and feedback on evolution of galaxies
  - Understand the physical state, composition and kinematics of baryons in the cosmic web
  - Multi-messenger studies with GW events

*An incomplete list

PCOS/PhysPAG Meetings and Community Interaction Opportunities

- **April 2015, American Physical Society meeting, Baltimore, MD**
  - PCOS table within display hall
  - Gamma-SIG mini-symposium “Future MeV Gamma-Ray Science and Missions”
  - GWSIG meeting on Saturday
  - Cosmic-Ray SIG meeting Monday afternoon
- **June 29-July 1, 2015 “Special HEAD meeting”**
  - X-Ray SIG meeting
  - Gamma-Ray SIG meeting
  - Joint PAG panel discussion: response to charge on large mission planning
- **August 2015, IAU-AAS meeting in Honolulu**
  - PCOS booth
  - Joint PAG splinter session
- **January 2016, American Astronomical Society, Kissimee FL**
  - Annual PhysPAG meeting
  - PCOS booth
- ***List of events regularly updated: pcos.gsfc.nasa.gov/physpag***

Thanks for Listening!

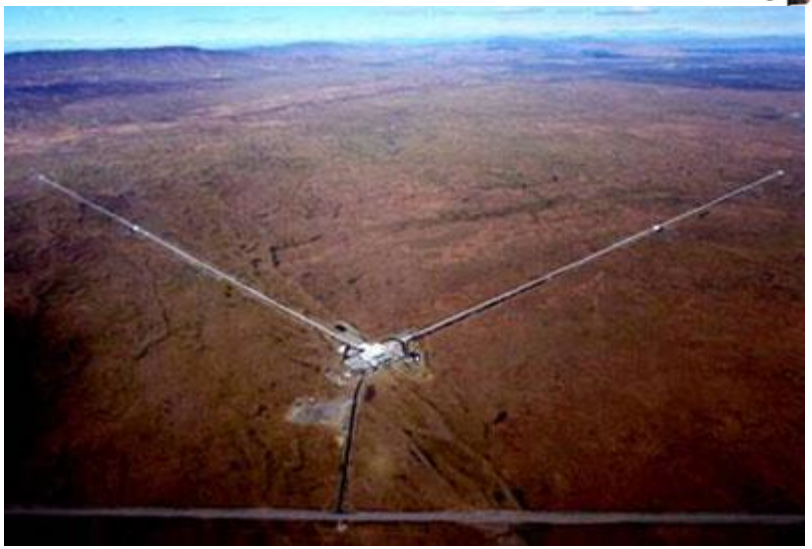
pcos.gsfc.nasa.gov

Advanced LIGO

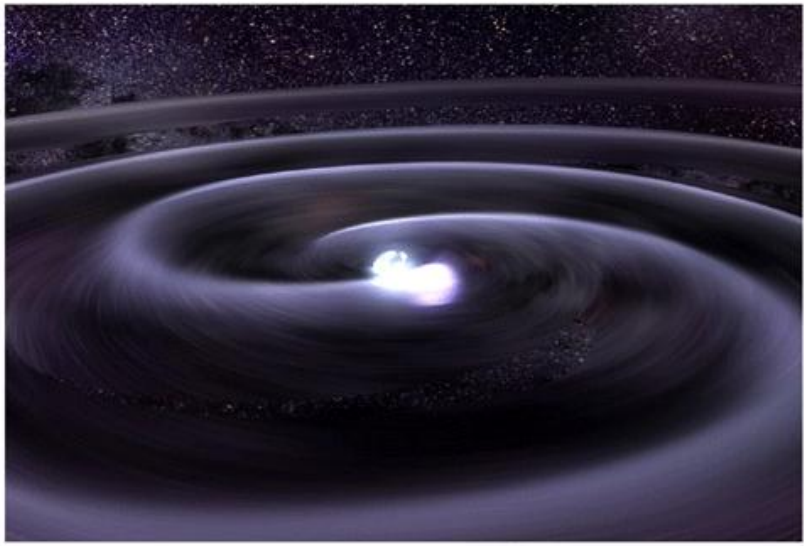
Advanced Laser Interferometer Gravitational-Wave Observatory

aLIGO interferometers will:

- improve sensitivity by >10 over the entire initial LIGO frequency band
- increases the bandwidth of the instrument to lower frequencies (from ~40 Hz to ~10 Hz)
- Can detect inspiraling binary neutron stars to 300 Mpc, some 15x further than the initial LIGO, and an event rate some 3000x greater
- Neutron star - black hole (BH) binaries will be visible to 650 Mpc
- Coalescing BH+BH systems will be visible to z=0.4
- First observing run starts fall 2015



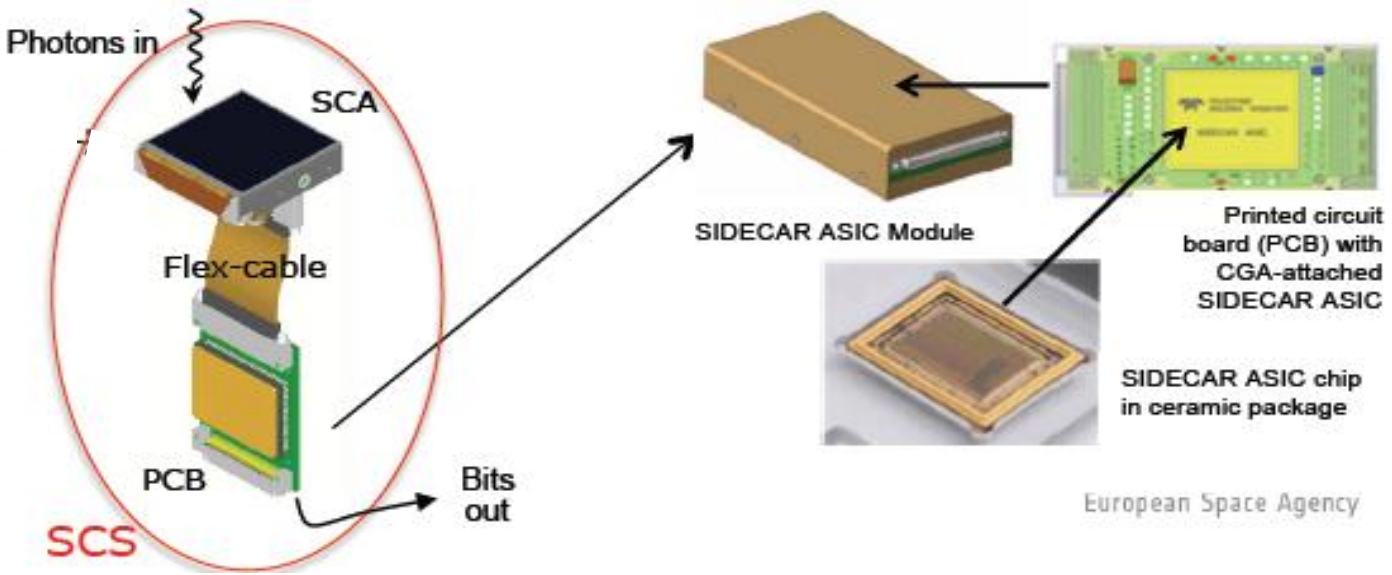
LIGO Hanford Facility



Rendering of Inspiraling Neutron Star Binary

NASA hardware contribution to ESA's Euclid mission

- **NASA's contribution to the Euclid mission will be the Near Infrared Spectrograph and Photometer (NISP) flight focal plane subassemblies that meet ESA's requirements for testing characterization:**
  - **16 flight (plus 4 flight spares) "triplet" Sensor Chip Systems (SCS)**
    - **2Kx2K HgCdTe array (H2RGs) + flex cable + SIDECAR ASIC control electronics**
  - **First flight SCS delivery to ESA planned in ~2015 (under evaluation)**



WFIRST-AFTA Dark Energy Capabilities

Weak Lensing (2200 deg^2)

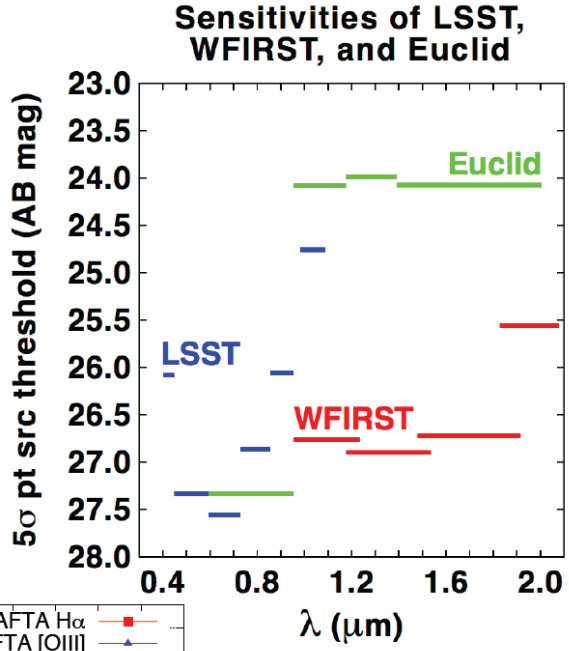
- High angular resolution
- Galaxy shapes in IR
- 380 million galaxies
- Photo-z redshifts
- 4 imaging filters

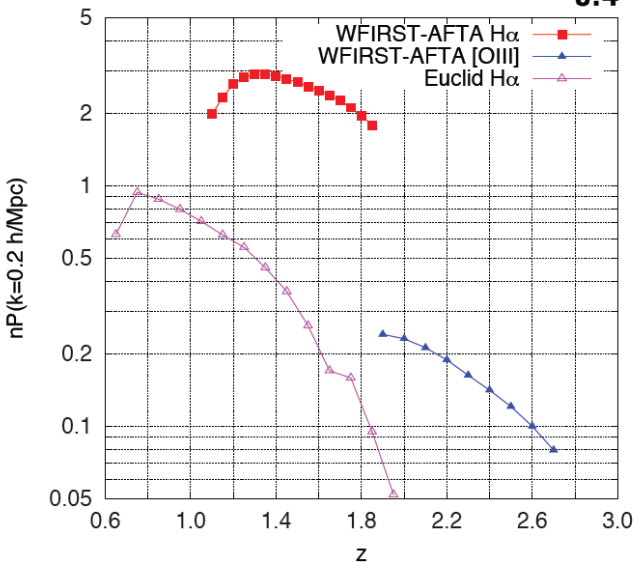
Supernovae

- High quality IFU spectra
- 5 day sampling of light curves
- 2700 SNe

Redshift survey (2200 deg^2)

- BAO & Redshift Space Distortions
- High number density of galaxies
- 16 million galaxies





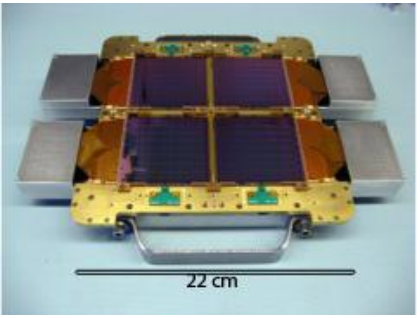
CMB Balloon Program

Currently NASA supports balloon-borne experiments to probe CMB polarization:

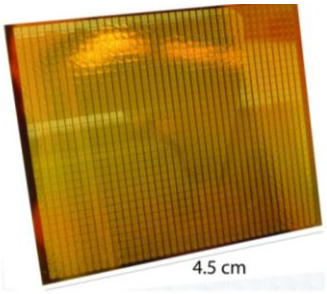
- **Access to higher frequencies**
- **Space-like environment**
- **Technology demonstrations**
- 2012: E and B experiment (EBEX; P.I. Hanany)
- 2015: Suborbital Polarimeter for Inflation Dust and the Epoch of Reionization (SPIDER; P.I. Bill Jones)
- 2016:Primordial Inflation Polarization Explorer (PIPER; P.I. Al Kogut)

SPIDER prepped for launch

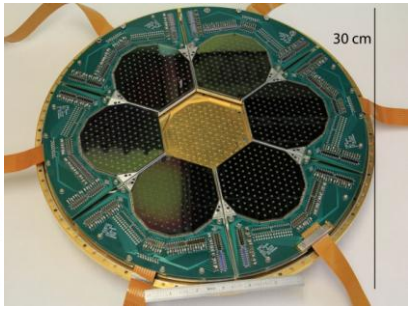
Superconducting Detector Technologies



SPIDER



PIPER



EBEX

SPIDER Flies from Antarctica in January 2015

Recent News from NuSTAR and XMM-Newton

- Observations of the supermassive black hole in PDS 456, an ultra-luminous quasar
- XMM-Newton observes at lower X-ray energy, NuSTAR at higher X-ray energy
- Iron emission and absorption features show winds in this quasar blow in all directions