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

Mark Bautz
MIT
PCOS Program Analysis Group Chair

Special thanks to:
Ann Hornschemeier, NASA’s GSFC
PCOS Program Chief Scientist

pcos.gsfc.nasa.gov
Where does Physics live at NASA?
Prioritization from Astro2010 Decadal Report

Astro2010 science themes map to the Astrophysics Division themes:

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

PCOS Science Objectives reflect the highest priority Physics of the Universe science:

**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 test General Relativity using X-ray emission and gravitational waves.
Physics of the Cosmos Science Objectives

- Increase 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

Chandra
XMM
Fermi
LISA Pathfinder

PCOS-RELATED

NuSTAR
Swift
The near future: PCOS missions in development

- Three of seven projects in development during FY17 are in the PCOS portfolio: NICER, ISS-CREAM and Euclid. A fourth, IXPE, is PCOS-related.

**NICER**  
NASA Mission  
Neutron Star Interior Composition Explorer

**CREAM**  
NASA Mission  
Cosmic Ray Energetics And Mass

**Euclid**  
ESA-led Mission  
NASA is supplying the NISP Sensor Chip System (SCS)
Provide scientific and technical stewardship for decadal-survey recommended missions:

• 3 of the 6 highly-ranked medium and large-scale space-based priorities in NWNH fall within the PCOS science program:
  o LISA (Gravitational Waves)
  o IXO (X-ray)
  o Inflation Probe (mid-scale)

2016 update includes:
• Response to Midterm Assessment
• Planning for 2020 Decadal Survey
Future Large Missions in PCOS: Athena, LISA and Lynx

• ESA Cosmic Vision program (2016-2035):
  – Athena/L2 (launch 2028) will be an X-ray observatory following the Hot and Energetic Universe theme
  – LISA/L3 (launch 2034) will be a gravitational wave observatory following the Gravitational Universe theme.

• Athena is in Phase A (formulation) with NASA participation

• Large mission studies in PCOS (preparation for 2020 Decadal)
  – NASA “L3 Study” recommended and will prepare case for NASA participation in LISA
  – Lynx (néé X-ray Surveyor) Study Team is preparing case for NASA development of a next-generation large X-ray Observatory (Lynx)

• After this talk: John Conklin (LISA) & Ralph Kraft (Athena and Lynx)
**Athena: Advanced Telescope for High Energy Astrophysics**

**CURRENT STATUS**
- Currently in 2-year Study Phase.
- NASA budgeting for a $100M-$150M hardware contribution, plus a U.S. GO program and a U.S. data center.
- NASA will contribute to both the X-IFU and the WFI instruments.
- NASA and ESA are discussing other possible NASA contributions to the observatory.
- NASA and U.S. community involvement in Athena Science Study Team (including its SWG) and Instruments facilitated via series of RFI and CAs.
- Athena team will expand at Adoption in 2020; NASA anticipates this will provide an opportunity to expand U.S. community involvement.

**Second ESA Cosmic Vision Large mission**
- L-class with NASA/JAXA participation
- Decadal Survey recommendation
- Large X-ray mirror, X-ray Integral Field Unit (XIFU) and Wide Field Imager (WFI) instruments

**Launch Date:** 2028

**Breakthrough Capabilities:**
- High Throughput, High spectral resolution X-ray Astronomy, Wide FOV
- 10x Chandra area, 100x improved non-dispersive spectral resolution, 5x FOV.

**Enabling Technologies:** Silicon pore optics, 3000+ pixel μ-calorimeter (XIFU), large DEPFET array (WFI)

**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?

www.the-athena-x-ray-observatory.eu
LISA Pathfinder ST-7/Disturbance Reduction System (DRS)

CURRENT STATUS:
- LISA Pathfinder completed nominal ESA science operation on June 25, 2016
- NASA’s DRS successfully completed its planned experiments and technology demonstration on December 7, 2016, ending the prime mission.
- Extended mission started December 8, 2016 and will continue into early 2017.
- LISA Pathfinder exceeded requirements and demonstrated critical technologies and systemic controls needed for a LISA-like gravitational wave observatory.

- 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
- Launched: December 3, 2015 GMT
- LPF prime mission: 7 months
- Data Analysis: 12 months

http://sci.esa.int/lisa-pathfinder/
• L3 Study Team (D. Shoemaker, Chair) delivered Interim Report on options for NASA participation in ESA’s L3 mission delivered June 20, 2016.

• The report identifies the major areas of interest for the US for gravitational wave technology development and provides an analysis of their respective benefits and limitations.

ATTENTION!
The L3 Study Team is holding an open meeting, immediately after APS, Tuesday afternoon and Wednesday morning. Details at link below.

http://pcos.gsfc.nasa.gov/studies/L3/
NASA is studying four large mission concepts for consideration by the 2020 Decadal Survey.

Origins Space Telescope

- Tracing the Signatures of Life and the Ingredients of Habitable Worlds
- Unveiling the Growth of Black Holes and Galaxies over Cosmic Time
- Charting the Rise of Metals, Dust, and the First Galaxies
- Characterizing Small Bodies in the Solar System

Lynx (PCOS)

- The Origin and Growth of the First Supersmassive Black Holes
  - What is their origin?
  - How do they co-evolve with galaxies and affect their environment?

LUVOIR

- Astrometry
- Exoplanets
- Cosmic Origins
- Solar System

- LUVOIR’s unprecedented resolution will resolve 1 arc-sec sized star forming regions of galaxies at distances up to 10-25 Mpc, providing an unprecedented view of the structure and composition of non-Earth-like planets, and image faint companion disks to provide insights into how planets form.

- LUVOIR will identify the first stars in the early universe, uncover the archaeology of early galaxies, and find the first black holes.

HabEx

- The primary goal of Nexus is to image and study exoplanet atmospheres. However, it will also observe the full range of exoplanets within four major regions:
  - Exoplates: hot Jupiters
  - Anematics: planetesimal systems
  - Solar Systems: extrasolar systems

Galaxy Evolution and the Growth of the Cosmic Structure

- Structure of the Cosmic Web through observations of hot IGM in emission
- How did the "universe of galaxies" emerge from initial conditions?
Lynx science drivers

The Origin and Growth of the First Supermassive Black Holes

What is their origin?

How do they co-evolve with galaxies and affect their environment?

Galaxy Evolution and the Growth of the Cosmic Structure

Structure of the Cosmic Web through observations of hot IGM in emission

How did the “universe of galaxies” emerge from initial conditions?

Lynx Study Leads: F. Ozel, A. Vikhlinin, J. Gaskin

https://wwwastro.msfc.nasa.gov/lynx/
Medium-size (Probe) Missions in PCOS: The Inflation Probe

- Prime measurement: B-mode polarization of the Cosmic Microwave Background arising from primordial gravitational waves
- The 2\textsuperscript{nd} ranked medium-scale mission in the 2010 decadal survey
- Main NASA-funded activities are via balloon & PCOS SAT programs, e.g..

Planar Antenna-Coupled Superconducting Detectors for CMB Polarimetry. \textbf{P.I. J. Bock}

High-efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization. \textbf{P.I. Ed Wollack}
Probe Studies for the 2020 Decadal Survey

• **Astrophysics Probe: total lifecycle cost $400M to $1B**
  • NASA solicited mission concepts for funded studies in preparation for the 2020 Decadal Survey
  • 27 compliant study proposals received in all areas of astrophysics; Many of these are for PCOS concepts

• **Next Steps**
  • Selection of 5-8 concept studies expected in February 2017
  • Community workshop/interim reports due at the Winter 2018 AAS meeting
  • Final reports due to NASA in September 2018

• **NASA will submit the final reports and NASA cost assessments to the 2020 Decadal Survey**
Fermi-LAT discovery of the most distant gamma-ray blazars

- Distant blazars known to be exceptionally bright, with powerful jets and home to massive Black Holes
- X-ray and gamma-ray data suggest they are brightest in the ‘MeV’ band, just below the Fermi LAT energy range
- 5 new gamma-ray blazars by Fermi-LAT at z>3, two of which have >10^9 M_\text{sun}
- Enabled by improved performance following revamped data processing software
- Challenges models of supermassive black hole formation

Fermi Guest Investigator program deadline Feb 24
see http://fermi.gsfc.nasa.gov/ssc
Suborbital and ISS activities in PCOS

• 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:** April 2017, SpaceX-11 resupply

• **Instrument:** X-ray (0.2–12 keV) “concentrator” optics and silicon-drift detectors. Microsecond timing, GPS position & absolute time reference
• 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
June 2017

Increase the exposure by an order of magnitude
How can you interact with NASA’s Physics of the Cosmos program?
Program Analysis Groups (PAGs): Community Input to NASA Astrophysics

- Program Analysis Groups (PAGs) are open community groups
- Purpose of PAGs: NASA / community communication
- There are three NASA Astrophysics PAGs:
  - Physics of the Cosmos PAG (PhysPAG)
  - Cosmic Origins PAG (COPAG)
  - Exoplanets PAG (ExoPAG)
- The Physics of the Cosmos Program Analysis Group (PhysPAG) communicates with NASA about PCOS program science & goals
- PhysPAG has Six Science Interest Groups:
  - Cosmic Rays (CosmicSIG)
  - Cosmic Structure (CosSIG)
  - Gamma-ray Astrophysics (GAMMASIG)
  - Gravitational Waves (GWSIG)
  - Inflation Probe (IPSIG)
  - X-ray Astrophysics (XRSIG)
- All are welcome to participate:

pcos.gsfc.nasa.gov
# PhysPAG Executive Committee Membership

- Six SIGs in operation for the Inflation Probe, Gamma Rays, Cosmic Rays, Gravitational Waves, X-rays & Cosmic Structure

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<th>Term Ends</th>
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<td>J. Conklin (Vice Chair)</td>
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<td>O. Doré</td>
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<td>A. Miller</td>
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<td>E. Wollack</td>
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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 broadly related to PCOS science goals
• The PhysPAG provides input on technology needs that influences NASA priorities for technology development funding.
• These priorities are published in the PCOS Annual Technology Report (PATR).
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 NASA GSFC:
    - Ann Hornschemeier
    - Terri Brandt
  • At NASA HQ:
    - Rita Sambruna
    - Dan Evans
    - Wilt Sanders
PhysPAG SIG sessions later today!

- **J4 : Cosmic Ray Science Interest Group I**
  - 10:45am Room Virginia A
- **K4: Cosmic Ray Science Interest Group II**
  - 1:30pm, Room Virginia A
- **K5 : Gravitational Wave Science Interest Group Mini-Symposium**
  - 1:30pm Room Virginia B
- **K9 : Gamma-Ray Science Interest Group Mini-Symposium**
  - 1:30pm Room Roosevelt 1

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

mwbc@space.mit.edu
Ann.Hornschemeier@nasa.gov

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(Sign up for email list at “PCOS News and Announcements tab)
THANK YOU

BACK-UP SLIDES