High Energy Astrophysics and Cosmology from Space: NASA's Physics of the Cosmos Program

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Where does Physics live at NASA?
Prioritization from Astro2010 Decadal Report

Astro2010 science themes map to the Astrophysics Division themes:

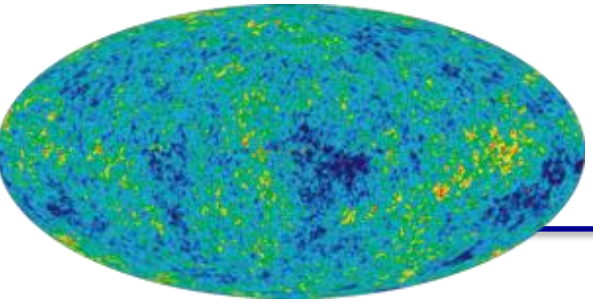
New Worlds		Exoplanet Exploration
Cosmic Dawn		Cosmic Origins
Physics of the Universe	→	Physics of the Cosmos

The highest priority science for Physics of the Universe are captured in the PCOS Science Objectives:

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

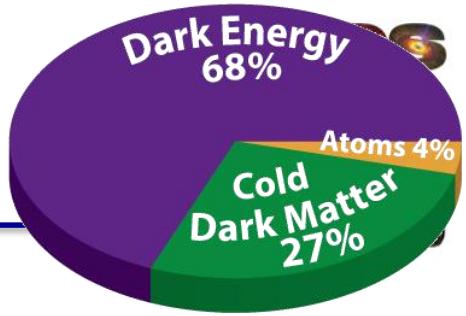
Theory of Inflation: Test the theory of inflation by measuring the polarization of the Cosmic Microwave Background.

Black Holes & General Relativity: Probe the properties of black holes and testing General Relativity using x-ray emission and gravitational waves.

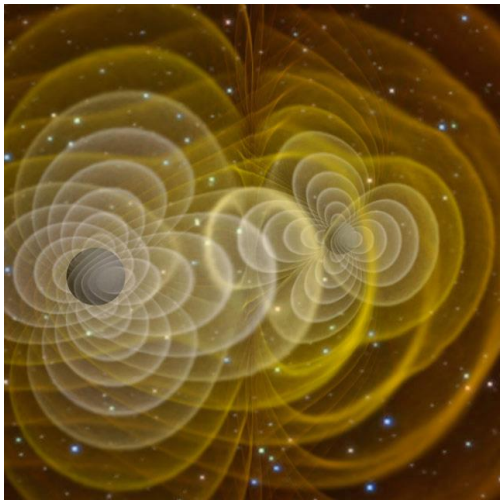


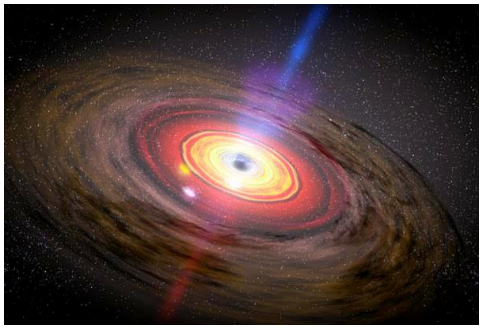
Physics of the Cosmos

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
- Understand the formation and growth of massive black holes and their role in the evolution of galaxies



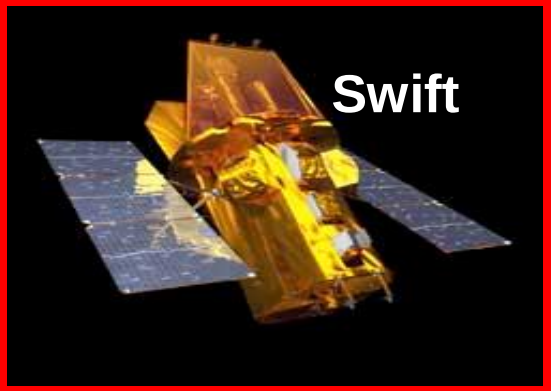


- Explore the behavior of matter and energy in its most extreme environments

OPERATING MISSIONS

PCOS

PCOS-RELATED



The near-future
PCOS Missions in Development

- Three of the six current developmental projects being prepared for launch during FY16 are in the PCOS portfolio: NICER, Euclid & ISS-CREAM

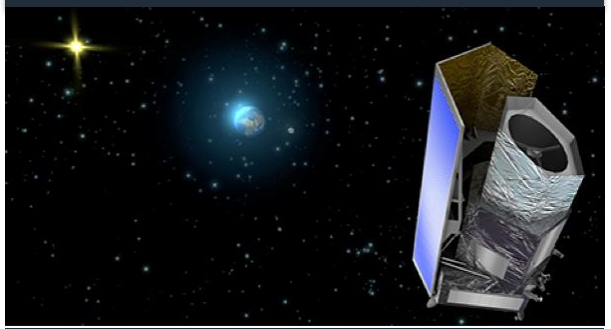
NICER 1/2017
NASA Mission

Neutron Star Interior Composition Explorer

CREAM 4/2017
NASA Mission

Cosmic Ray Energetics And Mass

Euclid 2020
ESA-led Mission

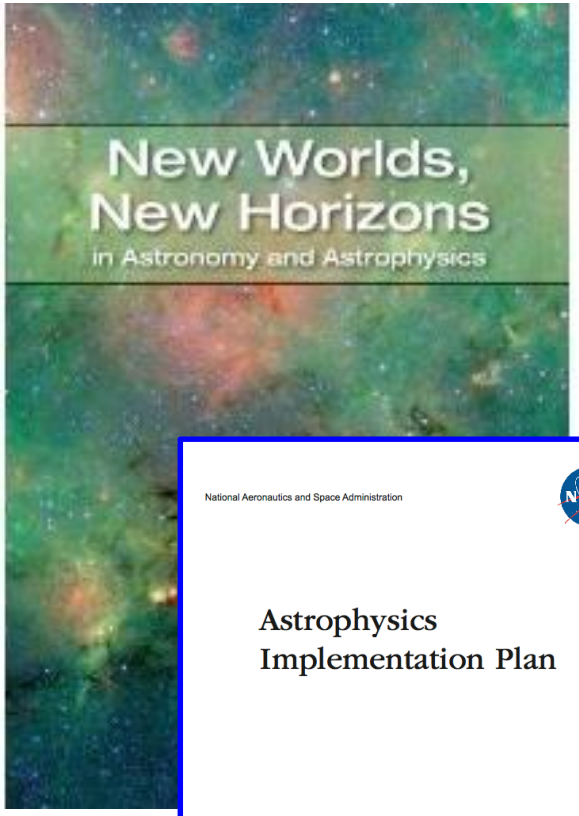


NASA is supplying the NISP Sensor Chip System (SCS)

XRSIG, R. Kraft CosmicSIG, E. Seo CosSIG, O. Dore'

Physics of the Cosmos (PCOS): Scientific and Technical Stewardship for future missions

- **Provide scientific and technical stewardship for decadal-survey recommended missions:**
  - Of the six highly-ranked medium and large-scale space-based priorities in NWNH, three fall within the PCOS science program:
    - LISA (Gravitational Waves)
    - IXO (X-ray)
    - Inflation Probe (medium-scale)
  - NOTE: Although dark energy SCIENCE is within PCOS program, WFIRST is located within the Exoplanet Program

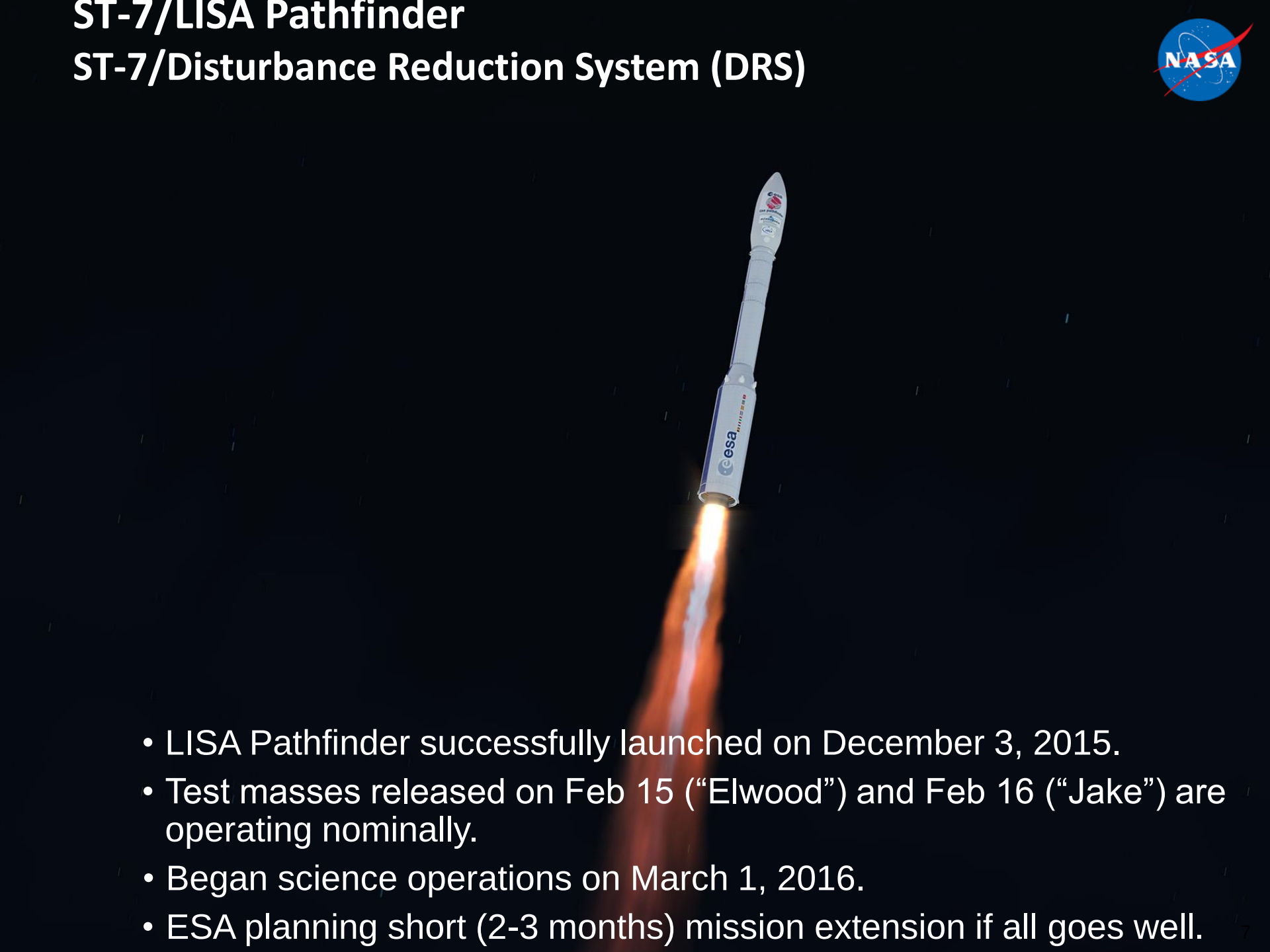


Large Mission Activities in PCOS: ESA L2, L3 and the X-ray Surveyor

- **ESA Cosmic Vision program (2016-2035):**
  - Athena/L2 (launch 2028) will be an X-ray mission following the Hot and Energetic Universe theme
  - L3 (launch 2034) will be a gravitational wave observatory following the Gravitational Universe theme.
- **Two new mission studies in PCOS:**
  - NASA-L3 Study
  - X-ray Surveyor Flagship Mission Study
- After this: John Conklin & Ralph Kraft

ST-7/LISA Pathfinder

ST-7/Disturbance Reduction System (DRS)



- LISA Pathfinder successfully launched on December 3, 2015.
- Test masses released on Feb 15 (“Elwood”) and Feb 16 (“Jake”) are operating nominally.
- Began science operations on March 1, 2016.
- ESA planning short (2-3 months) mission extension if all goes well.

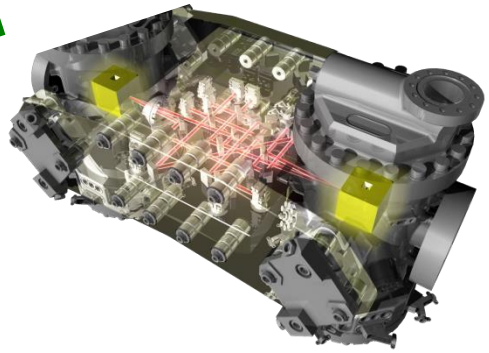
LISA Pathfinder Background (Operating!)

- **LISA Pathfinder (LPF) is an ESA-led dedicated technology demonstrator mission for LISA-like space-based gravitational-wave observ**
  - Key goal: demonstrate drag-fr… as an inertial referen… wave missio…
  - Val…
- **LPF …**
  - Sp… …ncludes cold-gas … drag-free control soft…
  - LISA Technology Package (LTP): A European payload composed of a full drag-free system
  - ST7 Disturbance Reduction System (ST7-DRS): A NASA payload (JPL)

LPF Spacecraft
A)

Monday 1:30PM!
S5: Space Based Gravitational Wave Astrophysics
"LISA Pathfinder: picometers and femtoNewtons in space"
Martin Hewitson

… Member States)



ST7-DRS (JPL)

NASA's L3 Study

- NASA intends to partner with ESA on the ESA-led L3 gravitational wave mission with launch in 2034. This responds to the recommendations of the 2010 Astrophysics Decadal for a space-based gravitational wave observatory.
- Following the successful launch of the LISA Pathfinder, NASA has formed an L3 Study Team (L3ST) drawing membership from members of the US astrophysics community.
- The goals of the L3ST are:
  1. Analyze the options for NASA participation in the L3 mission and work with the European L3 consortium on proposals to ESA; and
  2. Prepare a report to the 2020 Decadal Survey on NASA's participation, including possible options, in the L3 mission as a minority partner.
- 15 members (plus 6 member technology analysis group). David Shoemaker (MIT) is Chair. ESA has appointed observer Arvind Parmar.
- Multiple telecons and first face to face meeting here in Salt Lake City

Highlights, Final Report from ESA's GOAT (Gravitational Observatory Advisory Team)

- Significant U.S. participation : 3 out of 10 members are from U.S. institutions (Kasevich/Stanford, Klipstein/JPL and Mueller/UF) plus NASA observer Tuck Stebbins
- Final report is now released by ESA and available on the (3/28/2016). Highlights include:
  - Favors laser interferometry, 3 identical ... mission lifetime and at least interme... million km considered)
  - The technical ... are significant but should not be overe...
  - Four ...ority, high mission impact technologies not covered by LISA Pathfinder are identified:
    - Optical architecture
    - Telescope
    - Laser
    - Optical bench
  - Decline in data analysis activities (funded by member states) identified as a potential risk for the mission

This report is publicly available.
http://www.cosmos.esa.int/web/goat

Athena

Advanced Telescope for High Energy Astrophysics

- ESA L-class mission with NASA participation.
- Launch date: 2028
- Large X-ray mirror, X-IFU and WFI instruments.
- 10x Chandra area, 100x improved non-dispersive spectral resolution, 5x FOV.
- NASA budgeting for a $100M-$150M hardware contribution, plus a US GO program and a US data center.
- NASA will provide the sensor array for the X-ray Integral Field Unit (calorimeter)
- NASA and ESA are discussing other possible NASA contributions, such as:
  - A contribution to the WFI.
  - Use of the NASA XRCF for Calibration.
  - Contribution to science data center (U.S. node)

X-ray Surveyor
Large Mission Concept Study

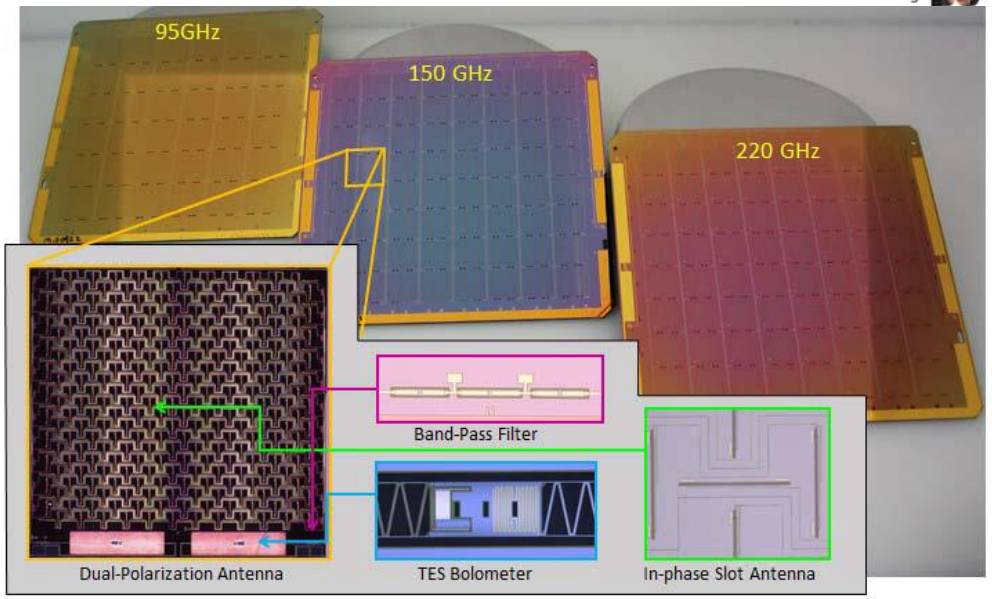
- **NASA-commissioned concept studies (2016-2018):**
  - Far Infrared Surveyor (COR)
  - Habitable Exoplanet Imaging Mission (ExEP)
  - Large Ultraviolet, Optical, and Infrared Surveyor (COR)
  - **X-ray Surveyor (PCOS)**
- **The four Large Mission Concept Studies will inform the 2020 NRC Decadal Survey.**
- Studies are to deliver to the Decadal Survey Committee compelling and executable concepts so that the science of all four large missions can be adequately prioritized by the 2020 Decadal Survey.
- X-ray Surveyor STDTs appointed March 2016: Chairs: Feryal Ozel (Arizona) & Alexey Vikhlinin (SAO), MSFC is study center (Jessica Gaskin, MSFC Study Scientist)

Medium-size (Probe) Mission in PCOS: The Inflation Probe

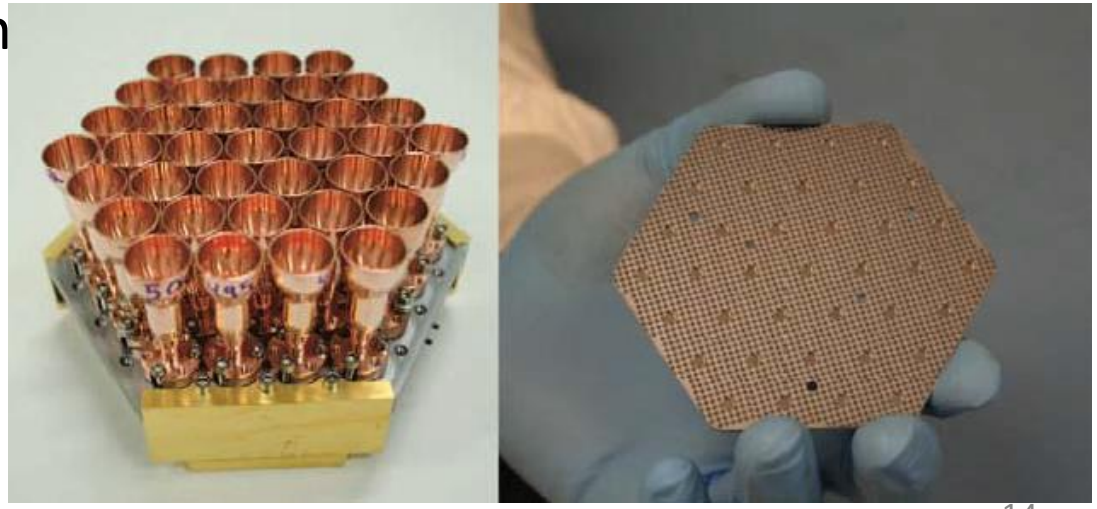
- **Prime measurement: B-mode polarization of the Cosmic Microwave Background arising from primordial gravitational waves**
- **An Inflation Probe is the 2nd ranked medium-scale mission in decadal survey**
- **Main NASA-funded activity is the suborbital balloon program and the PCOS SAT program.**
- **Ed Wollack speaks after this.**

PCOS Strategic Astrophysics Technology (SAT) activities for the Inflation Probe

- Planar Antenna-Coupled Superconducting Detectors for CMB Polarimetry, **P.I. Jamie Bock**



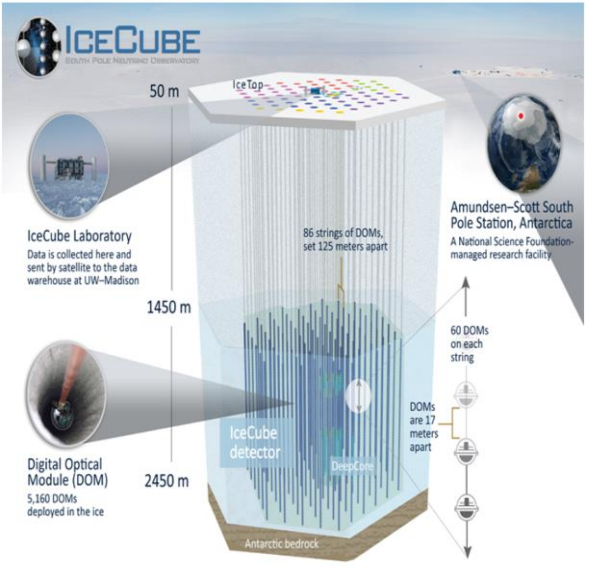
- High-efficiency Feedhorn Coupled TES-based Detectors for CMB Polarization, **P.I. Ed Wollack**

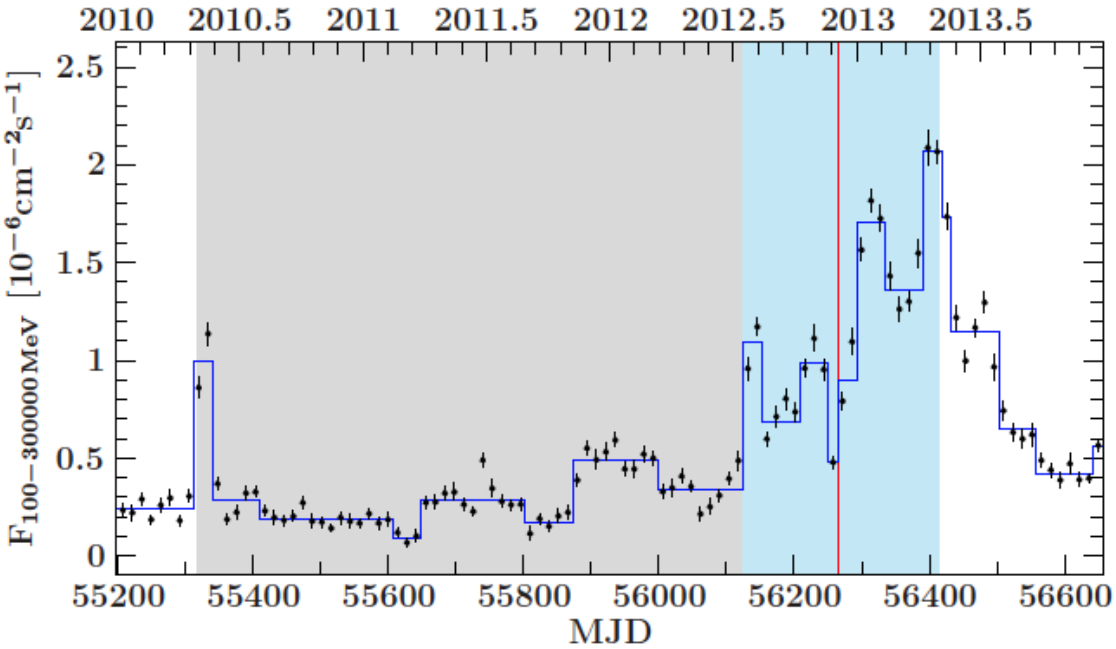


Fermi:

Powerhouse of multi-messenger astronomy

The physical process that produces high energy neutrinos also produces high energy gamma-rays





Gamma-ray lightcurve for PKS 1424-418 showing large outburst positionally and temporally consistent with the third PeV neutrino seen by IceCube (red line)

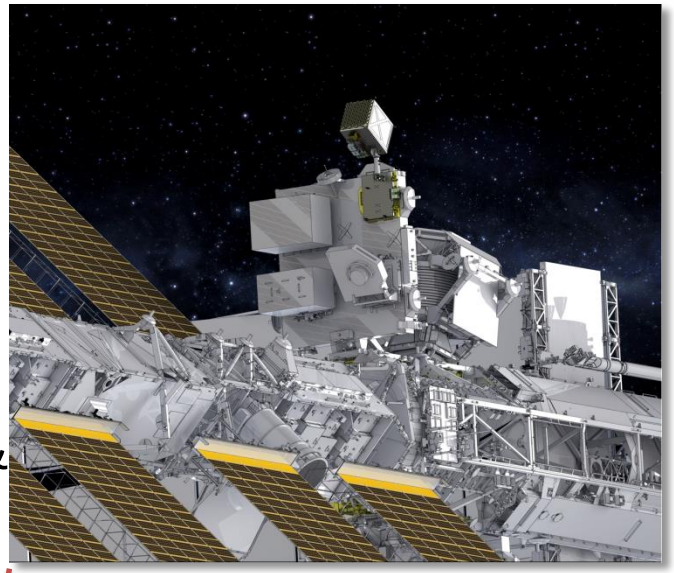
Fermi has found the first plausible association between the highest energy neutrino observed and a dramatic gamma-ray flare of the active galaxy PKS 1424-418.

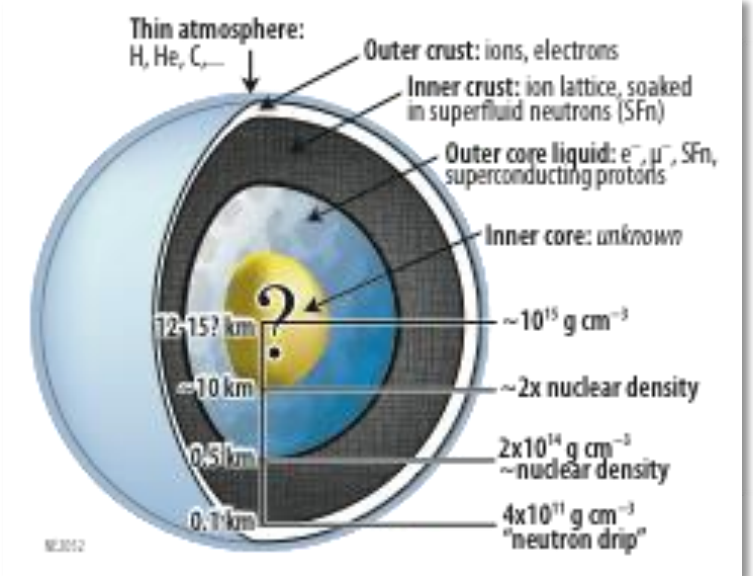
Smaller Activities in PCOS: Suborbital and ISS activities

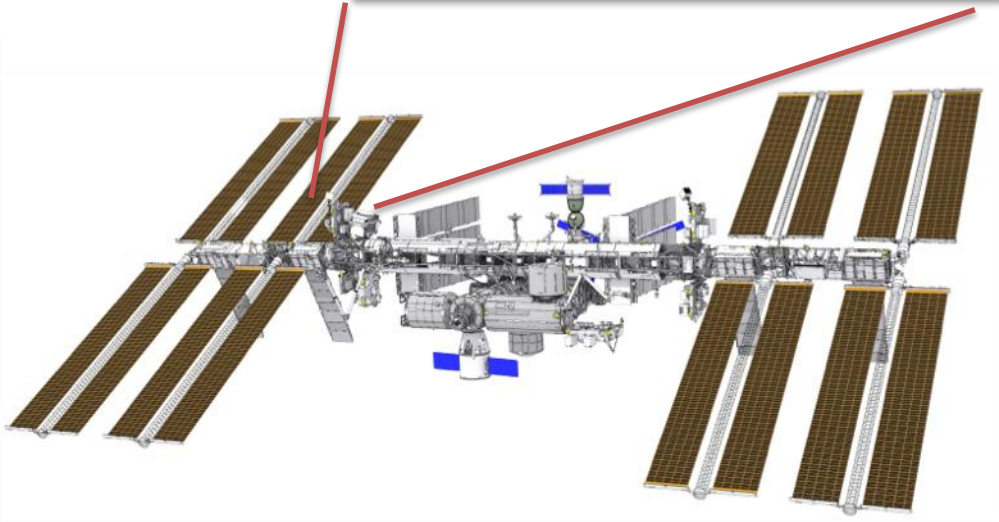
- **Too many PCOS-related experiments on suborbital and International Space Station (ISS) platforms to cover in one talk!**
- **Two highlights going to the ISS:**
  - NICER and ISS-CREAM, launching in 2017

NICER
(Neutron star Interior Composition ExploreR)

- *PI: Keith Gendreau, NASA GSFC*
- ***Science:*** Understanding ultra-dense matter through observations of neutron stars in the soft X-ray band
- ***Launch:*** January 2017, SpaceX-11 resupply
- ***Instrument:*** X-ray (0.2–12 keV) "concentrator" optics and silicon-drift detectors. GPS position & absolute time reference



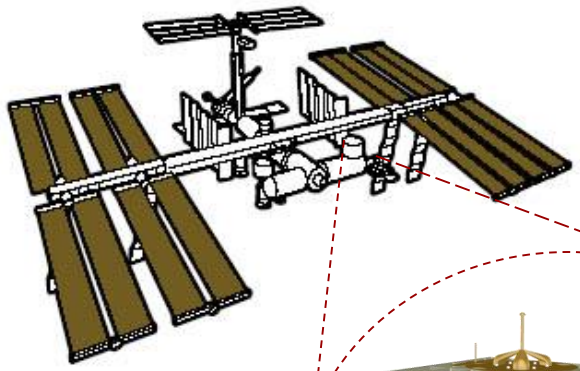


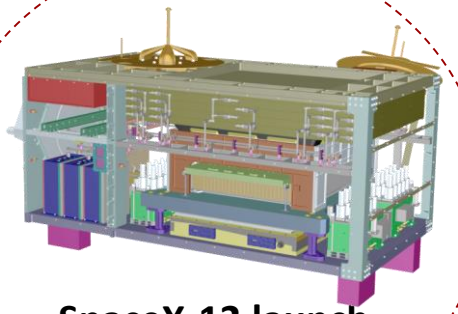


ISS-CREAM (CREAM for the ISS)

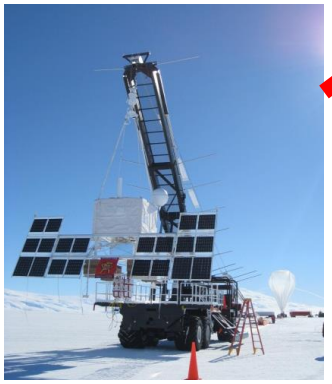
Cosmic Ray Energetics And Mass (CREAM)

- P.I.: Eun-suk Seo, Univ. of Maryland
- CREAM measures the energy spectra from 10^{12} to $>10^{15}$ eV over the elemental range from protons to iron.
- Building on the success of the balloon flights, the payload has been transformed for accommodation on the ISS (based on an APRA proposal).
- It extends the energy reach of direct measurements of cosmic rays to the highest energy possible to probe their origin, acceleration and propagation.





SpaceX-12 launch
April 2017



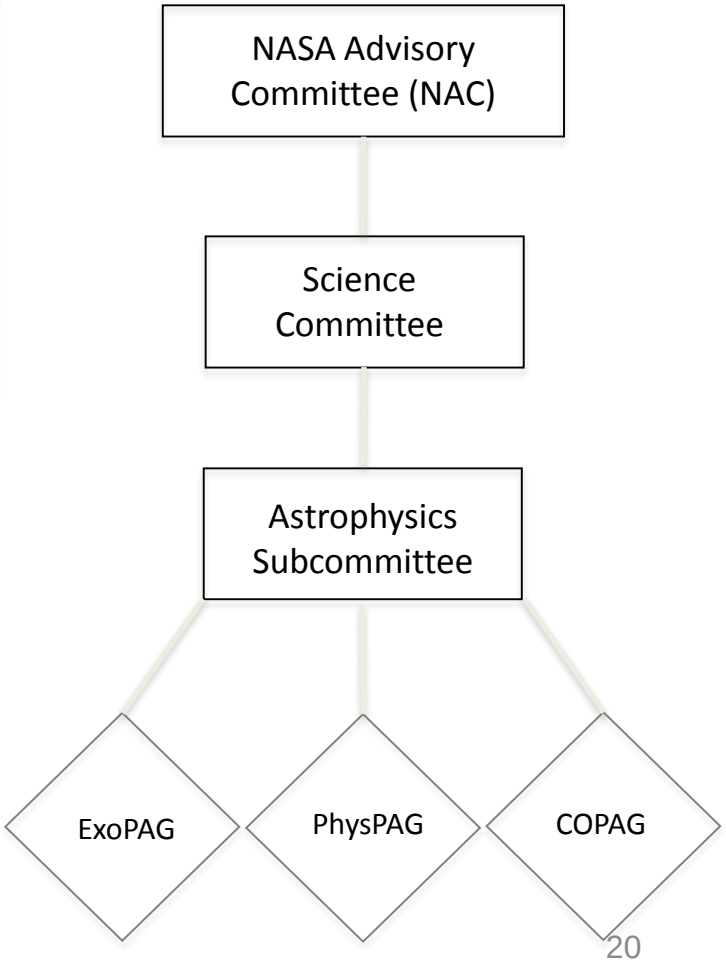
Increase the exposure by an order of magnitude

How can you interact with NASA's Physics of the Cosmos program?

Communicating with NASA Astrophysics via the Program Analysis Groups (PAGs)

- The Physics of the Cosmos Program Analysis Group (PhysPAG) serves as a forum for soliciting and coordinating input and analysis from the scientific community in support of the PCOS program objectives.
- The Program Analysis Groups (PAGs) include all members of the community interested in providing input to NASA on issues of strategic importance via analysis studies
- PAGs hold regular public meetings.
- PAGs identify specific, well-defined topics for further detailed studies assigned to Study Analysis Groups (SAGs) as well as longer-standing, discipline-centered analysis groups – Science Interest Groups (SIGs). All are task forces of volunteers.

Advisory Committees



PhysPAG Executive Committee Membership

- **Six SIGs in operation for the Inflation Probe, Gamma Rays, Cosmic Rays, Gravitational Waves, X-rays & Cosmic Structure**
- **Call for applications in Fall 2016**

Name	Affiliation	Area of Expertise	Term Ends
J. Bock, Chair	Caltech/JPL	CMB	Dec 2016
M. Bautz	MIT	X-ray astrophysics	Dec 2016
R. Bean	Cornell University	Dark Energy	Dec 2016
N. Cornish	Montana State University	Gravitational Waves	Dec 2016
M. McConnell	Univ. of New Hampshire	Gamma-ray astrophysics	Dec 2016
Eun-Suk Seo	Univ. of Maryland	Particle astrophysics	Dec 2016
J. Conklin	Univ. of Florida	Gravitational Waves	Dec 2017
O. Doré	JPL	Dark Energy	Dec 2017
H. Krawczynski	Washington University	Gamma-ray astrophysics	Dec 2017
A. Miller	Columbia University	CMB	Dec 2017
E. Wollack	NASA/GSFC	CMB	Dec 2017
I. Moskalenko	Stanford University	Particle astrophysics	Dec 2018
R. Kraft	SAO	X-ray astrophysics	Dec 2018

What the PhysPAG has been doing recently: flagship missions & probes

- In 2015 NASA Astrophysics Director Paul Hertz charged all 3 Program Analysis Groups (PAGS: Physics of the Cosmos, Cosmic Origins, and Exo-planets) to recommend large missions that should be studied in preparation for the 2020 Decadal Survey.

- In October 2015, the PAGS unanimously recommended four large missions for study; each now has a Science and Technology Definition Team.

- In response to community input, the PAGs also recommended that NASA study somewhat smaller missions ("Probe"-class, costing ~$1B) in preparation for the Decadal Survey

PhysPAG Probe Findings (#1)

We find broad and enthusiastic support in the PCOS community for furthering the development of probe-class missions, conceived as a new large mission class of the PI-led competed missions in the Explorer program.

- As an example of this enthusiasm, the PhysPAG received 14 white paper concepts from the community (in less than 30 days!) spanning PCOS science themes.

Summary of PCOS Probe White Papers (1/2)

Name	First Author	Type	Spectral Range	Science	Cost	Launch & ops?
High-Energy X-Ray Probe (HEX-P)	F. Harrison	X-ray	2--200 keV	Resolve X--Ray background, evolution of black hole spin, faint X-ray populations in nearby galaxies	$500M	Included
A Wide-Field X-Ray Probe	A. Ptak	X-ray	~1-10 keV	Measure mass and spatial distribution of clusters and AGN, define LF of AGN	$540M / $740M	Not included
An X-Ray Grating Spectroscopy Probe	R. McEntaffer	X-ray	5-50 Angstrom	Role of SMBH feedback in galaxy formation, distribution of hot baryons, characteristics of Galaxy's hot halo, GW counterparts	$784M	Included
AMEGO: A Medium--Energy Gamma-Ray Surveyor	J. McEnery	Gamma-ray	0.2 MeV -10 GeV	Time--domain GW counterparts, improved MeV surveying, nuclear line emission	$600--$800M	Included
Advanced Particle-Astrophysics Telescope (APT)	J. Buckley	Gamma ray	100 MeV -50 GeV	Definitive dark matter search, all-sky transient survey, GW counterparts	Probe-class	Not stated
A Large Observatory for X-Ray Timing Probe (LOFT-P)	C. Wilson-Hodge	X-ray Timing	2 -30 keV	Strong gravity and BH spins, matter in neutron stars, surveying the dynamic X-Ray sky, multi-messenger studies	$770M	Included
Death of Massive Stars (DoMaS)	P. Roming	Transients	X-ray/UV/IR	Study massive stars at reionization via GRBs and SNs.	$760M	Not stated

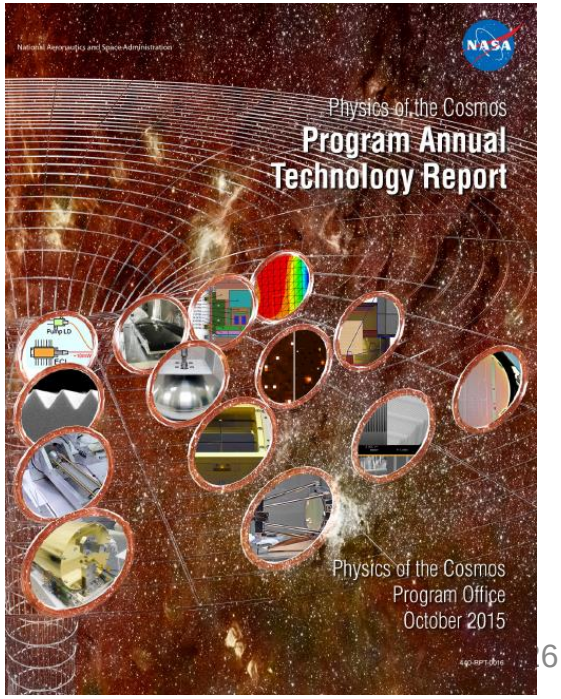
Summary of PCOS Probe White Papers (2/2)

Name	First Author	Type	Spectral Range	Science	Cost	Launch & ops?
Transient Astrophysics Probe (TAP)	J. Camp	Transients	X-ray/IR	Epoch of reionization from high-z GRBs and SNs, survey of the X-Ray sky, GW counterparts	$750M	Included
The Time-Domain Spectroscopic Observatory (TSO)	J. Grindlay	Transients	0.4 -5 um	Epoch of reionization from high-z GRBs studies, growth of SMBHs over cosmic time, GW counterparts, transient discoveries	$650M	Included
GreatOWL: A Space-Based Mission for Charged-Particle and Neutrino Astronomy	J. Mitchell	Cosmic Ray	--	Nature of ultra-high energy cosmic rays, GZK-induced neutrinos	$540M	Not included
The Inflation Probe	NASA IPSIG	CMB	30 -300 GHz	Inflationary gravitational wave background, reionization, large-scale structure, neutrinos	Probe-class	Not stated
Probe-Class Mission Concepts for Studying mHz Gravitational Waves	M. Tinto	Gravitational-wave	1 mHz-10 Hz	Spiraling massive and super-massive black holes, BH formation, tests of strong gravity,distribution of white dwarf binaries	$560M / $900M	Not stated
A Probe-Class Gravitational-Wave Observatory	S. McWilliams	Gravitational-wave	1 mHz-10 Hz	Massive BH binary mergers, stellar-mass BH and NS mergers, probe dark energy via z-L measurements	$830M-$1.2M	Included
99 Luftballons	T. Eifler	UV/Optical	270-1000 nm	Nature of dark energy, neutrino masses, tests of gravity	Not stated	ULDB

PCOS community activities

- Encourage your finishing students and early-career postdocs to apply for the Einstein fellows' program
  - Einstein Fellows hold their appointments at a Host Institution in the U.S. for research that is broadly related to the science goals of the NASA Physics of the Cosmos program.
- The PhysPAG provides input on technology needs to the PCOS program office that are fed into the PCOS Annual Technology Report (PATR) each year.

Wen-fai Fong, 2014 Fellow



Keeping up with PCOS

- http://pcos.gsfc.nasa.gov
- **View the latest newsletter.**
- **Sign up to the PCOS email list.**
- **Sign up to be included on SIG emails.**
- **Members of NASA PCOS Team include:**
  - At GSFC:
    - Ann Hornschemeier
    - Peter Bertone
  - At HQ:
    - Dan Evans
    - Rita Sambruna
    - Wilt Sanders

National Aeronautics and Space Administration

Physics of the Cosmos Newsletter

August 2015 Vol. 5 No. 1

Physics of the Cosmos Program Update

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

This year, 2015, marks the Centennial of General Relativity and the Physics of the Cosmos (PCOS) program is looking forward to the launch of LISA Pathfinder, currently for November 25, 2015 (see Ira Thorpe's article). General Relativity was a theme at the American Physical Society (APS) meeting in Baltimore, MD in April 2015 and we were happy to host the first-ever PCOS table at an APS meeting. At the APS, the new "Century

Contents

NASA's Chandra Captures X-Ray Echoes Pinpointing Distant Neutron Star

Astronomers using NASA's Chandra X-ray Observatory have discovered the largest and brightest set of rings from X-ray light echoes ever observed. These extraordinary rings, produced by an intense flare from a neutron star, provide astronomers a rare chance to determine how far across the Milky Way galaxy the star is from Earth.

The rings appear as circles around Circinus X-1, a double star system in the plane of our galaxy containing a neutron star, the dense remnant of a massive star pulverized in a supernova explosion. The neutron star is in orbit with another massive star, and is shrouded by thick clouds of interstellar gas and dust. Circinus X-1 is also the source of a surprisingly powerful jet of high-energy particles.

The light echo shows that Circinus X-1 is located about 30,700 light years from Earth, and settles the difference in results published in prior studies. The detection and characterization of the rings required the unique capabilities of Chandra—the ability to detect fine details combined with sensitivity to faint signals.

Circinus X-1, containing a neutron star—the collapsed core left behind after a star exploded—in orbit with a massive star. The Chandra data reveal a set of four rings that appear as circles around Circinus X-1. These rings can be seen in the composite image where X-rays from Chandra are red, green, and blue corresponding to low, medium, and high-energy X-rays respectively, which have been combined with a view in visible light from the Digitized Sky Survey. Credit: X-ray: NASA/CXC/Univ. of Wisconsin-Madison/S. Heinz et al; Optical: DSS

By comparing the Chandra data to prior images of dust clouds detected by the Mopra radio telescope in Australia, the researchers determined that each ring was created by the X-ray reflections off a different dust cloud. The radio data provides the distance to the different clouds and the X-ray echo determines the location of Circinus X-1 relative to the clouds. An analysis of the rings with the combined radio data allows researchers to use simple geometry to accurately determine the distance of Circinus X-1 from Earth.

"We like to call this system the 'Lord of the Rings,' but this one has nothing to do with Sauron," said co-author Michael Burton of the University of New South Wales in Sydney, Australia. "The beautiful match between the Chandra X-ray rings and the Mopra radio images of the different clouds is really a first in astronomy."

Read the full press release at http://chandra.harvard.edu/press/15_releases/press_062315.html

Upcoming PCOS/PhysPAG Community Interaction Opportunities

- **Full list of upcoming SIG meetings on website.**
- **January 2017 Grapevine, TX AAS**
  - Half-day PhysPAG meeting
  - SIG meetings
  - Reports from NASA's Program Analysis Groups
  - PCOS Table in NASA HQ SMD area
- **January 2017, APS meeting in Washington, D.C.**
  - There may be an Astrophysics Town Hall, APS Version
  - PCOS mini-symposium and SIG focus sessions
  - PCOS Table
- **MORE INFO: pcos.gsfc.nasa.gov/physpag**

And don't forget your next schedule issue at 10:45AM: the SIG sessions

- **J11 : Inflation Probe Science Interest Group**
  - Room 250C
- **J12 : Gravitational Wave Science Interest Group**
  - Room 250DE
- **J13 : Cosmic-Ray Science Interest Group**
  - Room 250F

- **Charts for –this- session and all three SIG sessions will be on the PCOS website starting tomorrow.**

THANK YOU

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THANK YOU

BACK-UP SLIDES

NASA's Plans for a GW Observatory

(Source: P. Hertz Astrophysics Subcommittee briefing March 2016)

Implications of the LIGO detection and announcement: it is about funding and priorities and timing.

- **Either we do a US-led LISA, or we participate in ESA's L3 gravitational wave observatory. If we do a US-led LISA:**
  - We are not doing it before WFIRST, because the Decadal Survey said WFIRST was the higher priority.
  - We would not change this unless the 2020 Decadal Survey tells us to do US-led LISA after WFIRST rather than one of the four large mission concepts that we are beginning to study.
  - ESA plans to launch L3 in 2034.
- **Possible outcomes from the 2020 Decadal Survey :**
  - Continue on the path we are on for a $150M share of L3 in 2034.
  - Increase our share scientifically and technologically, subject to ESA approval. This would require the Decadal Survey to allocate a medium-size mission priority to a US share in L3. This gets a better L3 at the expense of not doing something else in the NASA portfolio.
- **By the time of the 2020 Decadal Survey, we will have:**
  - Outcome of LISA Pathfinder (so far so good).
  - Another 4 years of LIGO results to inform our priorities for GW observatories beyond LIGO.

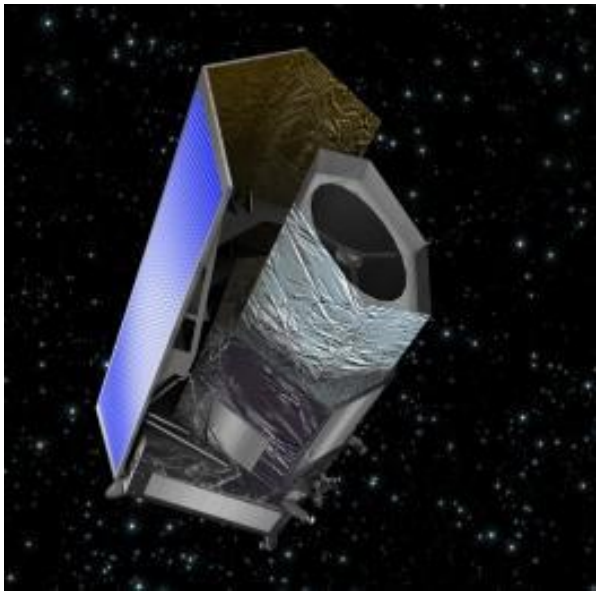
PCOS-Related: Hitomi

- JAXA mission with substantial US instrument contributions.
  - Soft X-ray telescope mirrors (SXT-S and SXT-I)
  - X-ray Calorimeter Spectrometer Insert (CSI), including Adiabatic Demagnetization Refrigerator (ADR) and ADR Controller
  - Aperture Assembly
  - X-ray Electronics Box (X-box)
  - High Temperature Superconducting Leads
- Launched: Feb 17, 2016.
- JAXA found that communication with the X-ray Astronomy Satellite "Hitomi" (ASTRO-H), launched on February 17, 2016 (JST), failed from the start of its operation originally scheduled at 16:40, Saturday March 26 (JST).
- JAXA has set up emergency headquarters, headed by the President, for recovery and investigation.
- JAXA is leading the investigation and is consulting with NASA from a technical and policy perspective.
- NASA fully supports JAXA and stands prepared to assist as requested going forward.

Euclid Science Objectives (Launch: Dec 2020)

Euclid will measure the expansion history and growth of large-scale structure :
goal is to distinguish time-evolving dark energy models from a cosmological constant, and to test the theory of gravity on cosmological scales.

- 15,000 square degree survey, with near-IR imaging and spectroscopy
- NIR focal plane needed for redshifts for millions of galaxies



NASA delivering flight hardware to ESA in March 2017:
the Near Infrared Spectrograph and Photometer (NISP) flight focal plane subassemblies

U.S. Science Participation in Euclid

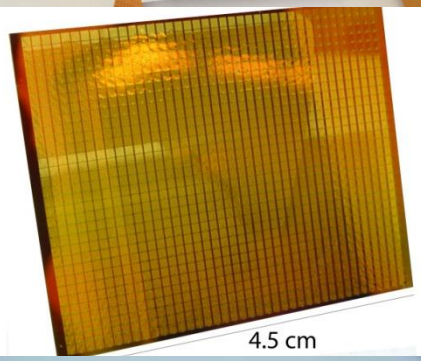
- **Three science teams:**
  - "Precision Studies of Galaxy Growth and Cosmology Enabled Through a Physical Model for Nebular Emission", PI Chary (Caltech)
  - "Looking at Infrared Background Radiation Anisotropies with Euclid", PI Kashlinsky (GSFC)
  - Constraining Dark Energy and Gravity with Euclid", PI Rhodes (JPL)
- **Jason Rhodes - member of Euclid Consortium Board and ESA Euclid Science Team**
- **Michael Seiffert - Project Scientist and participant in Euclid Consortium**

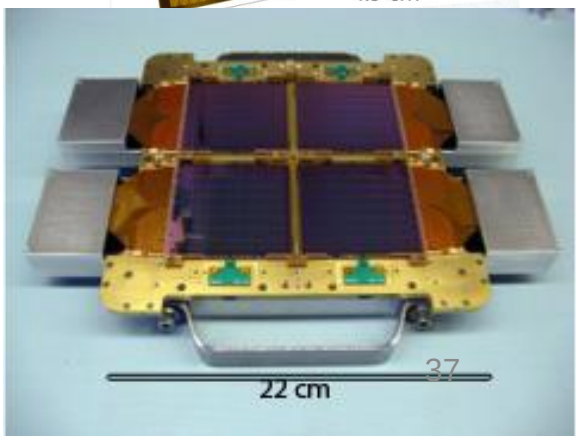
Euclid NASA Science Center @ IPAC

- **IPAC = Infrared Processing and Archive Center at JPL/Caltech**
- **ENSCI led by Harry Teplitz, IPAC**
- **ENSCI requirements signed July 2015:**
  - covers U.S. community support, Archiving of Detector Characterization Data and a US Science Data Center (SDC-US), part of Euclid SGS

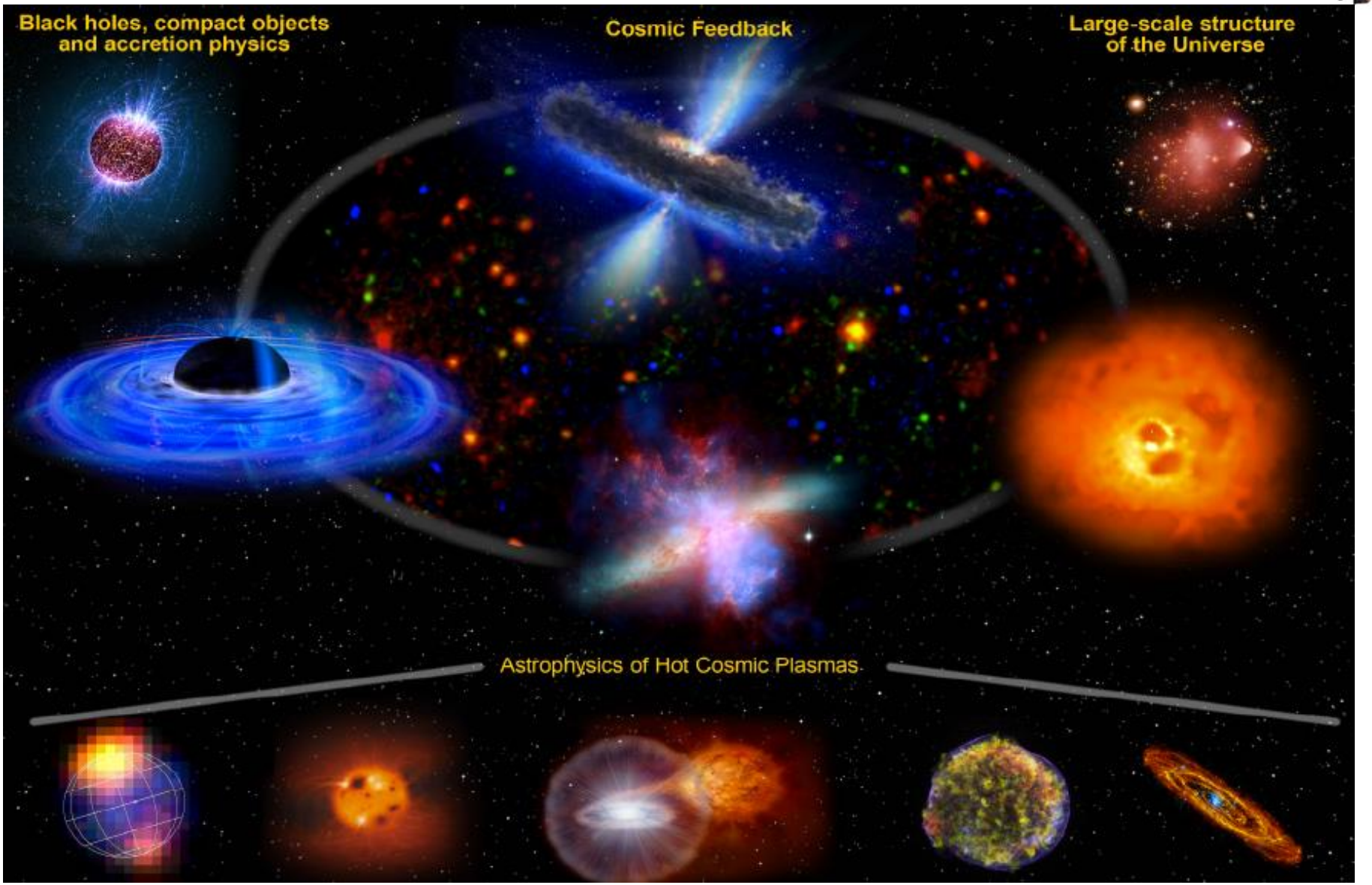
CMB Polarization from Space, Balloons

- **Note: APRA balloon experiments are "outside PCOS" programmatically.**
- **Currently NASA supports three balloon-borne experiments that probe the polarization properties of the CMB covering 90-600 GHz with Transition-Edge (TES) bolometers with different polarimetric approaches :**
  - 2012: E and B experiment (EBEX; P.I. Hanany)
  - Jan 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)





Athena science (credit: ESA)



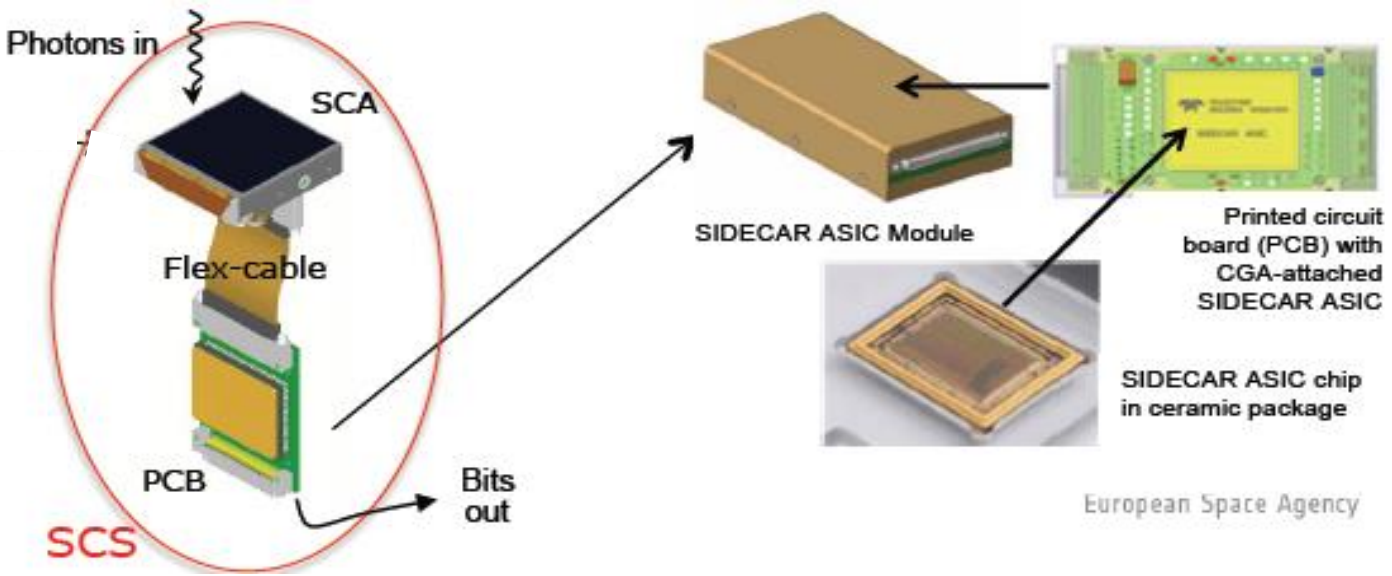
US Athena Team Involvement

- **Athena Science Study Team**
  - Chartered by ESA (10 members)
  - Randall Smith, US member
- **ASST Science Working Groups**
  - Set up by ASST
  - Now 119 US members
  - 24 selected for NASA travel funding
- **NASA hosts annual meetings of US SWG co-Chairs, presentations on PCOS website.**

- Proposals Summer 2016
- Athena X-IFU
  - PI Didier Barret, IRAP
  - Rich Kelley, GSFC, US co-I
  - Jon Miller, Science Team
  - TBD Proportional access to Science Team.
  - Access to GTO time
- Athena WFI (under discussion)
  - PI Kirpal Nandra, MPE
  - David Burrows, PSU, possible US co-I

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**



L3 NASA Study Activities (http://pcos.gsfc.nasa.gov/studies/L3)

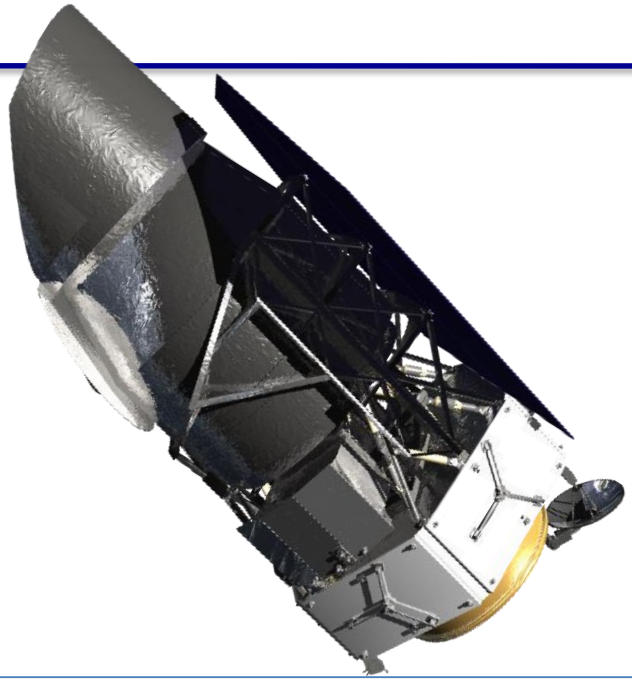
- **The purpose of the L3 Study is to understand how NASA might participate in ESA's L3 gravitational wave mission, to inform NASA's engagement through the mission's earliest stages, and to prepare for the 2020 decadal survey.**

Structure of the study:

- **<u>Phase 1 (FY16-17)</u>: Analyze the options for NASA participation in the L3 mission and work with the European L3 consortium on proposals to ESA.**
- **<u>Phase 2 (FY17-18):</u> Prepare a report to the 2020 decadal survey on NASA's participation, including possible options, in the L3 mission as a minority partner**

WFIRST** (Note: In Exoplanets Program)

Wide-Field Infrared Survey Telescope



Wide-Field 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 L2; using existing hardware, images 0.28deg^2 at 0.8-2μm

Instruments (design reference mission): Wide Field Instrument (camera plus IFU), Coronagraph Instrument (imaging/IFS)

Phase: Currently in Formulation (Phase A)

CURRENT STATUS:

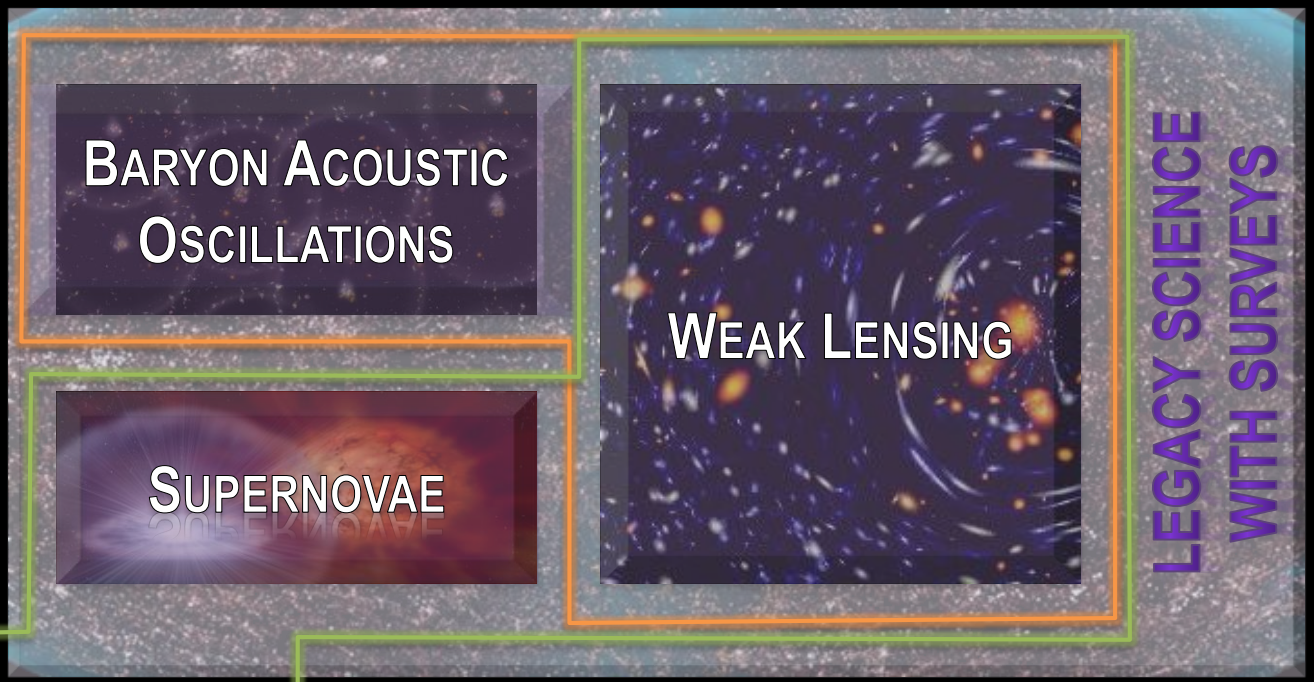
- **Mission Concept Review (MCR) December 2015**
- Formulation Science Investigation Teams selected in December 2015; first meeting held February 2016.
- Passed Key Decision Point A (KDP-A) in Feb 2016
  - Official start of formulation phase
  - Supported by FY16 appropriation and FY17 request
  - Developed and signed Formulation Authorization Document (FAD), Project Formulation Agreement (PFA), and preliminary Program Level Requirements Appendix (PLRA).
- **Schedule under revision to account for FY16 appropriation of $90M and FY17 budget request of $90M. Notional runout of FY17 budget request provides budget supporting launch in mid-2020s.**

WFIRST has begun Formulation

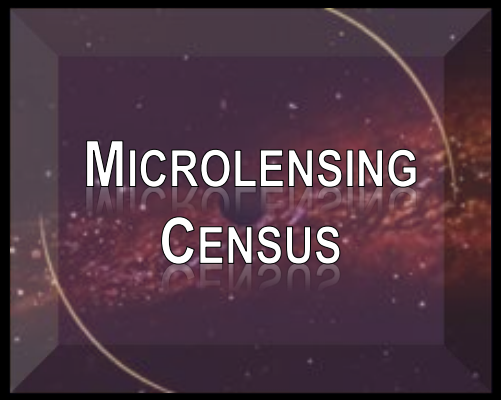
http://wfirst.gsfc.nasa.gov/

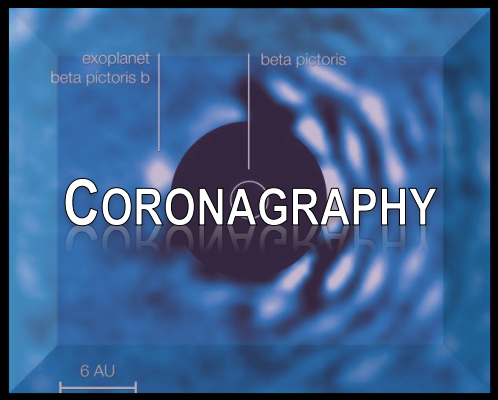
WFIRST Science (from N. Gehrels)

complements Euclid



complements LSST





continues Great Observatory legacy