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Physics of the Cosmos Newsletter

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Physics of the Cosmos Program Update

Terri J. Brandt, *Acting Chief Scientist*
Mansoor Ahmed, *PCOS Program Manager*
NASA Goddard Space Flight Center

Welcome to our 2017 **Physics of the Cosmos** (PCOS) Newsletter!

The PCOS program explores some of the most fundamental questions regarding the physical forces and laws of the universe: from gravitational waves and testing general relativity to better understanding the behavior of matter and energy in extreme environments, the cosmological parameters governing inflation and the evolution of the universe, and the nature of dark matter and dark energy.

This year's Newsletter focuses on PCOS's high energy particle and γ-ray astrophysics science themes, with articles on the current NASA landscape and future outlook of cosmic rays (CRs), neutrinos, dark matter, γ-rays, and the theory and modeling used to tie our understanding of these messengers together. I hope this focus will enable you to refresh and expand your view of the exciting scientific discovery space available both within and by combining information from the array of messengers now available to us. To help navigate the array, we've also included an **acronym list** for your reference.

One recent example of the exciting discovery space is the multimessenger detection of gravitational wave event GW170817 by **LIGO/Virgo**, NASA's ***Fermi*** **Gamma-ray Space Telescope**, ***Swift***, ***Hubble***, ***Chandra***, and ***Spitzer***, and dozens of ground-based observatories. It has brought a surge of interest in the power of multimessenger astrophysics to decipher the mysteries of the universe. With participation in European Space Agency's (ESA's) **Laser Interferometer Space Antenna** (LISA) mission, NASA and the PCOS program will make yet another contribution to this exciting field. The **LISA mission article** has more details.

In addition to LISA, NASA is partnering on ESA's ***Athena*** **X-ray Observatory** and ***Euclid*** optical and near infrared mission, mapping the dark universe's geometry. The ***Athena*** and ***Euclid***

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Acronyms

ACE	Advanced Composition Explorer	**HAWC**	High Altitude Water Cherenkov observatory
AdEPT	Advanced Energetic Pair Telescope	**HELIX**	High Energy Light Isotope eXperiment
AGILE	Astro-rivelatore Gamma a Immagini LEggero (γ-Ray Light Detector)	**HESS**	High Energy Stereoscopic System
AMEGO	All-sky Medium Energy Gamma-ray Observatory	**IACT**	Imaging Air Cherenkov Telescope
AMS	Alpha Magnetic Spectrometer	**ICRC**	International Cosmic Ray Conference
ANITA	ANtarctic Impulsive Transient Antenna	**IKAROS**	Interplanetary Kite-craft Accelerated by Radiation Of the Sun
ASCOT	Advanced Scintillator COmpton Telescope	**INTEGRAL**	International Gamma-Ray Astrophysics Laboratory
ATHENA	Advanced Telescope for High-ENergy Astrophysics	**IPAC**	Infrared Processing and Analysis Center
BESS	Balloon-borne Experiment with Superconducting Spectrometer	**ISEE**	International Sun Earth Explorer
CALET	CALorimetric Electron Telescope	**JPL**	Jet Propulsion Laboratory
CGRO	Compton Gamma-Ray Observatory	**LAT**	Large Area Telescope (Fermi)
COSI	COmpton Spectrometer and Imager	**LIGO**	Laser Interferometer Gravitational-Wave Observatory
CR	**Cosmic Ray**	**LISA**	Laser Interferometry Space Antenna
CREAM	Cosmic Ray Energetics and Mass	**MAGIC**	Major Atmospheric Gamma Imaging Cherenkov telescopes
CRIS	Cosmic Ray Isotope Spectrometer	**PAMELA**	Payload for Antimatter Matter exploration and Light-nuclei Astrophysics
CRRES	Combined Release and Radiation Effects Satellite	**POEMMA**	Probe of Multi-Messenger Astrophysics
CTA	Cherenkov Telescope Array	**POGOLite**	POlarized Gamma-ray Observer
DAMPE	DArk Matter Particle Explorer	**SAMPEX**	Solar, Anomalous, and Magnetospheric Particle Explorer
DM	**Dark Matter**	**SPB**	Super Pressure Balloon
ESA	European Space Agency	**STAR**	Solenoidal Tracker At the Relativistic heavy ion collider (Brookhaven)
GAP	GAmma-ray burst Polarimeter	**TAO**	Transient Astrophysics Observer
GAPS	General Anti-Particle Spectrometer	**TIGER**	Trans-Iron Galactic Element Recorder
GBM	Gamma-ray Burst Monitor	**RHESSI**	Reuven Ramaty High Energy Solar Spectroscopic Imager
GCE	Galactic Center Excess	**USRA**	Universities Space Research Association
GRB	Gamma Ray Burst	**VERITAS**	Very Energetic Radiation Imaging Telescope Array System
GSFC	Goddard Space Flight Center		

Definitions

Antiproton	Fundamental particle, with the same mass as, but opposite charge to, the proton. Symbol $\overline{p}$.
eV	One of several physics units of energy.
femto	Prefix signifying one quadrillionth, or 1 divided by a thousand trillion.
Field of regard	Total area that a sensing system can perceive by pointing a particular sensor.
g	Acceleration due to Earth's gravity.
Gamma-ray	The highest energy, shortest wavelength electromagnetic radiation.
γ-ray	Same as gamma-ray, using the lower case Greek letter γ.
GV	One of several physics units for "magnetic rigidity", or ratio of a particle's momentum to its charge.
Inverse Compton process	Transfer of energy from an electron to a photon in an electron-photon collision.
Kilonova	Collision of massive, compact stars that gives rise to strong electromagnetic radiation.
Mpc	Megaparsec: Astronomical measure of distance = 1 million parsecs, where one parsec is 3.26 light years or 19 trillion miles.

Definitions

Multi-messenger astronomy	Astronomy based on the coordinated observation and interpretation of disparate "messenger" signals. "Messenger" implies distinct origin and/or wavelength range and/or observational techniques.
OB associations	Associations of hot, massive, young stars.
Positron	Fundamental particle, with the same mass as, but opposite charge to, the electron. Symbol e^+.
r-process	Set of rapid nuclear reactions that lead to the creation of about half of atomic nuclei heavier than iron.
Synchrotron	Electromagnetic radiation emitted when charged particles are accelerated in non-straight paths in a magnetic field.
Transient	Short lived astronomical object or phenomenon.
Trans-TeV	With energies of a trillion eV or higher.
Z	Atomic number, i.e., number of protons in the nucleus of an atom, characteristic for a given element.

articles highlight recent news for these exciting missions.

NASA is also investing in the US Community's 2020 Decadal Survey process through **large and probe class mission studies**. The ***Lynx*** large X-ray mission concept study's science case focuses on PCOS science objectives, as do several probe mission concept studies. The collection of probe class studies also investigates if missions <$1B can achieve valuable astrophysics objectives. Both ***Lynx*** and the **probes** have articles in this newsletter.

Motivated by the 2010 Decadal, in August NASA also selected three Medium Class Explorer (MIDEX) missions and three Missions of Opportunity (MoO) for study. The three with a γ-ray and X-ray focus are described in greater detail in the **MIDEX and MoO article**.

The PCOS Program Office enables current and future missions to address the fundamental science questions by reviewing **strategic technology** gaps, prioritization, and development yearly, and by facilitating a number of community activities, including meetings and articles, through the Physics of the Cosmos Program Analysis Group (PhysPAG). The **technology gap prioritization article** describes the process and results for this year, along with how the gaps feed into the **strategic astrophysics technology** program. The **PhysPAG article** describes the community meetings and activities undertaken during this year as well as plans for 2018. This includes capitalizing on the gravitational wave excitement by forming a new Multimessenger Science Analysis Group (MMA SAG).

We round out this year's newsletter with an update from NASA's Astrophysics Division Director Paul Hertz. This year also saw the departure of Dr. Ann Hornschemeier from the Chief Scientist position on Oct 1st. We appreciate her years of significant contributions to the PCOS program and wish her well in her new position as the Deputy LISA Study Scientist and in continuing her X-ray research program.

As always, we greatly appreciate your comments and questions. Contact information for all program officers can be found in the "**PCOS Organization**" box near the end of the newsletter. News and announcements about upcoming events, activities, and ways to get involved in the PCOS program are periodically emailed to our mailing list. Sign up here: **https://pcos.gsfc.nasa.gov/pcosnews-mailing-list.php**

We also welcome your participation in **upcoming meetings** at AAS Mon 8 Jan 2018, at the Special HEAD meeting in March, and at APS in April 2018. We are working to have remote access for all meetings. We will also have a booth with staff, information, and technology examples during the AAS and APS meetings and hope to see you there!

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Composition and Spectra of Cosmic Rays from Hydrogen to Iron

James Beatty, *Ohio State University*

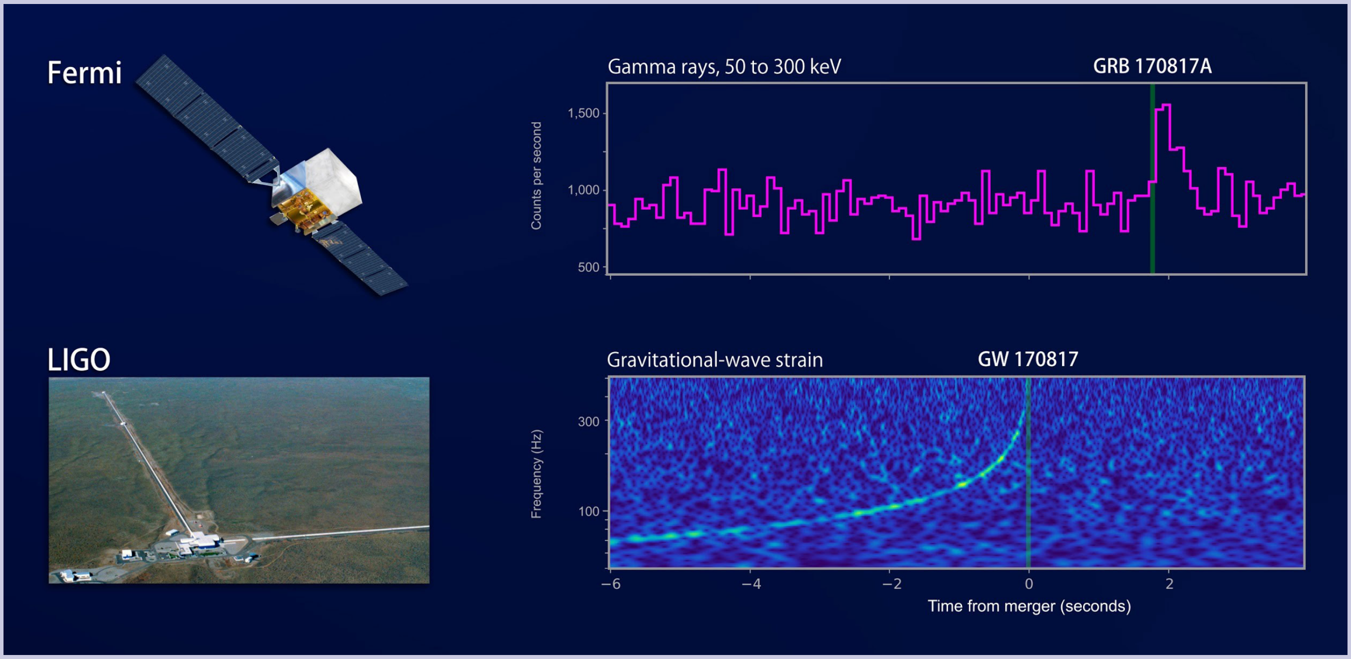
The spectra of cosmic rays have long been described as simple power laws in energy with very few spectral features or breaks. However, as we look more closely using instruments with improved resolution and better statistics, we find differences among the spectral indices of elements and breaks in the individual spectra. Experiments now flying aboard the International Space Station (ISS) are collecting important data for enhancing

Fermi’s GBM Triggers Global Multimessenger Effort

Elizabeth Ferrara, *University of Maryland College Park* and *NASA Goddard Space Flight Center*
Adam Goldstein, *Science and Technology Institute, Universities Space Research Association*
Eric Burns, *NASA Postdoctoral Program Fellow, NASA Goddard Space Flight Center*

August 17, 2017: The Gamma-ray Burst Monitor on board NASA's *Fermi* mission detects what appears to be a normal, short γ-ray burst. The spacecraft automatically reports the detection, and the GRB's position is sent to the world via the Gamma-Ray Coordinates Network. Thus began a series of events that led to the October 16th announcement of the first confirmed electromagnetic counterpart to a gravitational wave event.

While *Fermi*-GBM was the first to detect light from the two merging neutron stars, the combined LIGO/Virgo detectors provided a refined localization volume small enough for a number of observatories to tile observations in the region, searching for the source of the burst. These follow-up observations uncovered a kilonova event in the nearby galaxy NGC 4993, consistent with the distance estimated by LIGO/Virgo, and confirmed that the collision produced heavy elements like platinum and gold.



Fermi’s GBM triggers on a γ-ray burst only 1.7 seconds after LIGO detects gravitational waves from a binary neutron star merger. The delay of the γ-ray signal is consistent with theoretical expectations. Credit: NASA's Goddard Space Flight Center, Caltech/MIT/LIGO Lab

NGC 4993 lies only 40 Mpc away, indicating that the γ-ray burst seen by *Fermi*-GBM was quite sub-luminous. However, from the GBM's perspective it was a normal-looking burst. "This GRB was seen above the detection threshold in three of GBM's 12 sodium iodide detectors," said Adam Goldstein, a scientist with USRA in Huntsville who led the GBM analysis. "There was initially nothing to indicate that this burst was special in any way compared with other GRBs."

“Such a low luminosity likely indicates that the burst was not seen down the barrel of the jet,” said Eric Burns, a NASA Post-doctoral Program Fellow at GSFC, who led the *Fermi*-GBM's contribution to the joint publication with LIGO/Virgo. “The jet properties are likely different this far off-axis, which may explain why the GRB appeared so faint.”

With LIGO and Virgo improving their sensitivity and *Fermi*'s continuing all-sky observations, the number of jointly-detected neutron star mergers is certain to increase. A new age of multimessenger astrophysics has truly begun.

our understanding of the astrophysical processes influencing cosmic ray abundances and spectra.

Two calorimetric experiments, CREAM (Cosmic Ray Energetics And Mass) on the ISS and CALET (CALorimetric Electron Telescope) are currently collecting data on nuclear abundances and spectra at energies up to 10^{15} eV. NASA-sponsored ISS-CREAM, based on the CREAM balloon payload series, was launched on a SpaceX Dragon as part of the 12th resupply mission to the ISS on August 14, 2017. In 2010 CREAM reported a harder spectrum for helium than for protons at energies near 10^{13} eV. A similar difference between the proton and helium spectra at lower energy was also reported by the Italian-Russian PAMELA (Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics) satellite and from the flight of the Alpha Magnetic Spectrometer (AMS-01) aboard the Space Shuttle *Discovery*. The Japan-US-Italian instrument CALET, discussed in the **article on electron measurements**, has recently reported elemental spectra at high energies and continues to take data aboard the ISS.

AMS-02 was deployed on the space station in May, 2011. AMS-02 is a magnetic spectrometer and measures cosmic rays up to a few times 10^{12} eV. The AMS-02 collaboration has reported preliminary evidence of spectral hardening for light elements ranging from hydrogen through oxygen at magnetic rigidity (momentum per charge) at about 230 GV.

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Secondary Cosmic Rays

S. Nutter, *Northern Kentucky University*

Secondary cosmic rays are created in interactions in the interstellar medium as primary cosmic rays travel from their source to Earth and illuminate propagation details such as average amount of material traversed and containment time in the galaxy. The current crop of detailed, sophisticated, diffusive propagation models simultaneously track energy and interaction losses of all stable and radioactive elements and their isotopes, while incorporating a realistic galactic geometry including the disk, halo, and even the Local Bubble. Model input includes all secondary-to-primary elemental ratios, as well as ratios of secondary stable and radioactive isotopes. Different ratios probe different aspects of propagation and/or acceleration. Any claims of exotic particle sources, such as dark matter contributions to the positron spectrum, only carry weight if a full understanding of cosmic ray source composition, acceleration, and propagation effects on all secondary and primary cosmic ray spectra exists.

Well-measured secondary ratios (by AMS-02, BESS-Polar, and others) include B/C, $\bar{p}/p$, sub-Fe/Fe, and $^{3}He/^{4}He$. Improvements to these and other measurements are forthcoming in several missions. CALET and CREAM, both on the ISS, will extend the high quality existing B/C and sub-Fe/Fe ratio data to the limit of statistics, perhaps 10 TeV/n. Balloon-borne SuperTIGER, measuring elements with Z up to 56, has provided insight into source material and acceleration timescales. The instrument is scheduled for a second launch in the 2017–18 austral summer and a proposal is being developed for the ISS (see **Ultraheavy CRs article**). The isotopic landscape will greatly benefit from the balloon-borne HELIX magnetic spectrometer, to proceed in two phases. The first manifestation is tailored towards extending the famous radioactive "clock" ratio $^{10}Be/^{9}Be$ data up to ~3 GeV/n, high enough to test various classes of propagation models. The future second improved version could extend these measurements to ~10 GeV/n.

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Ultraheavy Cosmic Rays

Martin H. Israel, *Washington University in St Louis*

Ultraheavy (UH) cosmic rays, nuclei with atomic number (Z) greater than 30, are very rare. While the 5 m^2 SuperTIGER detector high in the stratosphere over Antarctica has detected about 10^5 iron (Z = 26) nuclei per day, it detected only about 25 UH nuclei per day. High statistics measurements of a wide range of individual UH elements' relative abundances will provide stringent tests of models of cosmic ray origin that have developed from observations of the much more abundant lower Z elements. Such models put the source of a substantial part of cosmic rays in clusters of high-mass stars (OB associations). Furthermore, cosmic ray observations of r-process nuclei, thought to be made in supernova explosions, will test the recent proposal that most r-process nuclei are in fact made in mergers of compact-star binaries.

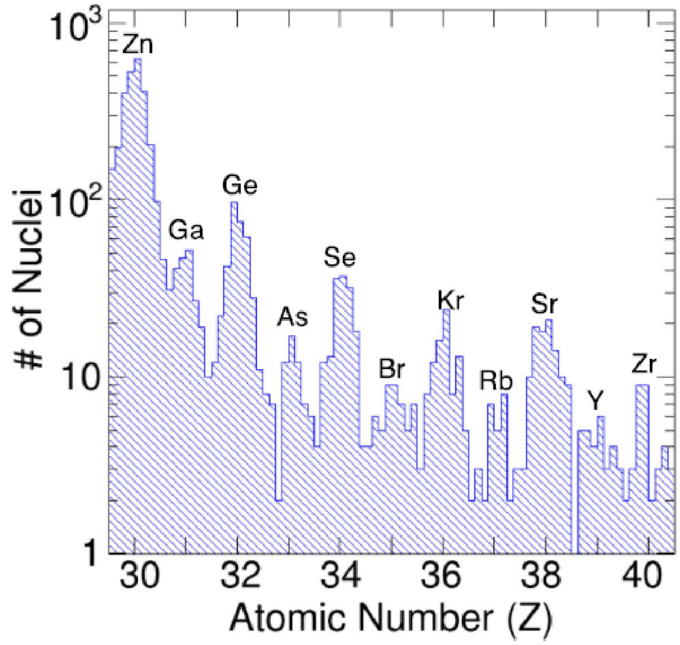

Figure 1. Abundances of UH cosmic rays from the 55 day flight of SuperTIGER over Antarctica. The same dataset detected 4.7 × 10⁶ Fe nuclei (Murphy et al., 2016, ApJ ***831****, 148).*

Because of UH cosmic rays' rarity, achieving high-statistics observations requires very large area detectors or very long exposure times above the atmosphere, or ideally both. SuperTIGER's first flight on a stratospheric balloon over Antarctica had a record duration of 55 days and obtained good statistics and excellent charge resolution for elements with Z as high as 40 (see **Figure 1**). Abundances continue to fall at higher charges, so another SuperTIGER flight over Antarctica is planned for launch in December 2017 with the goal of measuring higher Z, up to 56, as well as doubling statistics up to Z=40.

The much smaller CRIS instrument on the ACE spacecraft also provides data that complements the UH results from SuperTIGER. CRIS has an area of about 300 cm^2 and has been operating successfully in space for the past 20 years. It is limited to Z ≤ 40; a preliminary look at its UH data, although not part of its original design, shows results consistent with those already published from SuperTIGER.

Of course, really settling the UH abundances requires very large area detectors with excellent charge resolution in space for at least two years. Several groups are actively preparing proposals for such detectors. SpaceTIGER is such a detector with an area of a few m^2 proposed for attachment to the ISS.

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Cosmic Ray Isotopes: Evidence for Recent Nucleosynthesis and Future Measurements

Bob Binns, *Washington University in St. Louis*

The abundances of the isotopes and elements in galactic cosmic rays provide important constraints on their origin. Instruments aboard the ISEE-3, *Ulysses*, *Voyager* 1 & 2, SAMPEX, and CRRES satellites measured isotopes as high as nickel. Because of the small detector area of these instruments, it was not possible to collect sufficient statistics for significant measurements of some of the rarest isotopes. The Cosmic Ray Isotope Spectrometer (CRIS) instrument aboard the ACE satellite, which was launched in 1997, has a much larger geometry factor than previous instruments and has been collecting data for 20 years. In addition, the mass and charge resolution is excellent. Isotopes of elements up through germanium have been resolved.

Most recently we have measured the abundance of ^{60}Fe, a radioactive isotope that decays by β^--decay with a half-life of 2.6 Myr (Binns et al., *Science* **352**, 677, 2016). Using data collected over a period of 17 years, CRIS detected 3.6 × 10^5 iron nuclei. **Figure 2** shows a mass histogram of the stable iron isotopes (A=54–58) and a clump of 15 nuclei to the right which we have identified as ^{60}Fe. This is the first evidence that conclusively shows that there is a component of the galactic cosmic rays that has been synthesized recently (≲few Myr) and nearby (≲1 kpc). Possible sources of these particles are the nearby (<150 pc) Sco-Cen subgroups and the Orion OB1 association.

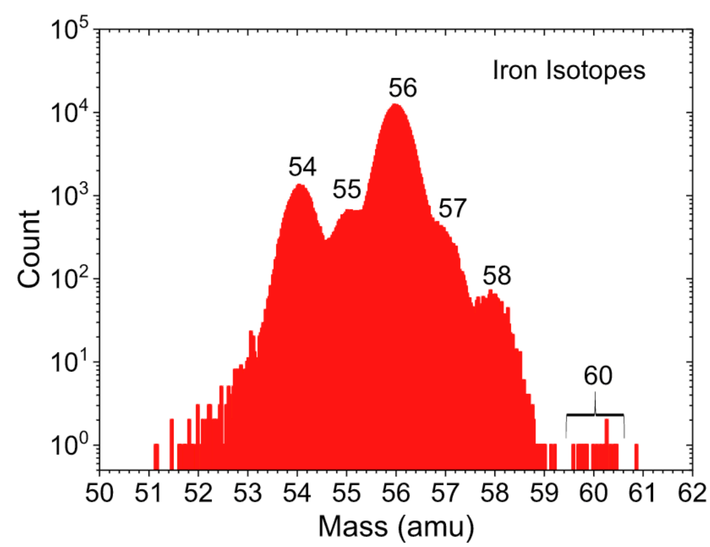

Figure 2. Mass histogram of iron isotopes

Future measurements of the isotopic abundances of ultra-heavy nuclei with Z>30 (which will require a considerably larger instrument than CRIS) can be used to constrain models of r-process production in binary neutron star mergers and supernova.

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Positron, Electron, and Total Electron Spectra

John P. Wefel, *Louisiana State University*

The energy spectra, into the trans-TeV region, of positrons, electrons, and "total electrons" (positrons + electrons) may hold the key to discovering local, Galactic sources of particle acceleration. These particles lose energy rapidly through synchrotron and inverse Compton processes, so at TeV energies, the particles can't travel very far from their source(s). Separating electrons from positrons requires a magnetic spectrometer. The best current data comes from AMS-02 (on the ISS), which has confirmed an increase in the positron fraction seen by earlier experiments and extended the measurements to much higher energy. The positron fraction shows no sign of decreasing. The positron spectrum itself contains interesting structure, and a longer exposure time is needed to study positrons at higher energies.

Positrons are produced as positron-electron pairs, and this suggests there may be structure in the total electron spectrum at TeV energies since the galactic secondary electrons decrease rapidly with increasing energy. Current data come from AMS-02, *Fermi*, Calorimetric Electron Telescope (CALET—Japan, USA, Italy—on the ISS), and Dark Matter Particle Explorer (DAMPE—China, Italy, Switzerland—satellite). The latter two are new, deep calorimetric instruments, launched at the end of 2015, with about 18–22 months of data analyzed. At the July 2017 International Cosmic Ray Conference, the data showed moderately good agreement between all four experiments on the electron spectrum up to several hundred GeV. Above that energy, the AMS-02 results continue to decrease, approximately following the spectrum calculated from interstellar propagation models. The *Fermi* results indicate a hardening of the spectrum. Very preliminary CALET data seem to agree better with AMS-02 than *Fermi*. However, look for potentially exciting trans-TeV and spectral structure first results from both DAMPE and CALET in the literature soon!

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Cosmic Ray Antiprotons and Antinuclei

Kenichi Sakai, *University of Maryland Baltimore County*

The precise measurement of the spectrum of cosmic ray antiprotons is critical to the investigation of elementary particle phenomena in the early Universe. Most cosmic ray antiprotons are produced by interactions of "primary" cosmic ray nuclei with interstellar gas (**Figure 3**). The energy spectrum of such "secondary" antiprotons peaks sharply near 2 GeV due to the kinematics of antiproton production and the local interstellar proton spectrum.

The NASA supported Balloon-borne Experiment with a Superconducting Spectrometer (BESS) measured a secondary antiproton flux consistent with theoretical expectations in conditions of minimum solar activity. The BESS spectrum generally agrees in shape with the satellite-borne PAMELA and AMS-02 spectra. Below 1 GeV, BESS shows no evidence of cosmologically "primary" sources, including the annihilation of dark matter particles and the evaporation of primordial black holes (PBHs) by Hawking radiation.

Cosmic-ray antideuterons are in a different situation. Thanks to their heavier mass, the probability of production in cosmic ray interaction is much smaller, especially at low energies, because of the very low production cross-section and strict kinematic requirement. So a single antideuteron event would be direct evidence of novel primary origins such as PBHs. To date BESS derived an upper limit for the differential flux of cosmic-ray antideuterons. The upcoming NASA supported GAPS (General Antiparticle Spectrometer) experiment will search for the antideuteron particles in cosmic rays (see **Indirect DM Searches Using Antimatter CRs article**).

The STAR experiment at the Brookhaven Relativistic Heavy Ion Collider reported the observation of antihelium in 2011. BESS established the lowest limit to date on the cosmic ray antihelium-to-helium abundance. At ICRC in 2017, AMS-02 reported the possible detection of

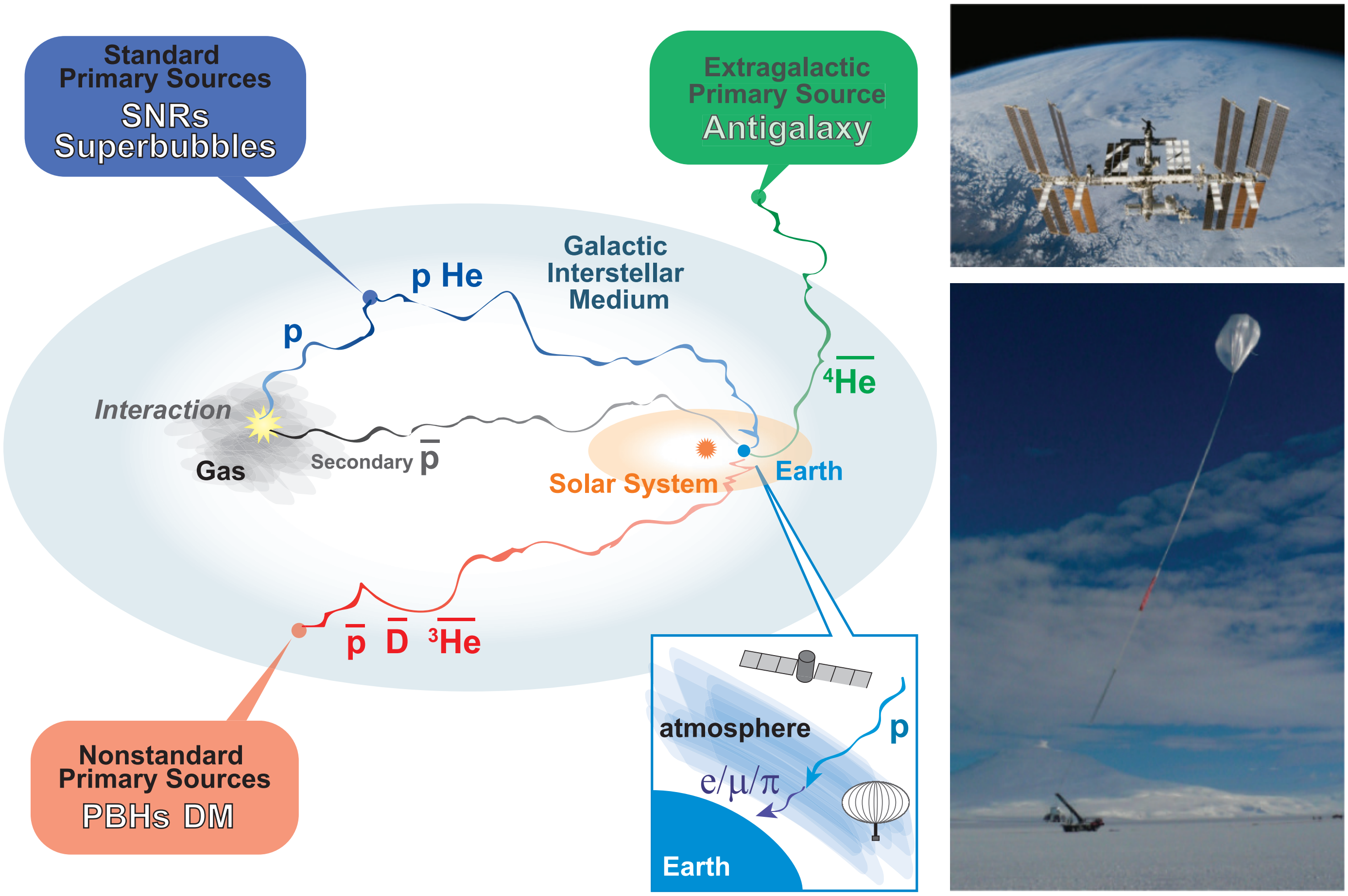

*Figure 3. (**Left**) Cosmic-ray antiparticles from birth to arrival at the earth. Secondary cosmic ray antiprotons are produced when primary cosmic ray protons diffuse from sources through the turbulent magnetic fields of the Galaxy and collide with interstellar gas. Both primary and secondary Galactic cosmic rays also diffuse by solar modulation; the observed modulated fluxes at the earth are relatively lower. Meanwhile, primary antiparticles may originate in processes which generate them directly without any primary interactions from sources such as PBHs and Dark Matter (DM). (**Right-top**) AMS-02 on the ISS; (**bottom**): BESS-Polar II launch from the Williams Field on December 23, 2007.*

antihelium-3, requiring further detector verification and better statistics. This provides strong support to GAPS's search for antideuterons.

The apparent asymmetry between particles and antiparticles is one of the fundamental problems in cosmology. Future experiments to detect antihelium-4, which would only originate in antigalaxies, should help better constrain the asymmetry level.

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Space Probes of the Most Energetic Cosmic Particles

Angela Olinto, *University of Chicago*

The origin of ultra-high energy cosmic rays (UHECRs), cosmic rays with energies above 1 EeV (=10^{18} eV), is still unknown. Decades of observations with giant ground-based observatories, the Pierre Auger Observatory and the Telescope Array, have established the shape of the spectrum, the composition, and the arrival directions' angular distribution below about 60 EeV. A remarkable recent result of this effort is the detection of a significant dipole that does not align with the Galactic plane for energies above 8 EeV. This result establishes the expected extragalactic nature of the sources of these most energetic particles.

To understand the nature of these extreme cosmic sources a significant increase in detected events above about 60 EeV is necessary. Building ground arrays orders of magnitude larger than thousands of square miles (Auger covers 3,000 km^2) is impractical if not forbidding. A much more effective approach to increase the number of observations above 60 EeV is to observe UHECRs from space. This enables the instantaneous observations of large volumes of the Earth's atmosphere where these rare particles produce emissions from extensive air showers.

The ANtarctic Impulsive Transient Antenna (ANITA) first detected UHECRs from above. ANITA was designed to study neutrinos at the highest energies and serendipitously detected dozens of UHECRs, inaugurating the radio detection of UHECRs from above. A complementary effort is underway to prepare a space mission to increase the exposure to UHECRs above 60 EeV by orders of magnitude. A NASA probe class mission named Probe Of Extreme Multi-Messenger Astrophysics (POEMMA) is now being designed to be submitted to the next decadal survey. POEMMA will significantly increase the exposure to UHECRs above 60 EeV and search for ultra high energy neutrinos produced by the propagation of UHECRs from extragalactic sources. POEMMA is built on the Orbiting Wide-angle Light collectors (OWL) design and Extreme Universe Space Observatory (EUSO) experience. The EUSO program, which began with the goal of deploying a wide field-of-view refractor on the International Space Station (ISS), has built a number of prototype space telescopes to prepare for a space mission: EUSO-Balloon, EUSO-SPB, and mini-EUSO. EUSO-Balloon flew an overnight test flight in Canada in 2014 under the sponsorship of CNES. EUSO-SPB (i.e., EUSO on a Super Pressure Balloon), was launched by NASA from Wanaka, New Zealand, in April 2017. Mini-EUSO will be operated in the pressurized module of the ISS starting in 2019. EUSO-SPB had an early termination so EUSO-SPB2 is now being developed. EUSO-SPB2 will pioneer the observations of direct Cherenkov signals from UHECRs and neutrinos from space over the next several years, preparing the way for POEMMA.

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Above the Earth, a Neutrino View of the High-Energy Universe

Stephanie A. Wissel, *California Polytechnic State University*

Outflows and flares from energetic objects like active galactic nuclei, γ-ray bursts, and pulsars may accelerate cosmic rays to the highest energies. The origin of the highest-energy cosmic rays remains unknown, but the key to their story may be the highest-energy neutrinos. Neutrinos are a by-product of cosmic ray travel, and could reveal the nature and histories of accelerators, but these messengers remain elusive. Slightly lower-energy (TeV–PeV) neutrinos were recently discovered coming directly from some cosmic ray sources. Current and planned NASA suborbital and space missions are poised to understand the dynamics of the high-energy universe, seeking these extreme energy neutrinos by observing the largest target volumes from high above the Earth.

The ANtarctic Impulsive Transient Antenna (ANITA) is built to observe the highest-energy (>1 EeV = 10^{18} eV) neutrinos. ANITA's dozens of antennas, hanging from a Long-Duration Balloon at 37 km altitude, are tuned to search for the radio spark emitted when a neutrino generates a cascade of secondary particles in the Antarctic ice sheet. ANITA can also detect cosmic-ray air showers reflected off ice, and even upgoing air showers resulting from a τ neutrino skimming the Earth. The second flight of ANITA resulted in the strongest limits on the flux of neutrinos at the highest energies. Searches for neutrinos and cosmic rays during the third (2014–2015) and fourth (2016–2017) flights are ongoing. Planned upgrades to ANITA include real-time interferometry to further reject noise, in order to probe the diffuse flux of lower-energy astrophysical neutrinos.

Higher still is the Extreme Universe Space Observatory (EUSO), a multi-mission program to observe extreme-energy (>50 EeV) cosmic rays and neutrinos. Part of this overarching program is the Probe of Multi-Messenger Astrophysics (POEMMA), a dual-satellite mission concept targeting ultra-high-energy neutrinos. On each satellite, a wide-field camera will image the fluorescence and Cherenkov light from air showers initiated by cosmic rays. POEMMA is specifically designed to see air showers made after τ neutrinos skim the Earth's surface. A pathfinder experiment, EUSO-SPB, flew on a superpressure balloon in 2017 with the goal of observing a cosmic ray air shower from above for the first time. A second flight (EUSO-SPB2) planned for 2020 will characterize the backgrounds for τ neutrino searches. Both superpressure flights serve as pathfinder experiments for POEMMA.

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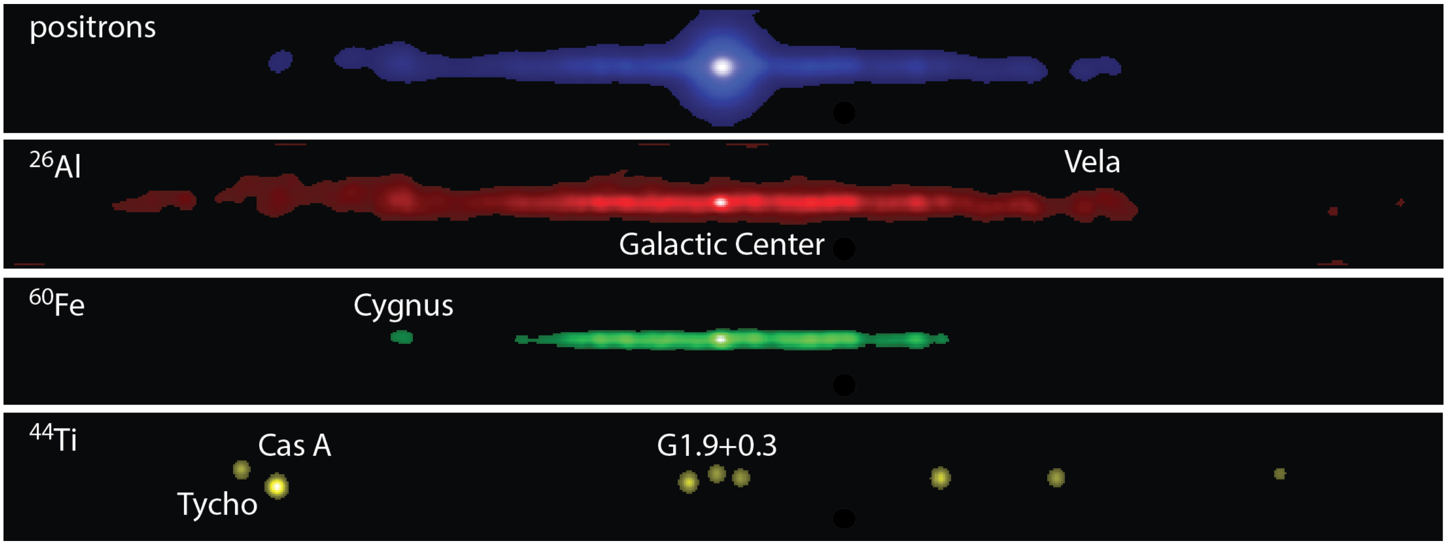

Figure 4. "Radioactive Milky Way" simulated images.

Motivations for Observations of Emission Lines in the MeV Bandpass

John A. Tomsick, Carolyn Kierans, and Andreas Zoglauer, *University of California, Berkeley*
Dieter Hartmann, *Clemson University*
Steven E. Boggs, *University of California, San Diego and University of California, Berkeley*

The MeV bandpass includes several nuclear emission lines that probe different physical processes in our Galaxy and beyond. Long-lived isotopes such as ^{26}Al (1.809 MeV line) and ^{60}Fe (1.173 and 1.333 MeV lines), predominantly produced in supernovae (SNe), provide information about the galaxy-wide star formation history, integrated over the past million years. To first order, images of the Galaxy at these energies trace the last ~10,000 core collapse SNe. ^{44}Ti (1.157 MeV as well as 68 and 78 keV lines in the hard X-ray range), with a half-life of 60 years, traces young Galactic SNe which occurred in the last few hundred years, and ^{56}Co (0.847 and 1.238 MeV) decays so rapidly (half-life: 77 days) that it is currently only seen by following up SNe in nearby galaxies. The ^{44}Ti and ^{56}Co lines trace the amount and distribution of these elements after they are created in the underlying SNe.

Another important emission line in this energy range is the electron-positron annihilation line at 511 keV. While the main source of positrons is expected to be from radioactive decay of ^{26}Al, INTEGRAL sees an excess of 511 keV emission from the Galactic bulge that defies easy explanation. The additional positrons may come from a known source population (e.g., accreting black holes with jets) or require a more exotic origin. One important piece to this puzzle is the unknown distance positrons can propagate before annihilating; comparing ^{26}Al and 511 keV maps can constrain propagation distances and thus advance our understanding of Galactic positrons.

The wide-field measurements required to study these emission lines over large regions of the sky can be obtained with coded aperture instruments, such as SPI on INTEGRAL, or with instruments that use Compton scattering techniques, such as COMPTEL did on CGRO. The Compton Spectrometer and Imager (COSI), which flew on NASA's superpressure balloon in 2016 and COSI-X (an Explorer Mission of Opportunity currently in Phase A) combine large field of view with high energy resolution for improved line studies. Both the e-ASTROGAM mission, which has been proposed to ESA, and the AMEGO mission concept are designed to address MeV emission line science.

Figure 4 shows "Radioactive Milky Way" simulated images with emission distributions consistent with measurements by CGRO and INTEGRAL. Each image covers the entire Galactic plane in longitude and latitudes between -15 and +15 degrees.

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γ-ray Polarimetry

Mark McConnell, *University of New Hampshire and Southwest Research Institute*
Sylvain Guiriec, *George Washington University and NASA Goddard Space Flight Center*

Although polarimetry remains largely unexploited in γ-ray astronomy, we are now starting to probe the high energy Universe with this unique, and also challenging, tool.

The soft X-ray polarization of the Crab has been known since 1974, but the first evidence of polarization at higher energies came in 2001 with the report of GRB polarization by RHESSI. Since that time, additional reports of GRB polarization have come from the IBIS and SPI instruments on INTEGRAL, the Japanese IKAROS-GAP instrument, and the Indian Astrosat-CZTI imager. At least one polarization measurement showed evidence of time variability. Unfortunately, these GRB measurements have limited statistical significance, and there is not yet a consistent picture of GRB polarization, a picture that may shed light on the magnetic field structure and emission mechanisms related to the GRB jet's innermost region. More GRB observations may soon be forthcoming. The POLAR experiment on the Chinese Tiagong 2 space station has observed several GRBs, but has yet reported any polarization results. In addition to GRB polarization, there have also been reports of high energy polarization from both the Crab (INTEGRAL, POGO-Lite) and from Cygnus X-1 (INTEGRAL).

Meanwhile, several instruments that will expand our studies of high energy polarimetry are under development. One effort (GRAPE) is dedicated to wide field-of-view GRB polarization measurements. However, any instrument that employs Compton imaging is intrinsically sensitive to polarization. The COSI balloon payload recently demonstrated its potential by deriving an upper limit on the polarization of GRB160530A, and efforts are underway to measure the Crab polarization; both use data from its 2016 ultra long duration balloon flight. A balloon prototype of the ASCOT Compton telescope will fly next year. The AMEGO and ASTROGAM instrument concepts both rely on Compton imaging in the energy range of 200 keV to 10 MeV, so they are also expected to have significant polarization sensitivity. At higher energies, it is possible to measure polarization with pair production techniques, but electron/positron scattering effects limit the efficacy. For this purpose, gas detectors may be required (e.g., AdEPT).

With the promising polarization results now available, the next generation of γ-ray missions will surely bring with it many exciting new discoveries.

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The Present and Future of *Fermi* and High-Energy γ-ray Astrophysics

Judith L. Racusin, *NASA Goddard Space Flight Center*

As *Fermi* approaches its first 10 years of on-orbit discovery, its ever-deepening observations have revealed the γ-ray sky with unprecedented clarity. The *Fermi* instruments' continuous monitoring captures exotic transient and variable phenomena from γ-ray bursts to Galactic binaries as they vary with timescales from milliseconds to years. The *Fermi* mission and its instruments, the Gamma-ray Burst Monitor (GBM) and the Large Area Telescope (LAT), are continuing operations and discovery in the coming years, especially with their prominent roles in multimessenger astrophysics. The observations of electromagnetic counterparts to gravitational wave, and potentially, neutrino sources promise exciting science ahead.

The thousands of sources detected by the *Fermi* instruments across 8 decades in energy (see **Figure 5**) have addressed many open questions in astrophysics, such as pulsar emission mechanisms (see **High-Energy γ- and CRs article**), and opened new ones, for instance regarding the origin of astrophysical neutrinos given a neutrino event's recent **candidate association** with a flaring blazar. *Fermi* is crucial to multiwavelength studies of the sky, with key synergies from radio to TeV. The high-energy end of the LAT sensitivity improves linearly with time as rare TeV photons are collected (**Figure 5**), bridging the gap with the imaging air Cherenkov telescopes (IACTs: VERITAS, MAGIC, HESS) and the water Cherenkov telescope (HAWC), and towards future experiments such as the Cherenkov Telescope Array (CTA). With no NASA follow-on mission yet

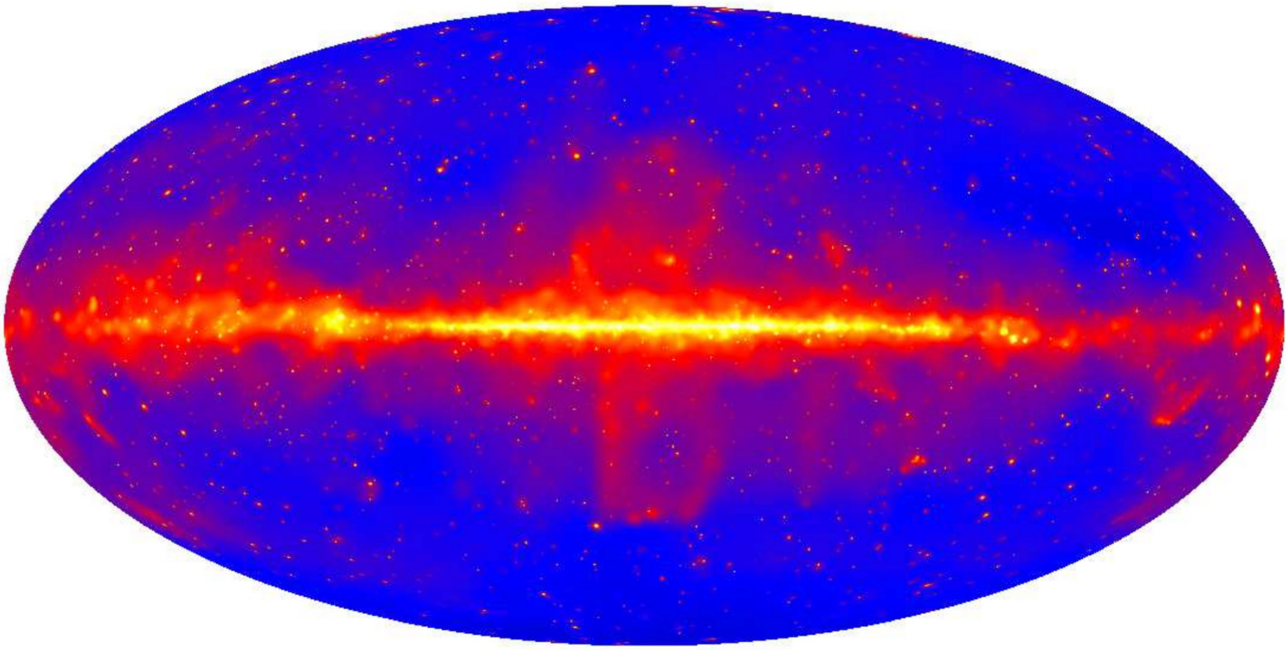

Figure 5. The Fermi-LAT 10 GeV–2 TeV 7-year sky map reveals complex diffuse structures in our Galaxy, and ~1500 sources (200 of them new) to guide IACT and other multiwavelength observations (see Ajello, M. et al. 2017, ApJS ***232****, 18 for details)*

planned, the continued operation of *Fermi* remains the key to maintaining this essential element of NASA's science portfolio.

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Dark Matter Searches Using γ-rays

R. Caputo, *University of Maryland and NASA Goddard Space Flight Center*

The era of precision cosmology, made possible by NASA led and supported satellites like the Wilkinson Microwave Anisotropy Probe and *Planck*, revealed that ~80% of the matter in the Universe is "dark." A leading candidate, motivated by both particle and astrophysics, is the Weakly Interacting Massive Particle (WIMP). The *Fermi* Large Area Telescope (*Fermi*-LAT) Collaboration continues to search for WIMP signatures spanning the 50 MeV to >300 GeV γ-ray energy range in dwarf spheroidal galaxies, galaxy clusters, pulsars, the Galactic center, and a variety of other astrophysical targets. Thus far, *Fermi*-LAT has not conclusively detected a dark matter signature. There is however an intriguing excess of γ-rays associated with the Galactic center (GCE, Hooper et al. 2011, *Phys. Rev. D* **84**, 123005). Identifying whether the GCE is a dark matter signature, a population of astrophysical point sources, or a combination of the two, requires the exploration of other dark matter targets. Recent searches for a dark matter annihilation signal from a stacking analysis of dwarf spheroidal galaxies yielded upper limits on the γ-ray flux (Ackermann et al. 2015, *Phys. Rev. Lett.* **115**, 231301). However, a measurement of a spatially extended γ-ray signal from the center of M31 reported that the emission broadly resembles the GCE (Ackermann et al. 2017, *ApJ*, **836**, 208).

Several other types of experiments can also search for γ-ray signatures of WIMP annihilation at or near the thermal relic cross section. In particular, imaging atmospheric and water Cerenkov telescopes are effective at searching for γ-ray signatures from high-mass WIMP annihilation. Instruments sensitive to fluctuations in the cosmic microwave background can also put limits on thermal relic WIMPs at lower masses. Furthermore, future space-based γ-ray missions tuned to the MeV energy range, such as the All-sky Medium Energy Gamma-ray Observatory (Moiseev et al. PoS(ICRC2017)798) or enhanced-ASTROGAM (De Angelis et al. 2017, Experimental Astronomy **44**, 25, arXiv:1611.02232), will help resolve the GCE and effectively search for low mass WIMPs. The combined measurements of these instruments

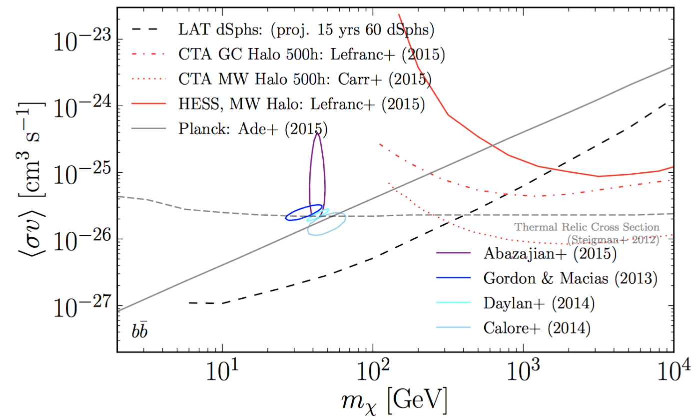

Figure 6. The figure compares the projected sensitivity of Fermi-LAT, the Cerenkov Telescope Array, the High Energy Stereoscopic System (HESS), and Planck to various dark matter targets, to the interpretation of the GCE as a source of dark matter annihilation (Charles et al. 2016, Phys. Rep., ***636****, pp. 1–46).*

will either confirm or place strong constraints on the leading dark matter candidate.

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Indirect Dark Matter Searches Using Antimatter Cosmic Rays

S. A. Isaac Mognet, *Pennsylvania State University*

Many theoretical dark matter candidates, including those from supersymmetry and universal extra dimension theories, are either their own antiparticle or will decay to standard model particles, producing equal parts matter and antimatter in either case. Antimatter excesses in cosmic rays above those expected from secondary production (spallation) are therefore promising ways to indirectly search for dark matter.

Past experiments (see **CR Antiprotons and Antinuclei article**) measured the observed antiproton flux to be consistent with secondary production processes and no signature suggesting a dark matter contribution. The Alpha Magnetic Spectrometer (AMS-02) and the upcoming General Anti-Particle Spectrometer (GAPS) balloon experiments are extending these measurements to higher and lower energies and improving statistics.

Another promising channel is antideuterons. The predicted flux of antideuterons from secondary production is below the sensitivity of current experiments (see also **CR Antiprotons and Antinuclei article**). However, a wide range of dark matter candidates could produce an excess in the antideuteron flux below ~1 GeV, several orders of magnitude above the secondary production and still consistent with current antiproton limits. AMS-02 has been collecting data since 2011 and will have good antideuteron sensitivity in some of the parameter space. When it flies in several years, the GAPS experiment will search for a low-energy antideuteron flux at least two orders of magnitude below the limit established by BESS (see **CR Antiprotons and Antinuclei article**) .

Positrons present a more complicated situation. AMS-02 and PAMELA have confirmed a strong excess in the positron flux consistent with a ~1 TeV dark matter particle, but there are serious issues with this interpretation. First, astrophysical sources for the excess such as a nearby pulsar wind nebula are quite likely. Anisotropy in the positron flux would be one way to distinguish between these possibilities; so far it has not been observed. Second, a dark matter interpretation is also in strong tension with the antiproton limits. The combined $e^+ + e^-$ flux, probed by instruments such as *Fermi*, CALET, and ISS-CREAM will also provide further insight at higher energies.

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High-Energy γ-Rays and Cosmic Rays – Theory and Modeling

Alice Harding, *NASA Goddard Space Flight Center*

This article highlights several recent, inter-related developments in the theory of high-energy γ-ray and cosmic-ray sources: particle acceleration to extreme energies, particle acceleration by relativistic magnetic reconnection, and new kinetic modeling of these processes.

The fields of high-energy γ-ray astrophysics and cosmic ray physics are linked by the central question of what processes can accelerate particles to mind-bending energies up to 10^{18} eV. These energies place us in the extreme radiation regime where particles emit photons at nearly their own energy. The processes that accelerate these particles thus push the envelope, challenging the standard models of particle acceleration. A recent example is the γ-ray flares detected from the Crab nebula by the *Fermi* Gamma-ray Space Telescope and AGILE. The April 2011 flare spectrum extended to 500 MeV, far exceeding the maximum photon energy expected from diffusive shock acceleration. This inspired a number of studies of magnetic reconnection in the "striped" pulsar wind, a mechanism that seems capable of accelerating particles to the required energy of a few 10^{15} eV.

Magnetic reconnection now also seems to be in vogue for blazar and γ-ray burst models. The very short timescales observed for blazar flares by *Fermi* and Imaging Air Cherenkov telescopes challenges more traditional models of relativistic shock acceleration and turbulence. Particle-in-cell (PIC) simulations of relativistic reconnection produce plasmoids filled with high-energy particles that could be responsible for the high-energy flares. γ-ray bursts also show rapid variability that magnetic reconnection models may be able to explain. This new view of particle acceleration in pulsar wind nebulae, blazars, and γ-ray bursts implies high magnetization in these sources' acceleration regions. If any are the sources of ultra-high energy cosmic rays and neutrinos, then acceleration of protons is required since they have lower radiation loss rates than leptons. Furthermore, energetic proton interactions can produce charged pions that decay into neutrinos.

With the improvement in computing power over the last ten years, PIC simulations that model the self-consistent distributions of particles and fields use has spread. In addition to simulating reconnection, several groups have begun using PIC techniques to model global pulsar magnetospheres and supernova remnant shocks, with the goal of understanding the high-energy acceleration of γ-ray emitting particles. PIC simulations are also being used to model the collisionless magneto-rotational instabilities that drive jets in black hole accretion disks.

With these exciting recent developments, we can look forward to theoretical investigations that probe deeper into the workings of cosmic accelerators, allowing us to understand in unprecedented detail the processes of energization at their extreme limits.

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Lynx X-ray Observatory

Feryal Ozel, *University of Arizona*

An international team of astronomers was assembled by NASA a year and a half ago to design the next generation great observatory capable of observing the universe in X-rays. Now, at about the midway point of the study that will be presented to the next decadal survey, a powerful telescope with a sharp vision—***Lynx***—is emerging as the next generation concept. With its unprecedented sensitivity, ***Lynx*** will be capable of seeing the first black holes being born in the universe, the vast amounts of wispy hot material surrounding all galaxies, and the light from nearby merging neutron stars.

The discovery of massive quasars at redshift ≥ 6 indicates that baby supermassive black holes must have been born and begun growing by redshift 10. It is unknown how massive these black holes were at birth, and only direct observations of these powerful but faint X-ray sources can help us understand their origins as well as their impact on

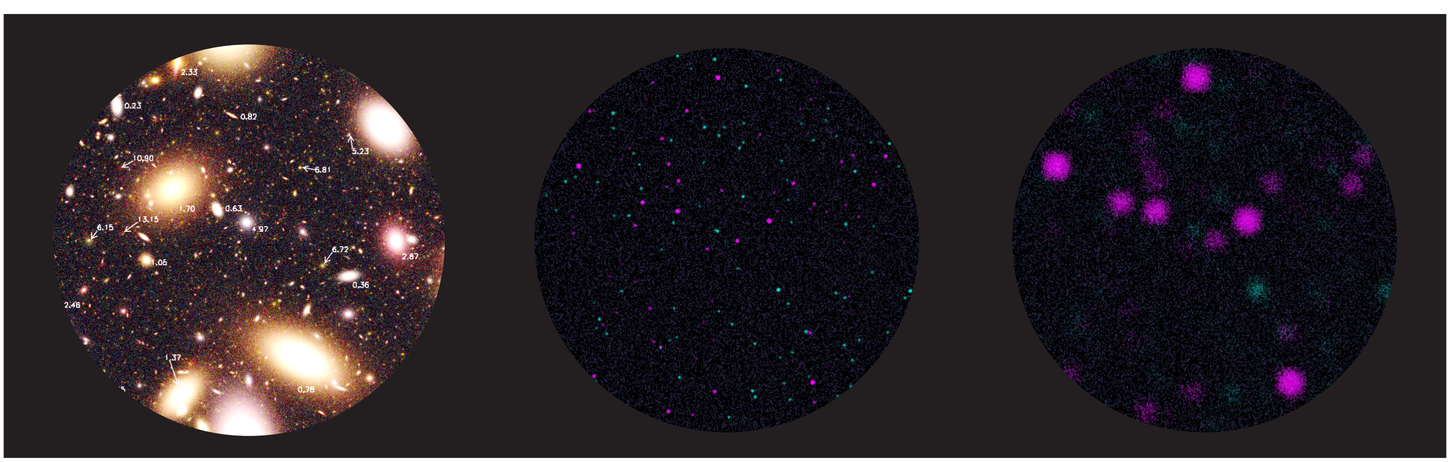

Figure 7. Simulated 2 × 2 arcmin² "deep field" high-redshift images for the James Webb Space Telescope (left), a 4 Ms Lynx "first accretion light" image (center), and a 5"-resolution X-ray image (right).

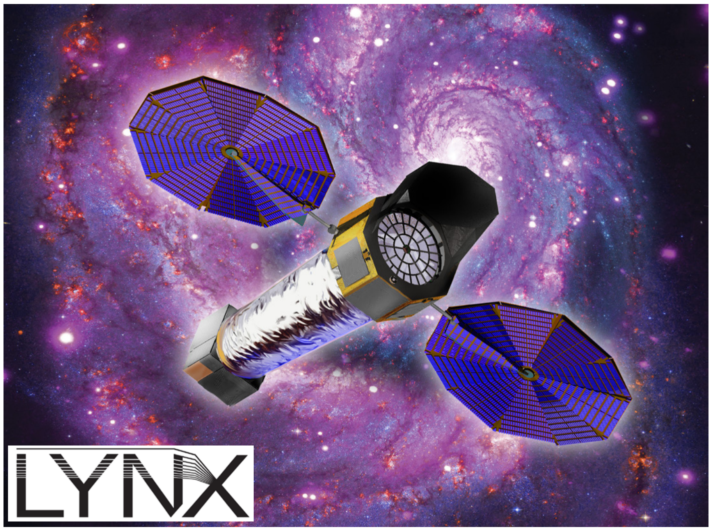

Figure 8. The Lynx X-ray Observatory

their host galaxies and the intergalactic medium. The *Lynx* X-ray Observatory will directly detect the emission from a 10^4 solar mass black hole at redshift 10, vastly improving our understanding of the formation, impact, and co-evolution of the giants in the centers of galaxies.

Lynx is also designed to detect and study the main drivers of galaxy formation, which are visible primarily in X-rays. In the current paradigm, violent processes produce and disperse large amounts of hot gas and metals into the circum- and intergalactic medium, driving the assembly, growth, and the state of visible matter in cosmic structures.

While the visible stellar material locked into galaxies reflects the consequences of the overall process, the direct imprint of the drivers can only be observed in the X-rays, by imaging the gas around galaxies. *Lynx* will detect low-surface-brightness continuum emission and carry out high-resolution spectroscopy to map large areas of the sky in the OVII, OVIII, and other important spectral lines to greatly advance our understanding of galaxy formation.

Such a sensitive telescope with high angular resolution will naturally also shed light onto the physics of the phenomena observed in our own Galaxy and nearby galaxies. *Lynx* will enable studies of young stars, at the height of their X-ray activity, to understand their magnetic field evolution and their effects on the habitability of their planets. It will uncover the lifecycles of elements by directly observing their dispersion by supernovae and γ-ray bursts. *Lynx* will directly observe many forms of feedback from stars and compact objects through high-resolution spectroscopy and measure their impact on their surroundings. *Lynx* will support multimessenger follow up of transient phenomena, operating as a powerful observatory for all of astrophysics.

Lynx will utilize lightweight X-ray mirrors, enabling a 2.3 m^2 effective area at 1 keV within a 3m telescope diameter. Three instruments are being considered to fully harness the sensitivity of the telescope design. A high-definition imager will enable deep surveys of the cosmos, detecting high redshift sources without suffering from confusion. A microcalorimeter will perform sensitive spatially-resolved spectroscopy of gas around galaxies, black holes, and star forming regions. Finally, gratings will enable the highest resolution X-ray spectroscopy of absorption lines around the Milky Way and galaxies in the local universe, mapping out the baryons. The optics and instrument teams have been making steady and rapid progress in developing the technologies for the mirrors and the instruments of *Lynx*.

With these inspiring science goals and the exciting unprecedented capabilities, it is no surprise that a large and diverse community has been closely involved in the science and technology discussions for *Lynx*. Indeed, in addition to the core team, some 350 enthusiastic astronomers have been regularly participating in defining the mission, generating simulations, attending *Lynx* workshops, and providing input. The fact that a sizable fraction of these scientists have previously not been involved in an X-ray mission is a testament to the broad appeal of this new X-ray telescope capable of penetrating the universe and uncovering its inner workings.

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Astrophysics Probes

Rita Sambruna, *Astrophysics Probes Program Officer, NASA Headquarters*

NASA is helping the US astrophysics community to prepare for the 2020 Astrophysics Decadal Survey by sponsoring studies of mission concepts for both Large and Medium size missions (**https://science.nasa.gov/astrophysics/2020-decadal-survey-planning**).

Table 1. Selected Probes studies

Principal Investigator	Affiliation	Title	Design Lab/PO
S. Hanany	Univ. of Minnesota	Inflation Probe Mission Concept Study	TeamX/ExEP
J. Glenn	Univ. of Colorado	Galaxy Evolution Probe	TeamX/ExEP
P. Ray	Naval Research Laboratory	STROBE-X: X-ray Timing and Spectroscopy on Dynamical Timescales from Microseconds to Years	IDC/PCOS-COR
W. Danchi	NASA's Goddard Space Flight Center	Cosmic Evolution through UV Spectroscopy (CETUS)	IDC/PCOS-COR
J. Camp	NASA's Goddard Space Flight Center	Transit Astrophysics Probe Concept Study	IDC/PCOS-COR
R. Mushotzky	Univ. of Maryland	AXIS: A High Spatial Resolution X-ray Probe Satellite	IDC/PCOS-COR
P. Plavchan	Missouri State Univ.	EarthFinder: A Diffraction-Limited Precise Radial Velocity Observatory in Space	No design lab run supported by NASA/ExEP
S. Seager	Massachusetts Institute of Technology	Starshade Rendezvous Mission	TeamX/ExEP
A. Cooray	Univ. of California, Irvine	Cosmic Dawn Intensity Mapper	TeamX/ExEP
A. Olinto	Univ. of Chicago	Concept Study of the Probe Of Extreme Multi Messenger Astrophysics (POEMMA)	IDC/PCOS-COR

Thus in summer 2016 NASA solicited proposals for Astrophysics Probes mission concept studies with the intent of selecting several competitive proposals for more detailed studies over 18 months. The selected studies' results will be provided by NASA as input to the 2020 Decadal Survey Committee, which will have the option to prioritize individual mission concepts for further study by NASA or/and to recommend a line of Probes (a program similar to the New Horizons program in Planetary Science).

During the January 2017 peer review of submitted proposals, unconflicted reviewers evaluated the proposals according to scientific merit and also provided input to the Astrophysics Division as to which considerations should be kept in mind when assembling the portfolio of Probe mission concept studies. Unanimously, the panels suggested that a diverse, broad portfolio of mission concept studies should be the major criterion for selection. Each selected mission concept should also address a compelling, focused science question while allowing room for broader science topics.

Table 1 lists the selected Probes studies. The Physics of the Cosmos (PCOS)/Cosmic Origins (COR) and Exoplanet Exploration (ExEP) Program Offices, at Goddard Space Flight Center (GSFC) and Jet Propulsion Laboratory (JPL), respectively, were directed to coordinate and assist the selected PI-led teams. Each PI-led team was funded to conduct an 18-month study; NASA also provided funding for design lab runs with either the Instrument Design Lab at GSFC or Team-X at JPL, as listed in **Table 1**. NASA will fund a final independent cost assessment from the Science Office of Mission Assessment (SOMA) office at Langley Research Center (LaRC). The PI-led teams will submit their written reports to NASA by December 2018.

Additionally, NASA is sponsoring two back-to-back splinter sessions on the mission concept studies at the 2018 Winter AAS meeting, for the mission concept teams to present a progress report. Please mark your calendars for this event. We hope to see you on January 9th in Washington, DC!

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Medium Explorers and Missions of Opportunity

Linda S. Sparke, *NASA Headquarters*

On August 9, 2017 NASA selected three Astrophysics Medium Explorer missions and three Explorer Missions of Opportunity for 9-month concept studies. These investigations would study γ-ray and X-ray emission from clusters of galaxies and neutron star systems, as well as infrared emission from galaxies in the early universe and

Figure 9. A) Arcus. B) COSI-X. C) ISS-TAO.

atmospheres of exoplanets. NASA expects to select one Medium Explorer mission and one Mission of Opportunity by 2019 to proceed with construction and launch. The earliest launch date would be in 2022. Medium Explorer mission costs are capped at $250 million each, excluding the launch vehicle, and Mission of Opportunity costs are capped at $70 million each. We focus here on selected proposals that pertain to γ-ray and X-ray missions.

Medium Explorer Mission Proposal

Arcus: *Exploring the Formation and Evolution of Clusters, Galaxies and Stars* (*PI: Randall Smith, Smithsonian Astrophysical Observatory, Cambridge, MA*) would provide high-resolution R >1500 grating spectroscopy in soft X-rays (12–50 Å), to study shock heating, radiative cooling, and powerful winds in the diffuse million-degrees gas where most of the cosmic baryons reside. It would study hot gas around stars, galaxies, and clusters of galaxies to characterize how the energy from accreting black holes and regions of rapid star formation feeds back into the gas, thus regulating the pace of subsequent accretion and starbirth.

Mission of Opportunity Proposals

Compton Spectrometer and Imager Explorer (*COSI-X, PI: Steven Boggs, University of California, Berkeley*) This is a Small Complete Superpressure Balloon Mission. It has a wide-field-of-view telescope designed to survey the γ-ray sky at 0.2–5 MeV, performing high-resolution spectroscopy, wide-field imaging, and pioneering studies of γ-ray polarization. Over 100-day balloon flights, COSI-X would map γ-rays from antimatter around the Milky Way's center and from newly-formed radioactive elements such as ^{44}Ti in the debris of supernova explosions.

Transient Astrophysics Observer on the International Space Station (*ISS-TAO, PI: Jordan Camp, NASA Goddard Space Flight Center*). This is a wide-field X-ray transient detector aboard the ISS that would observe numerous X-ray transient events each year related to compact objects. The primary goal is detection of X-ray counterparts to gravitational waves produced by neutron stars merging with black holes or other neutron stars. Other targets would be high redshift γ-ray bursts, supernova shocks, and Galactic transient sources.

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Physics of the Cosmos Program Analysis Group Report

Mark Bautz, *Massachusetts Institute of Technology*
John Conklin, *University of Florida*

The Physics of the Cosmos Program Analysis Group (PhysPAG) includes everyone interested in NASA's Physics of the Cosmos (PCOS) program. If you're reading this, you should probably consider yourself a member. Our purpose is to facilitate communication between the greater PCOS community and NASA, and the record shows that NASA listens to our community. More information about the PhysPAG and its executive committee is available **here**. Your input is always welcome.

Once again this year the PhysPAG supported NASA's assessment of technology development needs for future PCOS strategic missions. With the 2020 Decadal Survey not far off, a strategic mission study of *Lynx* well underway, and U.S. scientists helping to formulate ESA's *Athena* and

LISA missions, this year's exercise was particularly significant. As always, the PhysPAG solicited and consolidated community input on technology development needs ("technology gaps" in PCOS parlance) and forwarded that input to NASA's PCOS program office. NASA then prioritized these needs for purposes of funding future technology development. See the **PCOS 2017 Technology Gap Prioritization article** for details of this process. The prioritization results are published in the **2017 PCOS Program Annual Technology Report**.

The PhysPAG is also responding to a **request for information** from NASA's Science Mission Directorate's senior leadership about whether and how NASA might better solicit high impact, high risk research. One top level question was "Does the NASA's Science Mission Directorate Research and Analysis program have effective processes in place to solicit, review, and select high impact, high risk research projects?" Your PhysPAG Executive Committee and Astrophysics Division Research and Analysis lead Dan Evans discussed and then agreed that it would be worthwhile to encourage more high-impact research, which would require some modification of current NASA solicitation and proposal review practices. The PhysPAG will start soliciting broader PCOS community input on this topic soon: we welcome your input!

The next face-to-face meeting of the PhysPAG is scheduled as part of the January AAS meeting in National Harbor, Maryland on Monday, January 8, 2018. Our agenda will include discussion of a new PhysPAG initiative to consider ways to inform and shape NASA's response to the breathtaking new opportunities in multimessenger astrophysics presented in part by the advent of gravitational wave astronomy. Please plan to join us there.

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The Laser Interferometer Space Antenna (LISA)

Ira Thorpe, *NASA Goddard Space Flight Center*
David Shoemaker, *Massachusetts Institute of Technology*

The long-running effort to realize a space-based gravitational wave observatory gathered considerable steam during the latter half of 2016 and the first half of 2017. ESA's LISA Pathfinder spacecraft continued its mission to validate and characterize key LISA technologies. The first results obtained in Spring 2016 demonstrated near-perfect inertial flight of twin gold-platinum test masses, with deviations from free-fall measured in femto-g's. In July 2016, NASA's Disturbance Reduction System (DRS) payload was commissioned. The DRS used inputs from the European sensors and steered the spacecraft using an advanced electric micropropulsion system. The US and European teams continued to collaborate during the remainder of the nominal mission, through December 2016, and were awarded an extension into mid-2017 by both ESA and NASA. During this extended mission, additional tests were carried out to better understand the flight system and provide the developers of LISA with additional information. After achieving all its goals, on June 30th, 2017 the LISA Pathfinder mission ended.

In parallel with LISA Pathfinder's operations, ESA issued a call for mission concepts to fulfill the Gravitational Universe science theme in October of 2016 and the community responded with a proposal for the main LISA mission in January 2017. This version of LISA looks very much like that proposed for the 2010 Decadal Survey, with a complete triangular constellation of three arms spanning 2.5 million kilometers each. The three-arm configuration maximizes the scientific return by providing polarization information and also allows for graceful science degradation in the event of an interruption along one arm. On June 20th, 2017 ESA's Science Program Committee selected this proposal for the L3 mission slot. ESA, NASA, and the international science community continue to work together through the next phases of the project, with ESA expecting to enter Phase A in early 2018. In addition, the science community is working to identify and address pre-launch data analysis and astrophysics research tasks that will fully realize LISA's science potential.

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Athena: Revealing the Hot and Energetic Universe

Kirpal Nandra, *Max Planck Institut für Extraterrestrische Physik*
Didier Barret, *Institut de Recherche en Astrophysique et Planétologie*
Francisco J. Carrera, *Instituto de Física de Cantabria and Consejo Superior de Investigaciones Científicas - Universidad de Cantabria*
Robert Petre, *NASA Goddard Space Flight Center*
Randall Smith, *Harvard-Smithsonian Center for Astrophysics*
for the *Athena* Science Study Team (ASST), the *Athena* Community Office, and the US *Athena* Team

Athena will form part of a suite of major facilities across the wavebands operating in the late 2020s, which can work together to revolutionize studies of the early universe and the formation of structure, as well as new fields like multimessenger astrophysics. To probe these topics more deeply, the ASST has initiated a series of synergy studies. The first such exercise was the ESO-*Athena* Synergy Workshop, and the resulting **white paper** has been published. Synergies between the Square Kilometer Array (SKA) telescope and the *Athena* mission were discussed at a **workshop** held on April 24–25, 2017 at the SKA Organisation Headquarters at Jodrell Bank, UK. Planning is underway for the second major *Athena* science symposium, to be held in late September 2018.

One substantial issue *Athena* has faced is the estimate of the mission cost to ESA. The estimated cost exceeds the cap of €1.05B specified by the ESA Science Program Committee at the time *Athena* was selected, making cost mitigation mandatory. Cost mitigation options were defined to preserve the mission's best possible science performance while meeting its imposed programmatic constraints. The science community was fully involved in this via the *Athena* Cost-driven Observation Reprogramming Exercise, which was able to reuse a lot of the analysis done for the earlier "Science Impacts of the Mass-Saving Options" exercise. The initial proposal under consideration was to remove 5 rows of mirrors (reducing area at 1 keV to 1.4 m^2); to remove the deployable sunshield and solar array drive mechanism (with the effect of reducing the field of regard and impacting target-of-opportunity capabilities); and to reduce the baseline mission life from five to four years. Based on inputs from the science working groups, the ASST recommended preserving the capability of the mission to access the transient sky as otherwise key science objectives would be compromised, e.g., the studies of the warm-hot intergalactic medium via GRB followup. On the other hand, the ASST recommended that every effort should be made to retain at least some mirror rows to the design.

Athena continues to progress through an intensive Phase A study, with emphasis on the definition of the science instrument module holding the X-ray Integral Field Unit and the Wide Field Imager. In the coming six months the ESA study team, the two instrument teams, and the two competing industrial teams will work together to define, a new baseline configuration for *Athena* by mid-2018, meeting the cost, mass, and schedule constraints that will be taken forward through Phase A and beyond.

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Euclid: Probing the Geometry and Dark Side of the Universe

Ulf Israelsson, *Jet Propulsion Laboratory*

Euclid is a medium class survey mission under ESA's Cosmic Vision Science program. It will measure galaxy clustering and weak lensing in order to constrain dark energy and gravity models and to learn more about the nature of dark matter and the initial conditions that gave rise to the large-scale structure seen today.

There are three specific NASA contributions to the *Euclid* mission:

- The principal investigator teams led by Jason Rhodes (JPL), Ranga-Ram Chary (Caltech), and Alexander Kashlinsky (GSFC) are members of the *Euclid* Consortium, contributing to scientific data analysis and processing aspects of the mission.
- The ***Euclid* NASA Science Center at IPAC** team led by George Helou (Caltech) supports

the US PI teams and serves as the US node in the overall *Euclid* Science Ground System.

- Sixteen Sensor Chip Systems consisting of detectors, cold flexible cables, and cold readouts for *Euclid*'s Near Infrared Spectrometer and Photometer instrument focal plane are in development by JPL. Testing prior to delivery is done at GSFC's Detector Characterization Laboratory.

The US *Euclid* effort has made substantial progress over the past year working with ESA and the *Euclid* Consortium. On the hardware side, 9 of the 16 detectors and cold flexible cables required for the focal plane have been delivered to date, with the remaining 7 in testing at GSFC for delivery to ESA over the coming months. A reliability issue was discovered with the detector readouts during final acceptance testing. NASA convened a tiger team and their final, released report made clear that design changes are necessary to guarantee reliability. Two different options for the new readouts are underway, with a Preliminary Design Review planned for one of the options in early December 2017.

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PCOS 2017 Technology Gap Prioritization

Thai Pham, Harley Thronson, and Opher Ganel
PCOS *Program Technologists, NASA Goddard Space Flight Center*

The PCOS Program Office (PO) solicited technology gaps from the community to inform NASA Astrophysics Division's technology planning, solicitation, and selection. To ensure the gaps are accurate, compelling, and without overlap, the PO forwarded to the PCOS Program Analysis Group

Table 2. Prioritized technology gaps

Priority	Technology Gap Title	Submitted by
1	Highly stable low-stray-light telescope	L3ST
	Low-mass, long-term-stability optical bench	L3ST
	Precision microthrusters	L3ST
	High-power, narrow-line-width laser sources	L3ST
	Phase-measurement system (PMS)	L3ST
	Large-format, high-spectral-resolution, small-pixel X-ray focal plane arrays	Lynx STDT
	Fast, low-noise, megapixel X-ray imaging arrays with moderate spectral resolution	Lynx STDT
	High-efficiency X-ray grating arrays for high-resolution spectroscopy	Lynx STDT
	High-resolution, large-area, lightweight X-ray optics	Lynx STDT
	Non-deforming X-ray reflective coatings	Lynx STDT
	Long-wavelength-blocking filters for X-ray micro-calorimeters	Lynx STDT
2	Non-contact charge control for Gravitational Reference Sensors (GRS)	L3ST
	Advanced millimeter-wave focal plane arrays for CMB polarimetry	Community
	Polarization-preserving millimeter-wave optical elements	Community
	High-efficiency, low-cost cooling systems for temperatures near 100 mK	Community
	Rapid readout electronics for X-ray detectors	Community
	Optical-blocking filters (OBF)	Community
3	Gravitational reference sensor (GRS)	L3ST
	Very-wide-field focusing instrument for time-domain X-ray astronomy	Community
	Ultra-high-resolution focusing X-ray observatory telescope	Community
	Advancement of X-ray polarimeter sensitivity using negative-ion gas	Community
4	Low-power, low-resolution continuous GSa/s direct RF digitizer	Community
	Tileable, 2-D proportional-counter arrays	Community
	High-performance gamma-ray telescope	Community
	Lattice optical clock for Solar Time Delay (STD) mission and other applications	Community
	Fast, few-photon UV detectors	Community
	Lightweight, large-area reflective optics	Community
	Low-power time-sampling readout	Community
	Low-power comparators and logic arrays	Community

(PhysPAG) Executive Committee (EC) the 25 gaps from 2016 plus nine new entries.

In parallel, the L3 Study Team (L3ST) and the *Lynx* Science and Technology Definition Team (STDT) submitted seven and six gaps, respectively, to the PO. The Program Technology Management Board (TMB) reviewed and consolidated the lists received from PhysPAG and the study teams into 29 distinct and practicable gaps. The PO appreciates the support and input of the community, PhysPAG, and the study teams, which helps keep our gap list relevant and up to date.

The TMB used four criteria to arrive at priority recommendations: **Strategic Alignment**, **Benefits and Impacts**, **Scope of Applicability**, and **Urgency**, grouping gaps into tiers based on priority scores (see **Table 2**). All gaps within a tier have equal priority. This year, the TMB added a fourth tier for gaps not aligned with any strategic mission. Tier 4 gaps will not be automatically included in the 2018 process unless they are resubmitted with a convincing strategic alignment rationale, while those in tiers 3 and higher will. For complete details of gaps, please see Appendix A of our **2017 Program Annual Technology Report** (PATR).

By submitting new technology gaps and proposing edits to existing ones, the community helps NASA identify and fund the highest priority ones through such means as the **Strategic Astrophysics Technology** (SAT) program. Notice of intent to submit to the next SAT round are due 18 Jan 2018, while proposals are due 15 Mar 2018. The PO encourages community proposals as well as any new or modifications to technology gaps. Community gaps submitted by 1 Jun 2018 and STDT and PhysPAG gaps submitted by 30 Jun 2018 will be included in the 2018 prioritization process.

The **PCOS Program website** and the 2017 PCOS PATR have more details on PCOS science, our technology development program and process, recent SAT selections, and the status and plans of all current PCOS strategic technology development projects. The **technology webpage** contains a new searchable database of all current and past PCOS/COR strategic technology development projects. We welcome your questions or comments on our process or any other aspect of the Program, which should be directed to the **PCOS Technology Development Manager**.

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Message from the Astrophysics Division Director

Paul Hertz, *Astrophysics Division Director*, *NASA Headquarters*
August 2017

As I described during the NASA Town Hall at the 230th meeting of the American Astronomical Society (AAS), June 2017 in Austin, TX, the Astrophysics Division is continuing to execute a broad portfolio of research activities and missions for the community, many of which were the subject of sessions at the AAS meeting. In order to maximize the science return from the NASA astrophysics program, we rely on community participation at every level of the program. This includes the Astrophysics Advisory Committee (formally the Astrophysics Subcommittee), the Program Analysis Groups (PAGs), Science and Technology Development Teams for future missions, mission and archive User Groups, and peer review panels. I invite you to self-nominate yourself to participate in any of these community groups.

The FY17 appropriation and FY18 budget request provide funding for NASA astrophysics to continue its planned programs, missions, projects, research, and technology. The operating missions continue to generate important and compelling science results, and new missions are under development for the future. The next Senior Review of operating missions is in 2019. SOFIA is adding new instruments: the High-resolution Airborne Wideband Camera-plus (HAWC+) instrument has been commissioned; the High-Resolution Mid-Infrared Spectrometer (HIRMES) instrument is in development; a next generation instrument call is planned for early 2018. The Neutron Star Interior Composition Explorer (NICER), an Explorer Mission of Opportunity, was launched to the International Space Station (ISS) on June 3, 2017, with the science program starting in mid-July. NASA missions under development making progress toward launches: ISS-Cosmic Ray Energetics and Mass (CREAM) (2017), Transiting Exoplanet Spectroscopic Survey Satellite (TESS)

(2018), James Webb Space Telescope (2018), Imaging X-ray Polarimetry Explorer (IXPE) (2020), and Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO) (2021), Wide Field Infrared Survey Telescope (WFIRST) (mid-2020s). Partnerships with ESA and JAXA on future missions create additional science opportunities: *Euclid* (ESA; 2020), X-ray Astronomy Recovery Mission (XARM) (JAXA; 2021), *Athena* (ESA; 2028), LISA (ESA; 2034). Explorer AOs are being released every 2–3 years: MIDEX/MO selections are targeted for Summer 2017, and the next SMEX/MO Announcement of Opportunity in 2019.

NASA supports the astrophysics community through a number of competed programs, including Guest Observer/Guest Investigator (GO) programs, Research and Analysis (R&A) programs, and Postdoctoral Fellowship (*Hubble*, *Einstein*, and *Sagan*) programs. Funding for R&A has been increased by 20% since the 2010 Decadal Survey. However, proposal numbers have grown faster than funding over this period, so selection rates have fallen. The 2017 Research Opportunities for Space and Earth Science (ROSES) solicitation was released on February 14, 2017 and posted at **http://nspires.nasaprs.com/**.

NASA continues to make progress developing the James Webb Space Telescope according to plan during the integration and test phase. The ambient testing of the science payload has been completed at Goddard Space Flight Center, and it has been shipped to Johnson Space Center where end-to-end performance testing of the telescope and instruments are being conducted in space-like conditions within Chamber A; the spacecraft assembly is nearly complete at Northrup Grumman Space Park in Redondo Beach, CA; the spacecraft and sunshields will be completed and integrated this year. 2017 is also the year that the science community begins developing the Webb Telescope's science program. The call for Early Release science was issued in January 2017, and the call for Cycle 1 General Observer proposals will be issued in November 2017. Webb remains on cost and on schedule for an October 2018 launch. Information on the Webb Telescope is at **https://jwst.nasa.gov/**, and information on the proposal opportunities is at **https://jwst.stsci.edu/**.

Two critical mission technologies for the Wide-Field Infrared Survey Telescope (WFIRST) have successfully completed three-year technology demonstration activities. NASA is conducting a WFIRST Independent External Technical/Cost/Management Review (WIETR) in response to findings and recommendations in the National Academies' Midterm Assessment. Information on WFIRST is at **https://wfirst.gsfc.nasa.gov/**.

The National Academies conducted a review of NASA's progress during the first half of the decade, and NASA's plans during the second half of the decade, for implementing the 2010 Decadal Survey. This Midterm Assessment, available at **http://www.nap.edu/download/23560**, made recommendations to NASA regarding its implementation of WFIRST, the Explorers Program, and U.S. contributions to the European Space Agency's *Euclid*, *Athena*, and gravitational wave missions. NASA will be implementing all of the Midterm Assessment's recommendations; the full details can be found in the 2016 Astrophysics Implementation Plan Update at **https://science.nasa.gov/astrophysics/documents/**.

NASA is sponsoring community-based studies in preparation for the 2020 Decadal Survey. Four mission concept studies for large missions are underway. Each study is being led by a Science and Technology Development Team supported by the engineering capabilities of a NASA Center. The entire community is invited to get involved with one or more of these studies; links to each of the studies is at **http://science.nasa.gov/astrophysics/2020-decadal-survey-planning/**. NASA has solicited proposals to conduct mission concept studies for medium-size missions (probes), and selected ten proposals for mission concept studies. The probes implementation plan is available at **https://science.nasa.gov/astrophysics/2020-decadal-survey-planning**.

My entire Town Hall presentation from the June 2017 AAS meeting, which includes information on additional topics across the breadth of NASA astrophysics, is available at **http://science.nasa.gov/astrophysics/documents/**

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PCOS Organization

Program Office

Program Manager:
Mansoor Ahmed, mansoor.ahmed@nasa.gov
Deputy Program Manager:
Azita Valinia, azita.valinia-1@nasa.gov
Chief Scientist (Acting):
Terri J. Brandt, t.j.brandt@nasa.gov
Chief Technologist:
Harley Thronson, harley.a.thronson@nasa.gov
Technology Development Manager:
Thai Pham, bruce.t.pham@nasa.gov

Newsletter Team

Editor:
Terri J. Brandt, t.j.brandt@nasa.gov
Assistant Editor:
Panayiotis Tzanavaris, panayiotis.tzanavaris-1@nasa.gov
Desktop Publisher:
Pat Tyler, patricia.a.tyler@nasa.gov

Headquarters

Program Executive:
Shahid Habib, shahid.habib-1@nasa.gov
Program Scientist:
Rita Sambruna, rita.m.sambruna@nasa.gov
Deputy Program Scientists:
Daniel Evans, daniel.a.evans@nasa.gov
Thomas Hams, Thomas.Hams@nasa.gov

Calendar of Upcoming PCOS/PhysPAG Events

8–12 January 2018	AAS 231st Meeting Gaylord National Resort & Convention Center 201 Waterfront St., National Harbor, MD 20745
18–21 March 2018	HEAD Special Meeting: High Energy Astrophysics in the 2020s and Beyond Chicago, Illinois, USA
14–17 April 2018	APS April Meeting Columbus, OH

To stay up to date on PCOS and the PhysPAG
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