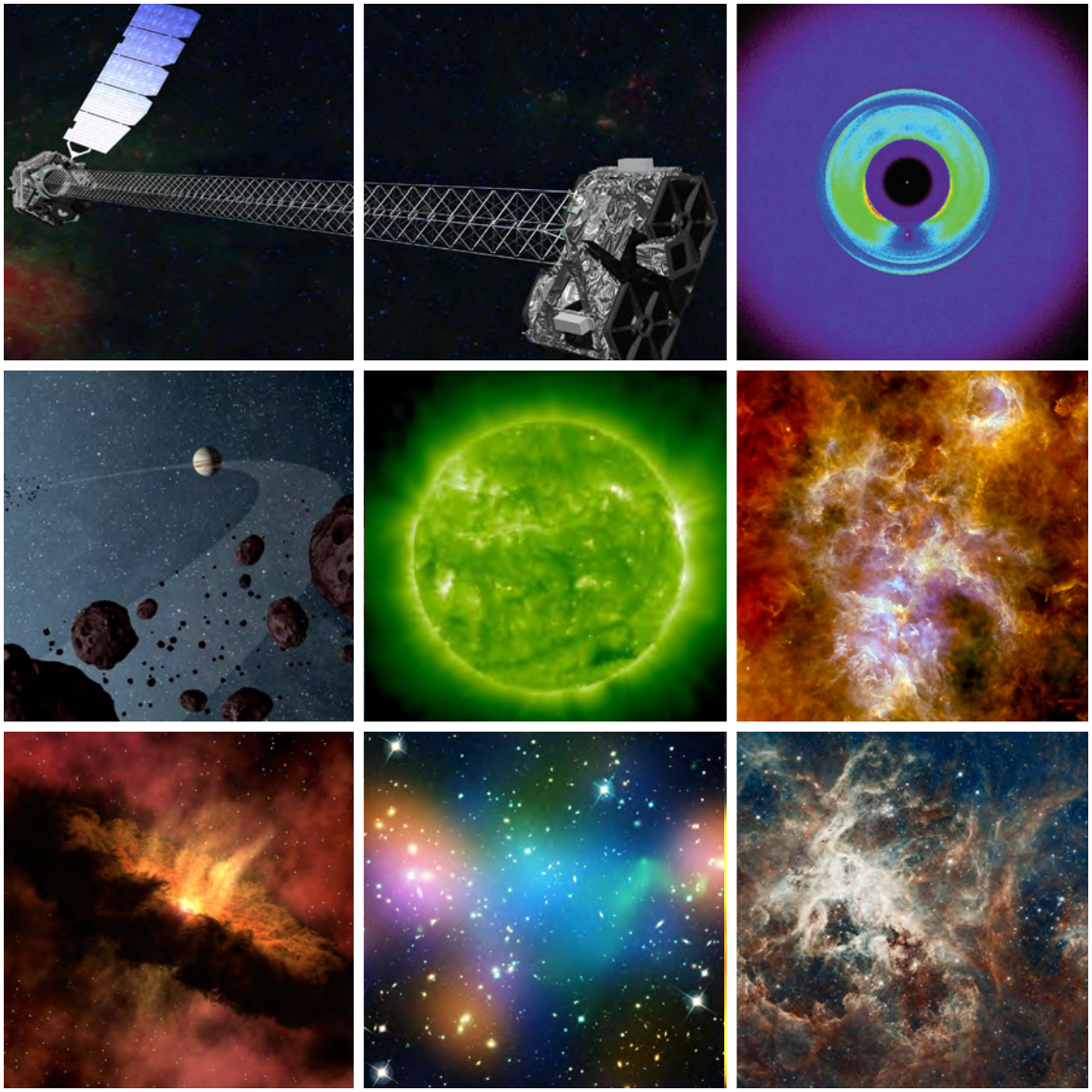
NASA/TM-2013-217509

Goddard's Astrophysics Science Division Annual Report 2012

Padi Boyd and Francis Reddy, Editors
Pat Tyler, Graphical Editor



NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

May 2013

The NASA STI Program Office … in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov/STI-homepage.html
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (443) 757-5803
- Telephone the NASA Access Help Desk at (443) 757-5802
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076

NASA/TM-2013-217509

Goddard's Astrophysics Science Division Annual Report 2012

Padi Boyd
NASA Goddard Space Flight Center, Greenbelt, Maryland

Francis Reddy
Syneren Technologies, Inc., Greenbelt, Maryland

Pat Tyler, Graphical Editor
Syneren Technologies, Inc., Greenbelt, Maryland

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

May 2013

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Table of Contents

2012: Year in Review

This was a year of highs and lows for the Astrophysics Science Division at Goddard.

The Gravity and Extreme Magnetism (GEMS) Small Explorer, an X-ray polarization mission to investigate strong gravity near spinning black holes and strong magnetic fields near pulsars and magnetars, which was being managed and developed at Goddard, was not confirmed to proceed into development. As can be imagined, this was a great disappointment to the team and to Goddard as a whole. The X-ray polarimeters—the heart of the mission—achieved a technology readiness level of 6 in October 2011, and the Integrated Independent Review Team (IIRT) judged the instrument ready to proceed into development. A Preliminary Design Review (PDR) was held in February 2012, and the Standing Review Board (SRB) stated that the mission met or exceeded PDR success criteria. However, in May 2012, NASA decided not to let the mission transition into the development phase, citing independent cost estimates that exceeded the cost cap by a significant margin. This was a difficult decision to accept, but we are collecting and studying the lessons learned and are moving forward with thoughts on how to employ this X-ray polarimetry technology in the future.

Early in the year, we also learned that the WFIRST mission, the 2010 Decadal's highest-rated large space mission, was not included in the president's budget from FY13 to FY17. A previous Science Definition Team (SDT), together with the WFIRST Project office at Goddard, had done an excellent job of re-designing the JDEM mission, proposed to the Decadal survey, to do the science envisioned for the WFIRST mission, which included microlensing, and sky surveys, as well as the dark energy surveys. As the SDT's efforts wound down, we learned that two optical telescope assemblies (OTAs) were being donated to NASA from another federal agency. These OTAs had primary mirrors of 2.4 m in diameter, and were diffraction limited over a large field of view—perfect for a dark energy survey. A new SDT was formed to study the use of these OTAs for WFIRST, and their report is due in the spring of 2013. Clearly, the larger aperture afforded by one of these OTAs would make WFIRST much more capable than the previous designs employing apertures half that size. We certainly hope that the budget will allow WFIRST to begin development in FY14.

Finally, we said goodbye to a reliable old friend in January 2012, when the Rossi X-ray Timing Explorer (RXTE) mission was decommissioned after 16 successful years of operation. RXTE featured unprecedented time resolution in combination with moderate spectral resolution to explore the variability of X-ray sources on timescales from milliseconds to decades. It was a ground-breaking mission that resulted in 2,049 refereed papers published from 1996–2011 and 91 Ph.D. theses. Jean Swank was the project scientist for the mission, and Tod Strohmayer succeeded her in the later years of the mission. In the spring of 2012, more than 100 scientists from around the world attended the Goddard meeting "16 Years of Discovery with RXTE: A Celebration of the Mission."

During the year, NASA selected our proposed upgrade of the HAWC instrument on SOFIA, led by Johannes Staguhn of Johns Hopkins University. Goddard will contribute upgraded detector arrays to enable wide-field polarimetric imaging of dust. Dominic Benford is the Goddard lead, and the team also includes Ed Wollack and Eli Dwek, with Harvey Moseley as a collaborator. The team is partnering with a JPL-led group (including Dave Chuss from Goddard) providing polarimetric optics to realize both new and greatly increased capability for SOFIA. Darren Dowell of JPL is the overall PI of the combined development.

Significant progress has been made on the Astro-H mission, for which Goddard is supplying the X-ray calorimeter instrument (SXS) and X-ray mirror. Engineering models of the detector and mirrors were shipped to JAXA in 2012, and testing has begun. Despite a failure of a heat switch, work-arounds were successful, allowing cold-alignment measurements and some performance tests. The heat switch has been redesigned and will be incorporated in the flight system after extensive testing. Near the close of the year, the first flight mirror was tested at Goddard, and found to meet the requirements by a healthy margin. Excellent progress is also being made on the flight detectors.

Scientists from ASD are significantly involved in the development of NASA's highest-priority mission, the James Webb Space Telescope (JWST). We have 11 project scientists working on the mission, covering the instruments, telescope, ground system, testing program and outreach program. JWST was re-planned in 2011, and is now set for launch in 2018. During 2012, significant progress was made and the project is on-schedule and within the re-phased budget. All mirror segments have been coated and polished, and two of the flight instruments have been delivered to Goddard for testing (the other two will be delivered in 2013). Cryogenic testing has begun and will pick up steam in 2013. A more complete summary of JWST status can be found in the "Projects in Development" section.

The Neutron Interior Composition ExploreR (NICER) team finished their 11-month Phase A study and turned in their Concept Study Report (CSR). Keith Gendreau, the PI, promptly took a few hours off before beginning to prepare for the NASA site visit in late January 2013. NICER is an X-ray timing instrument proposed for installation on the ISS. This instrument will deliver the science of a full Explorer mission for half the price of a SMEX!

The Transiting Exoplanet Survey Satellite (TESS), with George Ricker/MIT as PI, also submitted their CSR as an EX-class Explorer. TESS proposes to conduct an all-sky survey of nearby bright stars for exoplanets. Goddard is providing project management, systems engineering and science team members to the TESS team. Stephen Rinehart is the GSFC project scientist.

The NuSTAR Explorer mission (Fiona Harrison, PI/Caltech) was successfully launched on June 13. NuSTAR carries the first space telescope for imaging in the hard X-ray band. The glass segments for its two X-ray mirrors were fabricated by a team led by Will Zhang in our X-ray astrophysics Lab. Zhang also serves as the mission scientist. Ann Hornschemeier, Andy Ptak, Craig Markwardt, Jane Rigby, Stacy Teng, Bret Lehmer and Dan Wik are contributing to analysis of the early science data and observatory operations.

Our suite of operating missions continue to make new discoveries and push the limits of their capabilities beyond what they were originally designed to do. The veteran Hubble Space Telescope shows no signs of slowing down its research productivity after 22 years in orbit and is now operating at the peak of its scientific capabilities. Recent discoveries include finding a fifth moon around Pluto, determining the trajectory of the Andromeda galaxy, which appears to be on a collision course with the Milky Way in the distant future, uncovering a "Waterworld"—a new class of exoplanet—and detecting changes in a distant exoplanet's atmosphere While it continues to chase and follow up gamma-ray bursts, the Swift satellite has also recently made multiwavelength observations of comets, galactic black holes, ultraluminous X-ray sources in other galaxies, and even detected the first-ever changes in an exoplanet's atmosphere. Similarly expanding its reach, the Fermi Gamma-ray Space Telescope has made recent new strides in observing solar flares, gamma-ray flashes from terrestrial thunderstorms, dark matter and ancient starlight. All missions completed the 2012 NASA Senior Review of the Astrophysics Division Operating Missions and were awarded funds to continue operations. Preparations will soon be underway for the 2014 Senior Review which will be used for planning FY15 budgets for the operating missions.

The Wide-field Infrared Survey Explorer (WISE) team (Ned Wright, PI/UCLA) announced its All-Sky Data Release, the public dissemination of a whole-sky catalog and image database for the mid-infrared. David Leisawitz (Goddard) is the WISE mission scientist, Dominic Benford is the WISE deputy mission scientist, and Debbie Padgett is a member of the science team. Goddard postdoctoral fellows Xavier Koenig and Nick Bond are also involved with WISE science data analysis. All of them contributed to the Data Release and its accompanying Explanatory Supplement. The WISE All-Sky Data Release contains about 1.5 million individual WISE exposures, a coadded image atlas of 18,240 images covering the sky, and a catalog listing the infrared properties of around 564 million individual objects found in the images. WISE, launched on December 14, 2009, mapped the entire sky in 2010 with vastly better sensitivity and angular resolution than its predecessors.

Bill Danchi and Karl Stapelfeldt of our Exoplanets and Stellar Astrophysics Lab, were selected as members of NASA's Exozodi Key Science Team for the Large Binocular Telescope Interferometer (LBTI). Alycia Weinberger (Carnegie DTM) was also selected with Aki Roberge as a collaborator. The LBTI is a NASA-funded mid-infrared instrument that will null beams from the LBT's two 8-meter telescopes to perform the most sensitive survey yet for dust in the habitable zones of nearby stars.

In high-contrast imaging technology development, Rick Lyon and Mark Clampin have achieved $> 10^{-9}$ contrast in laboratory tests of the Goddard Visible Nulling Coronagraph (VNC). This effectively meets the contrast milestone requirement of their ROSES Technology Development for Exoplanet Missions (TDEM) project. The contrast achieved is averaged over a region extending from 1–4 telescope resolution elements from a simulated star, over a 60-degree arc in azimuth, and using narrowband light at a wavelength of 0.6328 nanometers. The next milestone in the coming year is to achieve this result in a wider bandpass. The VNC is a very promising coronagraph technology for the future because it works with a segmented primary mirror.

This was an excellent year for our suborbital missions. In October, the ProtoEXIST balloon instrument had a successful flight from Fort Sumner, N.M. It is a sensitive hard X-ray imager observing black hole sources. The PI is J. Grindlay (Harvard) and the detector electronics and mechanical/thermal packaging system was developed at Goddard by Scott Barthelmy and others in the Astroparticle Physics Lab. The flight

had 8 hours time at float with successful observations of 4 sources.

On December 12, we also had a successful sounding rocket launch of the DXL/STORM payload from White Sands. DXL is the "Diffuse X-ray from the Local Galaxy" instrument (Massimillano Galeazzi, U of Miami, PI) built in collaboration with Goddard (Scott Porter is the lead scientist in our Division). The goal was to obtain observations of heliospheric Solar Wind Charge Exchange (SWCX) and differentiate the foreground SWCX emission from the background emission from the Local (interstellar) Hot Bubble separately in the 0.25 keV and 0.75 keV bands. Real-time data indicated a clear detection of the He focusing cone. The DXL instrument also demonstrated the first use of "Lobster-eye optics" in space.

The Super-TIGER (Super Trans-Iron Galactic Element Recorder) team completed an exceptionally successful Antarctic long-duration balloon flight to investigate the origins of cosmic rays. The instrument launched on December 8, 2012, from McMurdo Station, and it flew for slightly over 55 days, making nearly three circumnavigations of Antarctica. The flight set two duration records: longest flight for a heavy scientific payload and the longest flight of a heavy-lift scientific balloon, including NASA's Long Duration Balloons. Super-TIGER measured the element abundances and energy spectra of cosmic-ray nuclei heavier than iron with nearly an order of magnitude higher sensitivity than any previous balloon or satellite instrument. These measurements will provide definitive tests of current theories of the origin and acceleration sites of cosmic ray nuclei and the mechanism by which different nuclei are selected for acceleration, addressing the ongoing mystery of the origins of cosmic rays, which has persisted ever since their discovery more than 100 years ago.

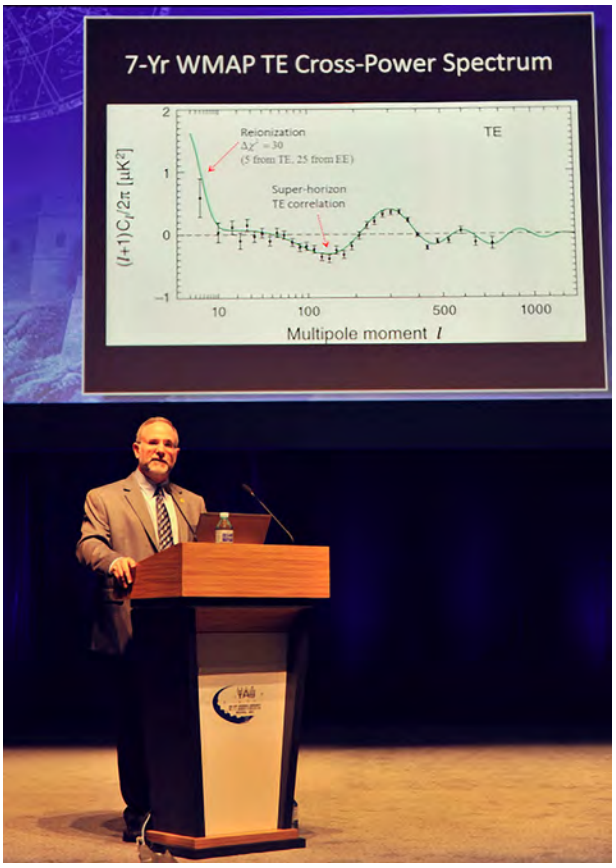
Three of our senior scientists retired in 2012: Jean Swank, Allen Sweigart and Bruce Woodgate. All have had extremely productive research careers and have contributed many decades of exceptional support to NASA missions. Luckily for us, all three will continue to come in to work (well, maybe not every day) as part of the emeritus program at Goddard.

William Oegerle
Director

Awards

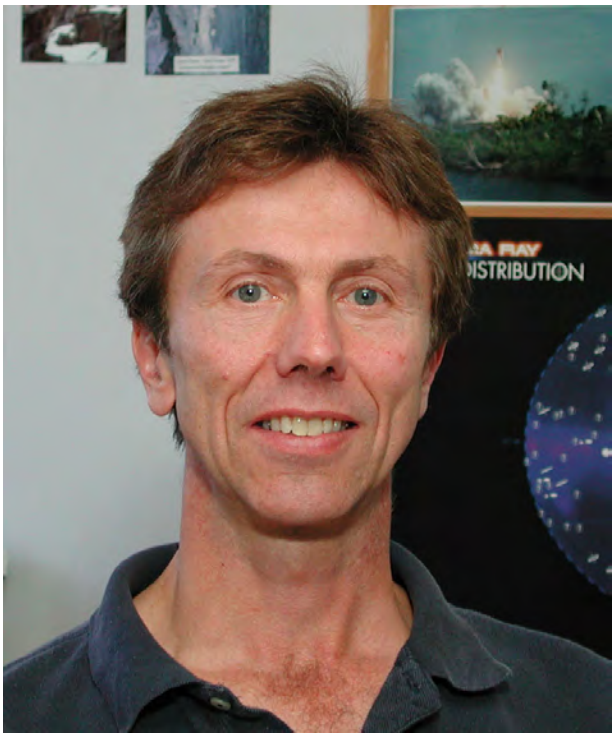
In 2012, several individuals and teams within the Astrophysics Science Division (ASD) were honored for their extraordinary contributions to their respective fields.

NASA's Wilkinson Microwave Anisotropy Probe, also known as WMAP, transformed the science of cosmology by establishing the age, geometry, and contents of the universe to astonishing precision. The Gruber Foundation recognized this outstanding accomplishment by awarding its $500,000 2012 Cosmology Prize to WMAP principal investigator Charles Bennett at Johns Hopkins University in Baltimore and the 26-member science team he led "for their exquisite measurements of anisotropies in the relic radiation from the Big Bang—the Cosmic Microwave Background." Chuck was previously a member of ASD's Observational Cosmology Lab; other Goddard members of the team include Al Kogut, Ed Wollack, Robert Hill, Michael Greason, Janet Weiland, and Nils Odegard. The annual prize, co-sponsored by the International Astronomical Union, honors a leading cosmologist, astronomer, astrophysicist or scientific philosopher for theoretical, analytical, conceptual or observational discoveries leading to fundamental advances in our understanding of the universe.



Charles Bennett (pictured) and the entire WMAP team received the 2012 Gruber Cosmology Prize at the International Astronomical Union's General Assembly in Beijing. Gruber Foundation

The Committee on Space Research, COSPAR, was established in 1958 by the International Council for Scientific Unions to promote international scientific research in space, with emphasis on the exchange of results, information and opinions, and to provide an open forum for scientists to discuss the problems that may affect scientific space research. The COSPAR Massey Award honors Sir Harrie Massey for outstanding contributions to the development of space research in which a leadership role is of particular importance. The 2012 Massey Award went to Dr. Neil Gehrels, who began his career at Goddard as an experimental physicist working in gamma-ray astronomy. Neil served as the project scientist for NASA's Compton Gamma-Ray Observatory and is the U.S. Mission Scientist for the European Space Agency's INTEGRAL satellite, the Principal Investigator for NASA's Swift mission, and a Deputy Project Scientist for NASA's Fermi Gamma-ray Space Telescope. The citation states: "Throughout his career, Dr. Gehrels has been dedicated to advancing high-energy astrophysics from



Neil Gehrels received the 2012 COSPAR Massey Award. Unless otherwise noted, all images by David Friedlander.

Alice Harding (center) received the 2012 John C. Lindsay Memorial Award on Sept. 28, 2012. The presenters are Goddard Deputy Director Dr. Colleen Hartman and Dr. Nicholas White, director of Goddard's Sciences and Exploration Directorate. NASA's Goddard Space Flight Center/Bill Hrybyk

space and to increasing our understanding of explosive events in the universe. . . . His contributions have significantly increased our understanding of gamma-ray phenomena, unveiling the long-sought origin of short gamma-ray bursts."

Dr. Alice Harding in the Gravitational Astrophysics Laboratory received the 2012 John C. Lindsay Memorial Award for Space Science for "her achievements in the understanding of pulsars, through theoretical studies and interpretation of data from the Fermi mission." Her work focuses on understanding the mechanisms by which pulsars emit gamma rays. Launched in 2008, Fermi has increased the known number of gamma-ray-emitting pulsars from less than ten to more than 100. The award honors Dr. John C. Lindsay, who joined NASA Goddard on December 28, 1958, and pioneered exploration of the sun by both satellite- and rocket-borne experiments, and commemorates the launch of the first Orbiting Solar Observatory on March 7, 1962. It is the highest space science honor Goddard bestows and is awarded annually to employees who best exhibit the qualities of broad scientific accomplishments in the field.

Rick Lyon in the Exoplanets and Stellar Astrophysics Lab received the 2012 James Kerley Award, which is presented annually by Goddard's Innovative Partnerships Office. Rick is being honored "for his enthusiasm and technical leadership in technology development and his support in outreaching to industry for commercial and other Government Agency applications of the Wavefront Sensing suite of technologies." The award is named for James Kerley, a former Goddard employee who was a champion of technology transfer and commercialization.

Dr. Julie McEnery, the project scientist for the Fermi mission, was elected a Fellow of the American Physical Society (APS), the world's second largest organization of physicists. APS Fellows are recognized by their peers for advances made in knowledge, through original research and publications. Her citation reads:

"For her fundamental contributions to the understanding of the gamma-ray sky through her leadership of the Fermi mission as Project Scientist and her discoveries of gamma-ray burst high energy properties."

Many ASD personnel received recognition from the American Astronomical Society (AAS) in the past year.

Dr. Don Reames, a former civil servant in the Laboratory for High Energy Astrophysics at Goddard and now an emeritus scientist, was awarded the society's 2012 George Ellery Hale Prize, an international award given annually to a scientist for outstanding contributions to the field of solar astronomy over an extended period of time. The citation reads: "In recognition of his pioneering work on the composition and transport of Solar Energetic Particles, and for the key insights that firmly established the modern paradigm for SEP production, the 2012 Hale Prize is awarded to Don Reames of the NASA Goddard Space Flight Center." Don participated in the design, construction and testing of the Energetic Particles, Acceleration, Composition and Transport (EPACT) experiment on NASA's Wind spacecraft, which launched in 1994. EPACT is 100 times more sensitive than previous instruments and continues to greatly extend the element and isotope resolution and the energy coverage of particle observations. He is also a co-investigator on the In-situ Measurements of Particles and CME Transients (IMPACT) experiment on the NASA's STEREO mission, launched in 2006. The Hale Prize is named in memory of solar astronomer George Ellery Hale.

Alice Olmstead, a graduate student at the University of Maryland, College Park (UMCP), was one of nine graduate student winners—out of about 260 entrants—of the Chambliss Astronomy Achievement Awards, given to recognize exemplary research by undergraduate and graduate students who present at one of the AAS meeting poster sessions. Her poster, "A Magnified View of Star Formation at z=0.9 from Two Lensed Galaxies," was presented at the January 2012 AAS meeting in Austin, Texas. ASD's Jane Rigby and Sylvain Veilleux (UMCP) advised this work.

Emeritus scientist Don Reames was awarded the American Astronomical Society's 2012 George Ellery Hale Prize.

Erika Nesvold, a graduate student at University of Maryland, Baltimore County, won a Student Stipend Award from the AAS Division of Dynamical Astronomy to present her work, "A New Method for Modeling Collisions in Debris Disks," at a meeting in Mount Hood, Oregon. Marc Kuchner is Erika's advisor at Goddard.

Finally, Jennifer Wiseman, now the senior project scientist for the Hubble Space Telescope, was recognized by the AAS Society Council for three years of service as an AAS Councilor, for service on the AAS Committee on Astronomy and Public Policy, and for representing the AAS Council on the U.S. National Committee of the International Astronomical Union.

New Faces in ASD

Fabio Felinto Acero

After receiving a doctorate studying supernova remnants in X-rays in CEA-Saclay near Paris, Fabio joined the TeV community as a postdoc with the High Energy Stereoscopic System collaboration for three years. He decided to bridge the gap and work on the GeV gamma-ray sky as seen by the Fermi Large Area Telescope (LAT). Fabio joined the ASD in January 2012 as a NASA Postdoctoral Program (NPP) Fellow to unveil part of the mystery of the Fermi gamma-ray sources with no multi-wavelength counterparts in existing catalogs—the "unassociated sources"—under the supervision of David Thompson. His work at Goddard will also expand his understanding of Galactic sources of cosmic rays such as supernova remnants and pulsar wind nebulae.

Laura Blecha

Laura arrived at Goddard in fall 2012 after finishing her Ph.D. at Harvard University. Prior to this, she completed an M.Phil. degree at Cambridge University in England and undergraduate work at Northwestern University. She originally hails from Manhattan, Kan. Her research concerns the behavior of supermassive black holes and their relationship with their host galaxies, particularly during galaxy mergers. Active black holes play a key role in the evolution of galaxies, and when triggered by mergers, they may be observed as dual or recoiling AGN. These phenomena provide crucial information about the growth history of supermassive black holes as well as their merger rate; such events could be detected with pulsar timing arrays or future gravitational-wave observatories. Her affiliation with ASD is primarily through membership in the Joint Space-Science Institute, which provides a great opportunity for interaction with scientists in her field both at Goddard and at the University of Maryland

Martha L. Boyer

Martha Boyer earned her Ph.D. at the University of Minnesota, working on infrared observations of resolved dwarf galaxies and globular clusters with Bob Gehrz, Evan Skillman, and Chick Woodard. After graduating, she went on to become a postdoc with Karl Gordon at the Space Telescope Science Institute in Baltimore, working on the mass loss and dust production of Asymptotic Giant Branch (AGB) stars in the Magellanic Clouds as part of the SAGE Spitzer Legacy program. She joined NASA Goddard as a James Webb Space Telescope NPP Fellow. Her main interests are the evolution of and dust production in evolved stars and how they contribute to a galaxy's evolution. She is currently working on Spitzer observations of AGB stars in nearby galaxies in anticipation of the science that will be achievable with the James Webb Space Telescope and is excited to become more involved in the telescope's development.

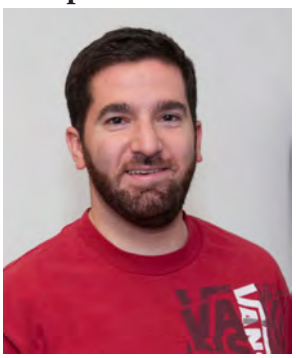
Esra Bulbul

Esra arrived in ASD in January 2012 after completing the first half of her postdoctoral appointment with Maxim Markevitch at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. She completed her PhD. at the University of Alabama in Huntsville in 2010. Her main research interest is the physics of the largest gravitationally bound objects in the universe – galaxy clusters. In particular, she looks for the observational signal of dark matter annihilation in the X-ray observations of these massive dark matter reservoirs using the XMM-Newton and Chandra satellites. She looks forward to studying high-resolution X-ray spectroscopy of galaxy clusters with the microcalorimeter array on Astro-H.

Teruaki Enoto

Teruaki Enoto arrived at ASD in July 2012 as a visitor in the X-ray polarimeter group following two years in a postdoc program at Kavli Institute for Particle Astrophysics, Stanford University. His current home is the Institute of Physical and Chemical Research (RIKEN) in Japan, working under a Superlative Postdoctoral Fellowship program of the Japan Society for the Promotion of Science (JSPS). His major research interest is X-ray observation of compact objects, especially neutron stars and ultra-strongly magnetized neutron stars. He previously worked on the development of soft gamma-ray detectors onboard ASTRO-H and also studied hard X-ray emissions from magnetars using the Suzaku and Swift satellites. In addition to his new participation in the X-ray polarization group, he is also working for the ASTRO-H science team's white paper task force, focusing on high mass X-ray binaries and magnetars.

Philip B. Graff



Philip joined ASD's Gravitational Astrophysics Lab as an NPP Fellow in September 2012. He comes to Goddard after completing his doctorate in the Cavendish Laboratory at the University of Cambridge in England. Philip works under the supervision of John Baker and is focusing on the analysis of gravitational wave data from LIGO and Virgo. This includes Bayesian inference techniques and the application of machine learning through artificial neural networks, both of which Philip is interested in applying to astrophysical data analysis in general. He looks forward to interacting with the wide community of astrophysicists at Goddard. Philip's research is aimed at accurately and quickly detecting and characterizing gravitational wave signals.

Alaina L. Henry

Alaina came to ASD in September 2012 as an NPP Fellow. She joined the division after completing her Ph.D. at UCLA and a postdoc position at UCSB. Her research investigates the formation and evolution of galaxies, from early cosmic times to today. She aims to understand feedback from galactic outflows, as well as the enrichment and reionization of the intergalactic medium. To study these issues, she uses observations from the Hubble Space Telescope, as well as Keck and Magellan Observatories. Alaina is excited about using the James Webb Space Telescope to study galaxy evolution; while at Goddard, she wants to develop plans to take advantage of its capabilities the new telescope.

Daniel Kocevski

Daniel joined ASD as an NPP Fellow in October 2012 and is participating in the Fermi mission under the supervision of Julie McEnery and Neil Gehrels. He received his doctorate from Rice University in Houston, Texas. His research interests include a broad range of topics in the field of gamma-ray burst (GRB) and time-domain astronomy. He spent the last four years as a Kavli postdoctoral fellow at SLAC, where he studied the GeV emission from gamma-ray bursts using Fermi's Large Area Telescope (LAT). He is currently the science coordinator for Fermi's GRB group and plans to further investigate the nature of high-energy emission from GRBs using joint Fermi and Swift observations.

Thomas I. Madura

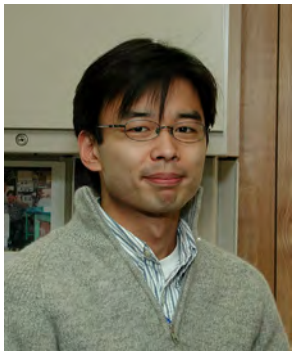
Thomas joined the ASD as an NPP Fellow in July 2012 to work with Theodore Gull in the Exoplanets and Stellar Astrophysics Laboratory. Thomas is a theoretical astrophysicist whose research interests include computational-radiation hydrodynamics, massive stars, stellar atmospheres and winds, and colliding wind binaries. A former NASA Graduate Student Researcher's Program Fellow, Thomas obtained

his Ph.D. in physics from the University of Delaware in 2010 under the supervision of Stanley Owocki. Shortly after completing his doctorate, Thomas moved to Bonn, Germany, where he was a postdoctoral researcher in the Infrared Astronomy Group at the Max Planck Institute for Radio Astronomy. His current research focuses on using supercomputers to perform state-of-the-art three-dimensional time-dependent hydrodynamical and radiative transfer simulations of the massive colliding wind binary system Eta Carinae. Thomas uses these complex 3D computer models to generate synthetic observations for comparison to data being obtained with the Hubble Space Telescope. At a distance of 7,500 light-years, Eta Carinae is the closest, most luminous evolved stellar object we can study in detail, and the closest and best example of a pre-hypernova or pre-gamma-ray-burst environment. Through his work, he hopes to help shed important new insights on our understanding of the evolution of very massive stars into supernovae, gamma-ray bursters, and black holes, both in our Galaxy and in the early universe.

Nathan Miller

Nathan joined ASD as an NPP Fellow in July 2012, where he works under the supervision of David Chuss. He received his doctorate in January 2012 from the University of California, San Diego. His research involves data analysis for experiments studying the comic microwave background (CMB). At Goddard, he will be working on understanding the systematics of and developing analysis tools for the variable-delay polarization modulator that is being developed for deployment on the PIPER and CLASS CMB experiments, which aim to detect primordial CMB B-mode polarization. He will also continue working on data analysis for the POLARBEAR CMB experiment that he performed as part of his graduate work.

Takashi Okajima



Takashi joined the X-ray Astrophysics Laboratory in July 2002 as a JSPS postdoctoral fellow and became a NASA civil servant in January 2011. He has worked on the development of X-ray mirrors and detectors for various missions for more than 15 years, including suborbital experiments and satellites. He graduated with a Ph.D. from Nagoya University in 2002 and successfully developed the first hard X-ray mirror with a depth-graded multilayer coating. It flew several times on Goddard's balloon-borne experiment, InFOCuS, and similar hard X-ray mirrors are now used on Astro-H and NuSTAR. Soon after he completed the JSPS program, he started working on developments of semiconductor hard X-ray detectors using CdZn/CdZnTe as well as improving performance of his X-ray mirrors. He has worked and has been working on upcoming InFOCuS flights, X-Calibur balloon experiments (a hard X-ray polarimeter), the XACT sounding rocket, and the GEMS mission. Takashi now leads the development of soft X-ray mirrors for two flight projects, Astro-H (2014 launch) and NICER (2016 launch). He is also interested in studies of active galactic nuclei and clusters of galaxies.

Margaret Pan

Having arrived in October 2012 from UC Berkeley, Margaret is a new NPP Fellow in ASD. Her research interests focus on planetary dynamics and its applications to a variety of solar system and exoplanetary phenomena, including Saturn's rings, the Kuiper and asteroid belts, exoplanet orbits and circumstellar debris disks. She has side interests in self-similar solutions that led to some work on ultrarelativistic shock propagation. Margaret is looking forward to studying disks and planets with the disk specialists in the Exoplanet and Stellar Astrophysics Lab. She also hopes to discuss related but more local phenomena with members of the Solar System Exploration division.

Sang Jun Lee

Sang-jun joined the X-ray Calorimeter Group at ASD in August 2012 as an NPP Fellow. He recently received his doctorate from Seoul National University (SNU) under the joint supervision of Sun Kee Kim

from SNU and Yong-Hamb Kim from the Korea Research Institute of Standards and Science. His dissertation was based on the development of low-temperature detectors for rare event experiments such as neutrinoless double beta decay and the search for dark matter. Since coming to ASD, he continues work on development of low-temperature detectors for X-ray astronomy. He is excited about the state-of-the-art scientific research going on around him.

Mairan Teodoro

Mairan arrived at Goddard in September 2012 as a science collaborator after spending two years as a post-doctoral fellow at IAG/USP in Brazil. He graduated in Physics and got his MSc. and PhD. in Astronomy from the University of São Paulo. His research is focused on massive stars. He has a good experience in observational techniques and data reduction, processing, and analysis. At Goddard, he is working with Theodore Gull on one of the most intriguing stellar objects in the sky: the "doomed star" Eta Carinae, a massive binary system with a period of 5.5 years. He is analyzing a multitude of spectroscopic data to assemble some pieces of this puzzle in order to better understand what is going on with this fascinating object. He is organizing an international, multi-spectral, and multi-institutional campaign to observe Eta Carinae during the next periastron passage in late July 2014.

Nicholas Thomas

Nick joined ADS in January 2012 after completing his Ph.D. at the University of Miami. He is a postdoc affiliated with the University of Maryland, Baltimore County and is supervised in the X-ray Astrophysics Lab by Scott Porter. He is primarily working on the Diffuse X-ray Emission from the Local Galaxy (DXL) sounding rocket mission, which had its first flight from White Sands Missile Range, N.M., in December 2012. DXL utilizes two refurbished large-area proportional counters to observe soft X-ray emission from solar wind charge exchange in the 0.25 and 0.75 keV bands. Nick also works on a prototype large-field-of-view soft X-ray camera called the Sheath Transport Observer for the Redistribution of Mass (STORM) instrument, which uses a newly developed slumped micropore ("lobster eye") optics to focus soft X-rays onto a microchannel plate detector. STORM flew on the same sounding rocket as DXL. Nick is currently assisting with data analysis for both DXL and STORM. He is extremely interested in participating in future sounding rocket missions and learning more about low-temperature detectors

Kate Whitaker

Kate joined the Observational Cosmology Lab in July of 2012 as an NPP Fellow. She recently graduated from Yale University, working with Pieter van Dokkum. Her dissertation focused on studying the properties of massive galaxies over the last 11 billion years of cosmic time with the NEWFIRM Medium-Band Survey. During her time in the ASD, Kate is excited to use Hubble Wide Field Camera 3 data from the 3D-HST and CANDELS surveys to understand what shuts off star formation in massive galaxies. She is also interested in understanding more about the stellar populations and dust properties of high-redshift galaxies.

Brian Williams

Brian Williams joined ASD's X-ray Astrophysics Laboratory as an NPP Fellow in April of 2012, working with Rob Petre. Before that, he was at North Carolina State University, where he obtained his Ph.D. in Physics in 2010 and then continued on for a short post-doc position. His research interests are in multi-wavelength observations of supernova remnants and the interaction of gas and dust behind fast shock waves. He is active in both X-ray and Infrared astronomy, having worked with data from Chandra, XMM-Newton, Suzaku, Spitzer, and Herschel. He looks forward to the opportunity to extend his research to the next generation of observatories, including NuStar, Astro-H, and the James Webb Space Telescope.

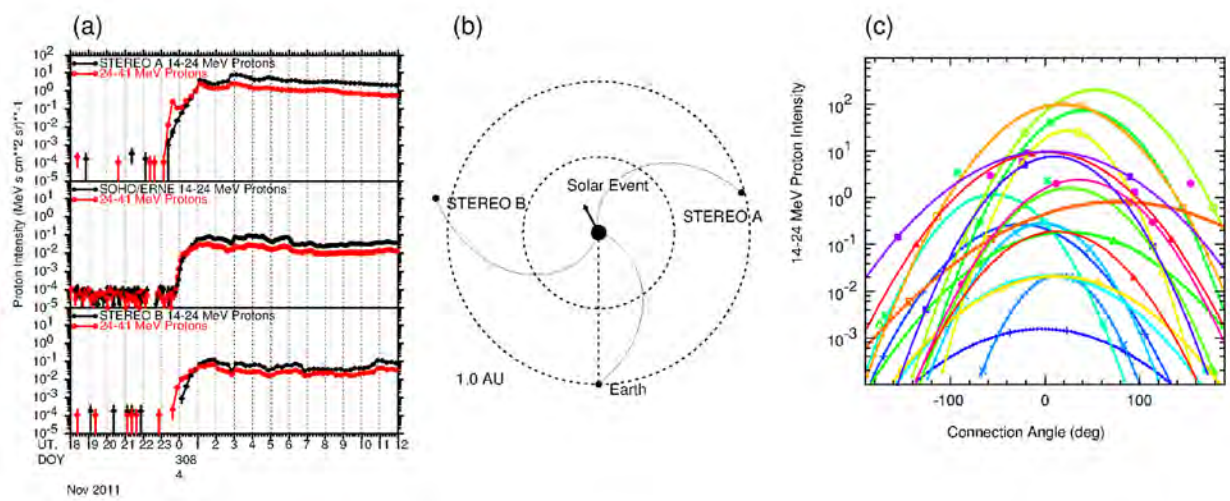
Research Highlights

STEREO Spacecraft Observations of Solar Proton Events

Drs. Tycho von Rosenvinge and Ian Richardson (Astroparticle Physics Laboratory) have been using observations from the twin STEREO A and B spacecraft and near-Earth spacecraft to investigate the propagation of energetic protons and electrons in the inner heliosphere following flares and coronal mass ejections at the Sun. The STEREO spacecraft were launched on Oct. 26, 2006, and placed into heliocentric orbits such that STEREO A (Ahead) is moving ahead of the Earth by 22° of heliolongitude/year, while STEREO B (Behind) is trailing the Earth by a similar distance. On Feb. 6, 2011, the spacecraft were 180° apart above the western and eastern limbs of the Sun as viewed from Earth, allowing, for the first time, full 360° observations of the Sun, including the far-side, which cannot be viewed from Earth.

It has long been suspected that energetic particles accelerated by solar events on the far-side of the Sun can reach Earth, but with the 360° coverage provided by STEREO this can be demonstrated unambiguously. A remarkable particle event on Nov. 3, 2011, was detected promptly at Earth and at both widely separated STEREO spacecraft following a solar far-side event that was observed directly by STEREO B.

STEREO A was most closely connected to the solar event and observed the highest proton intensities. Nevertheless, the proton enhancement was observed clearly at all the spacecraft, with the onsets at Earth and STEREO B at 14–24 MeV occurring only about 20 minutes and 40 minutes, respectively, after that at STEREO A. The whole inner heliosphere was rapidly filled with energetic protons following this event. The explanation for this is currently unclear. For example, the protons may have spread in longitude near the Sun, possibly through acceleration by an expanding shock or wave driven by the coronal mass ejection that accompanied the solar event, or by particle propagation in large-scale magnetic loops in the corona. Alternatively, the spread in longitude may have occurred in the interplanetary medium, which would then require unexpectedly large cross-field propagation. Gaussian fits to the peak 14–24 MeV proton intensity for events observed at both STEREO spacecraft and Earth plotted against the angle between the footpoint of the magnetic field line passing through the observing spacecraft and the solar event location illustrate the tendency for peak intensities to be observed at the better-connected spacecraft. The mean FWHM is 99°. Such observations may help to constrain models to explain how particles spread in longitude in the inner heliosphere. The combined spacecraft observations



The Nov. 3, 2011, solar particle event occurred on the far-side of the Sun and was observed promptly by the widely separated STEREO A and B probes and spacecraft at Earth. The first panel (left) shows intensity-time profiles of 14-24 and 24-41 MeV protons from the Goddard/CalTech High Energy Telescopes aboard the STEREO spacecraft and from the University of Turku ERNE instrument on SOHO near Earth. The diagram at center illustrates the spacecraft configuration relative to the solar event, along with nominal spiral interplanetary magnetic field lines linking the spacecraft to the Sun. Right: Gaussian fits to the peak 14–24 MeV proton intensity of events observed at both STEREO spacecraft and at Earth are plotted against the angular separation of the field line footpoint and the related solar event.

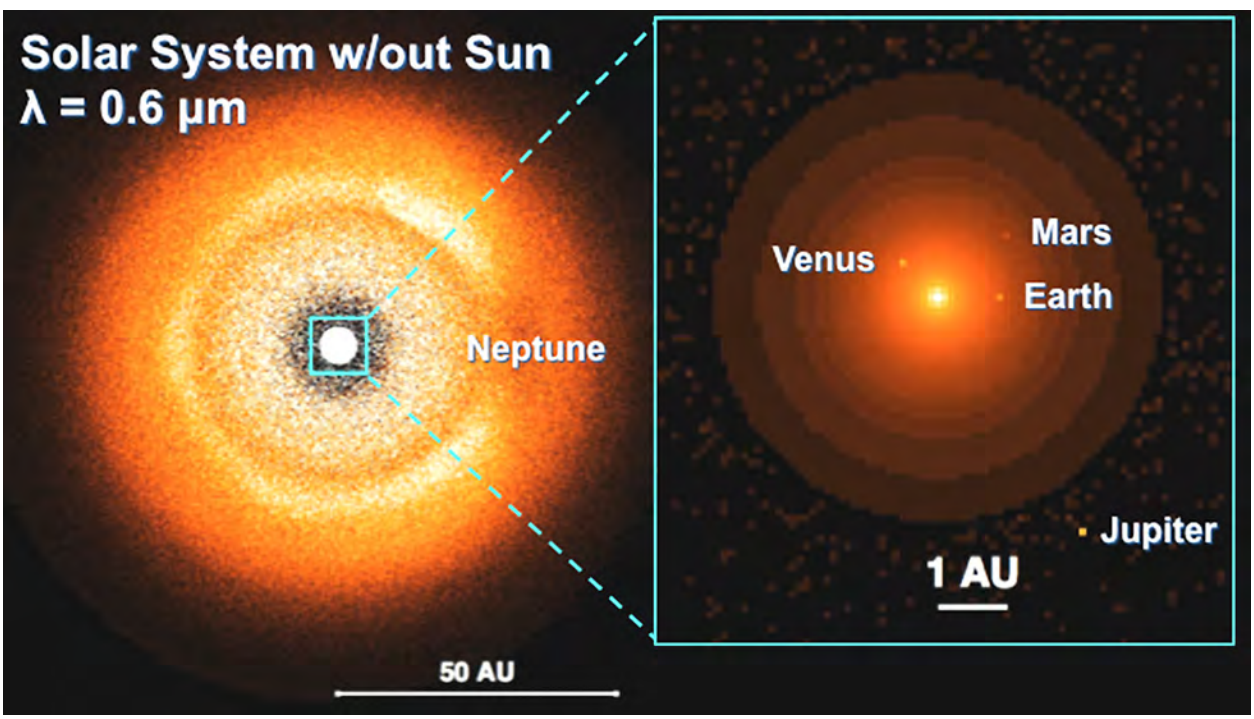
demonstrate that of the solar particle events including ~25 MeV protons detected at Earth since the beginning of the STEREO mission, around a quarter originated behind the west limb and ~5 percent behind the east limb. This east-west asymmetry reflects the influence of the spiral interplanetary magnetic field.

The Exozodiacal Dust Problem for Direct Observations of Exo-Earths

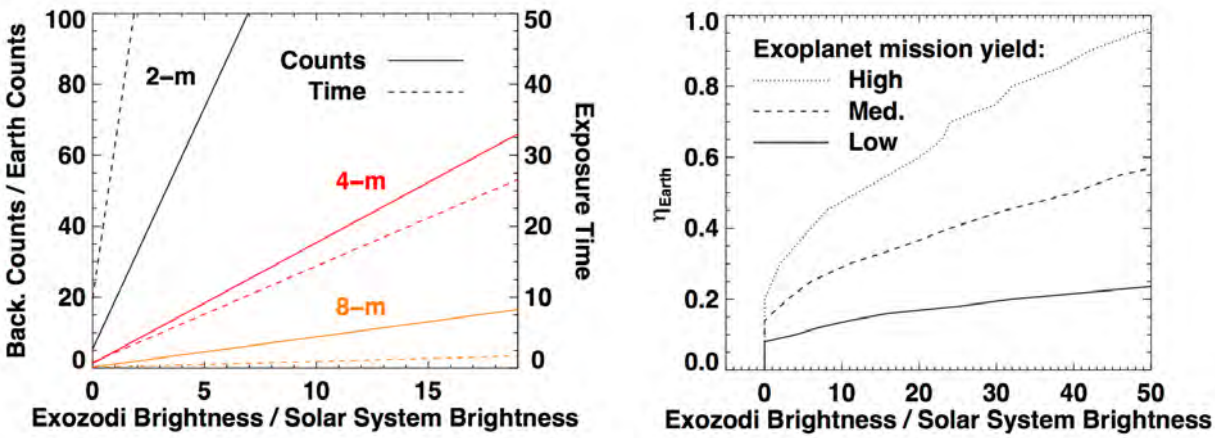
When viewed from a distance, the most conspicuous feature of the solar system after the Sun is its interplanetary dust, which forms a tenuous debris disk with a large surface area. Debris dust in the habitable zones of stars—otherwise known as exozodiacal dust—comes from extrasolar asteroids and comets and is thus an expected part of other planetary systems. A state-of-the-art model of the face-on solar system developed by Aki Roberge and Marc Kuchner of the Exoplanets and Stellar Astrophysics Laboratory and their students. For a 4-meter telescope, the local zodiacal dust plus a solar-system-twin disk of exozodiacal dust viewed at 60° inclination is about five times brighter at optical wavelengths than is Earth at 10 pc.

Background flux from the solar system's zodiacal dust and the exozodiacal dust in the target system is likely to be the largest source of astrophysical noise in direct observations of terrestrial planets in the habitable zones of nearby stars. Such observations would be the prime focus of a future UV/optical "New Worlds" flagship mission, as envisaged in the Astro2010 Decadal Survey. Furthermore, dust structures like clumps, produced by dynamical interactions with exoplanets, are a possible source of confusion in direct exoplanet observations.

As part of NASA's Exoplanets Exploration Program Analysis Group (ExoPAG), a group of community researchers led by Roberge came together in 2010 to form the Debris Disks and Exozodiacal Dust Study Analysis Group. The charges to the group were 1) to assess the impact of exozodiacal dust on a generic "New Worlds" mission concept, and 2) to collect reliable information on the expected sensitivity of current and upcoming facilities to debris dust at



Our model of the solar system includes spectral information for every element, which allows us to generate images at any wavelength between 0.3 microns and 2.5 microns. For ease of viewing, the Sun is not shown. The image on the left shows the entire solar system, the image on the right shows the inner 5 AU. The density model for the outer solar system dust is from Kuchner & Stark (2010). The model for the inner solar system dust, otherwise known as zodiacal dust, is based on a fit to observations from the DIRBE instrument on the COBE satellite (Kelsall et al. 1998). At both distance scales, and at all wavelengths, the most conspicuous feature of the solar system after the Sun is the haze of emission coming from interplanetary dust. The partial ring in dust in the outer solar system is caused by the dynamical influence of Neptune. M. Rizzo and A. Roberge.



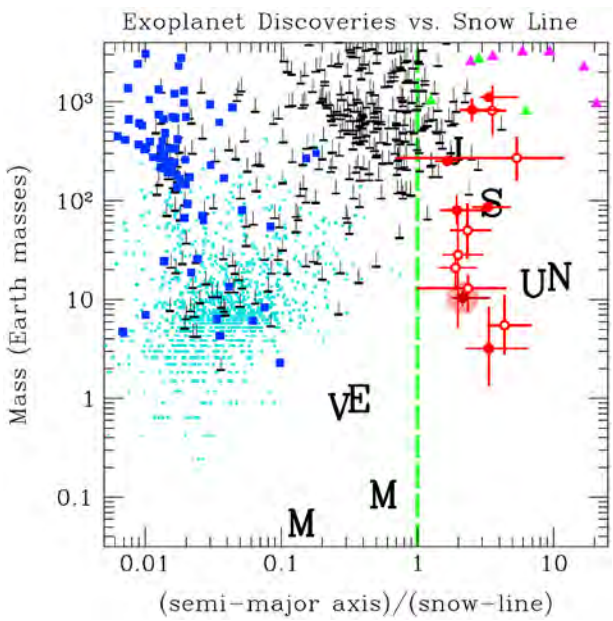
The impact of exozodiacal dust emission on direct observations of exo-Earths. Both x-axes give the exozodi surface brightness at the Earth-equivalent insolation distance relative to the brightness of a solar-system-twin disk. Left: Dust counts and imaging exposure time vs. exozodi brightness. The counts ratios and exposure times were calculated for three different telescope aperture diameters: 2 m (black lines), 4 m (red lines), and 8 m (orange lines). Smaller apertures are more sensitive to background emission. Right: The combined effect of exozodi emission and the fraction of stars with an Earth-size planet in the habitable zone (?Earth, y-axis) on the yield of a direct imaging/spectroscopy exoplanet mission. The curves were created using a simple mission-planning code that chooses real stars within 30 pc for observation until 5 mission years is reached, assuming a 4 m telescope, some value of ?Earth, and that all the stars have the same exozodi level. At each value of ?Earth, the "tolerable exozodi" (x-axis) is the largest exozodi level for which the desired mission yield (expected number of exo-Earths characterized) is achieved. The analysis was performed for three values of mission yield: high (dotted line), medium (dashed line), and low (solid line). The smaller ?Earth is, the lower the exozodi level that can be tolerated while still characterizing the desired number of exo-Earths. A full description of the figure appears in Roberge et al. (2012).

different distances from nearby stars. The group fulfilled its goals this year by publication of a refereed journal article (Roberge et al., 2012), which should serve as a community resource by providing simple, explicit prescriptions for assessing the primary impact of exozodiacal background on exoplanet direct imaging observations.

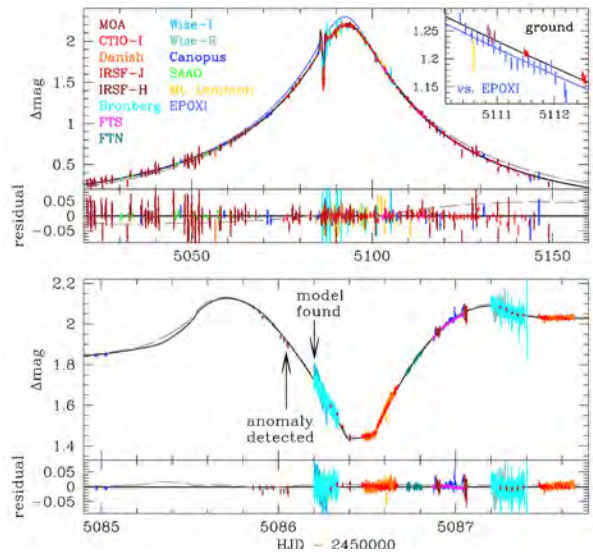
The report also summarizes the current knowledge of debris dust, the strengths and weaknesses of different dust-observing techniques, and the path toward getting the exozodiacal dust knowledge needed to design a highly capable "New Worlds" flagship mission. That path hinges on the Large Binocular Telescope Interferometer (LBTI), a NASA-funded instrument for the LBT on Mount Graham, Ariz. (Hinz et al., 2008). NASA has selected a Key Science Team to execute the LBTI Exozodiacal Dust Survey, called Hunt for Observable Signatures of Terrestrial Systems (HOSTS). Karl Stapelfeldt, William Danchi, and Aki Roberge are HOSTS team members from the Exoplanets and Stellar Astrophysics Laboratory. LBTI is in commissioning this winter and science operations are expected to begin in spring 2013.

Testing Planetary Formation Theory with Gravitational Microlensing

In the leading core-accretion planet formation model, the "snow line"—the radius where the proto-planetary disk becomes cold enough for water ice to condense—plays a key role. The timescale for agglomeration of small bodies into protoplanets is shortest just beyond the snow line, because this is where the surface density of solid material is highest. The largest protoplanets in these regions are expected to quickly reach a mass of ~ 10 M_{Earth} by accumulating the majority of the solid material in their vicinity. They then slowly accrete a gaseous envelope of hydrogen and helium. The envelope can no longer maintain hydrostatic equilibrium when it reaches the mass of the core, so it collapses, starting a rapid gas accretion phase that leads to a massive giant planet. The hydrostatic accretion phase is predicted to have a much longer duration than the other two phases of solid accretion and rapid gas accretion. This has several possible implications, including a higher frequency of low-mass, rocky/icy planets than gas giants; a feature in the final mass function of plan-



The masses of known exoplanets are shown as a function of their semi-major axis divided by the snow line, which is assumed to depend on the host star mass as ~2.7 M/ M_{Sun} AU. Red error-bar crosses indicate microlensing discoveries, with MOA-2009-BLG-266Lb indicated by the dark red spot surrounded by the light red halo. The black, upside down Ts and blue squares indicate exoplanets discovered by the radial velocity and transit methods, and the magenta and green triangles are planets discovered by imaging and timing. The small cyan-colored dots are planet candidates found by Kepler, but not yet validated or confirmed (using a rough mass-radius relation). The microlensing planets indicated by open circles have had their masses and semi-major axes estimated by a Bayesian statistical analysis.



Data and best-fit model of the MOA-2009-BLG-266 microlensing event plotted with respect to magnitude of the unmagnified source. The upper panel shows the part of the microlensing light curve magnified by more than 25 percent and the lower panel shows a close-up of the planetary deviation. The sub-panel at the bottom of each panel shows the residual to the best-fit model, which is given by the solid black curves. The light-blue curve in the top panel is the model light curve for the position of the Deep Impact spacecraft (the EPOXI mission) and the inset shows the data binned EPOXI photometry from the ~2-day period of observations from the EPOXI/HRI instrument. The grey-dashed curve in each panel is the best-fit non-parallax microlensing model.

ets near the critical core mass of ~ 10 M_{Earth}; a relative paucity of planets with masses of 10–100 $M_{Earth;}$ and the formation of very few gas giants orbiting low-mass hosts, where the gas disks are expected to dissipate before the critical core mass is reached.

These predictions follow from general physical considerations, but they also rely upon a number of simplifying assumptions that make the calculations tractable. Consequently, they could be incorrect. For example, recent work suggests that uncertainties in the initial surface density of solids in the protoplanetary disk, grain opacities in protoplanetary atmospheres, and the size distribution of accreting planetesimals can radically alter the timescales of these various phases and thus the resulting distribution of final planet masses. Therefore, the measurement of the mass function of planets down to below the predicted critical core mass will provide important constraints on the physics of planet formation.

Attempts to test core-accretion theory predictions with the mass distribution of the ~500 detected exoplanets and the ~ 1,200 candidate exoplanets found by the Kepler mission have met with varied success. Radial velocity detections confirm the prediction that massive gas giants should be rare around low-mass stars, but the prediction that 10–100 M_{Earth} planets should be rare in short period orbits is contradicted by the data. Kepler finds a large population of planets at ~ 2.5 R_{Earth} in short-period orbits (which are mapped into masses of ~ 6 M_{Earth} by our rough mass-radius relation), which is consistent with a result from the radial velocity planet-detection method (10). This might be considered a confirmation of the core-accretion theory prediction that ~ 10 M_{Earth} "failed gas-giant core" planets should be common, but in fact all of the low-mass planets found by radial velocity and transit methods have been well interior of the snow line, where these

"failed core" planets are thought to form. It is possible that the exoplanet mass (or radius) function is quite different outside the snow line due to such processes as sorting by mass through migration and photo-evaporation of gaseous envelopes. Thus, a study of the exoplanet mass function beyond the snow line should provide a sharper test of the core-accretion theory.

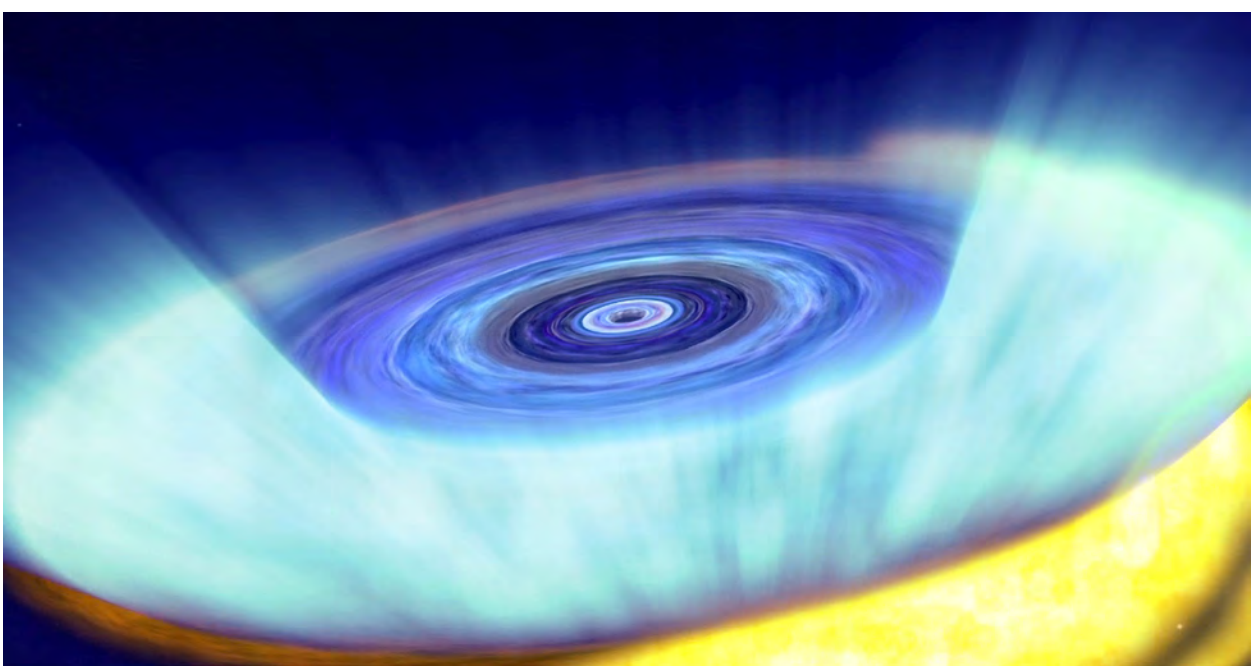
The gravitational microlensing method has demonstrated sensitivity extending down to planets of mass < 10 M_{sun} in orbits beyond the snow line, where the proto-planetary disk becomes cold enough for ices to condense. Thus it can provide a complementary probe of the physics of planet formation for planets that have migrated little from their putative birth sites.

The research team, including Dr. Richard K. Barry of ASD's Laboratory for Exoplanets and Stellar Astrophysics, presented the first example of a mass measurement for a cold, low mass planet discovered by microlensing, which has a mass very similar to the expected critical mass for gas accretion. The light curve of microlensing event MOA-2009-BLG-266 exhibits a planetary signal due to a companion with a mass ratio of ~ 6×10^{-5}. The light curve also reveals a microlensing parallax signal due to Earth's orbital motion. When combined with the information from the finite size of the source during the planetary perturbation, this allows one to work out the complete geometry of the microlensing event, yielding a measurement of the host and planet masses. In addition, observations from the Deep Impact spacecraft in a heliocentric orbit corroborate the mass measurement for MOA-2009-BLG-266Lb, and, for the first time, demonstrate the potential of using orbiting spacecraft for obtaining masses of planetary events that are too brief for a parallax measurement from Earth.

A better understating of the theory of giant planet formation will enable us to better formulate the scientific questions to be answered by the Wide Field Infrared Survey Telescope (WFIRST), the highest ranked recommendation for a large space mission in the 2010 *New Worlds, New Horizons* decadal survey. Measurements such as these are critical to improve the estimate of the planet detection rate from WFIRST. A new estimate of this detection rate—a figure of merit on which the success criterion for the entire exoplanet portion of the mission depends—has the potential to significantly reduce scientific risk for WFIRST.

Swift Discovery of a New Galactic Black Hole Candidate

X-ray novae are outbursts of compact binary systems that contain a central black hole and a stellar-mass companion that donates mass to the primary by overflow to an accretion disk. The physical conditions of the accretion disk depend on the mass-accretion rate. Their high-energy spectra are characterized by either a "hard/low" (kT > 15 keV) or a "soft/high" state. Dur-



This illustration shows a black hole accretion disk, constructed from gas drawn from a companion star (not shown). An instability in the disk has begun to send a surge of matter toward the black hole. This sudden inward flow produces large amounts of high-energy radiation (bluish-green glow), marking the onset of an X-ray nova like Sw J1745–26.

ing stable conditions, the accretion disk can be either optically thick or a "slim disk" with an advection-dominated accretion flow. X-ray novae are notoriously difficult to detect in their stable quiescence state with orbiting X-ray observatories due to their low fluxes. However, during the transition between the high/low states, they can undergo rare but dramatic X-ray and optical outbursts where they brighten by up to eight orders of magnitude. Few such outbursts have been detected to date. The cause of the sudden state change and brightening is thought to be an instability in the accretion disk that causes a drastic increase in the accretion rate.

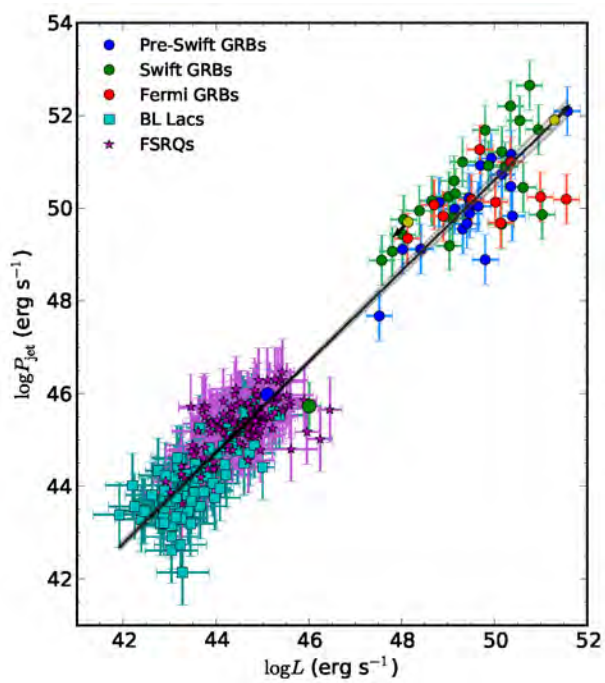
The Burst Alert Telescope (BAT) aboard Swift triggered on a previously unknown hard X-ray source a few degrees from the galactic center on Sept. 16, 2012, at 9:16 UT, at 12:36 UT, and again the following day. The observations marked the onset of a dramatic transition from the low/hard to the high/soft state of the X-ray nova Sw J1745–26. Continuous monitoring with BAT revealed that the hard X-ray emission (15–150 keV) peaked on Sept. 18, when it reached an intensity equivalent to that of the Crab Nebula, a supernova remnant that serves as a calibration target for high-energy observatories and one of the brightest gamma-ray sources in the sky. Observations with Swift's X-ray Telescope showed that as of mid-November 2012, the source continued to brighten in the soft X-ray band (0.2–10 keV) by more than a factor of 30, and the fading X-ray source may be detectable by Swift into 2013.

Observations with INTEGRAL showed that the source increased by 60 percent in hard X-rays from Sept. 17 to the next day and brightened by more than a factor of 1,000 compared to September 12–15. The high hard X-ray flux corresponds to the Eddington Limit for accretion onto a compact object of two solar masses. An infrared counterpart was detected by GROND on Sept. 17 with an AB magnitude of J = 16.5±0.5. Infrared spectroscopy with the 10.4m Gran Telescopio Canarias showed that the spectrum is consistent with an X-ray binary. Due to the high reddening in the direction of the source, no prompt optical counterpart has been detected. High radio flux densities were recorded with the Jansky Very Large Array and the Australian Compact Array on September 17–18 and 20, well above the limits of neutron star binaries, and indicate optically thick synchrotron emission from a black hole jet ejection.

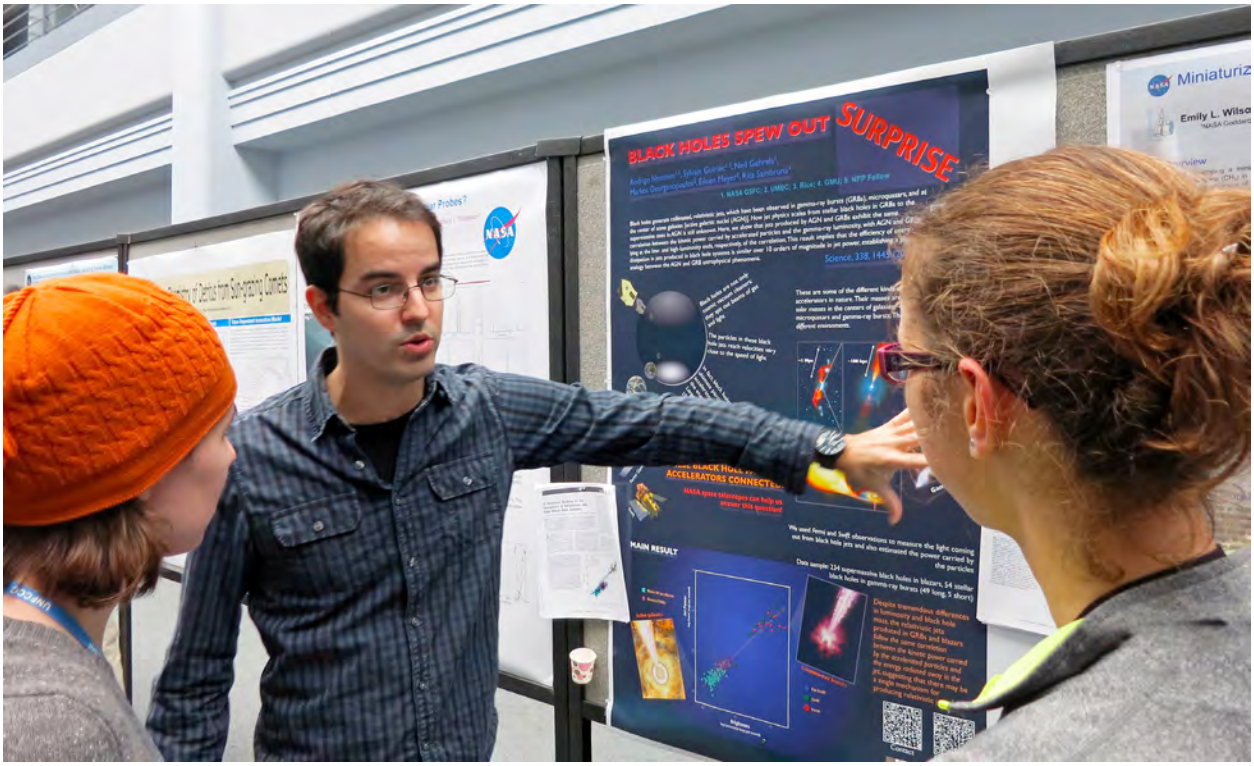
Black hole binaries are very faint in the quiescent state and difficult to detect. Rare outbursts such as the one for Sw J1745–26 present a unique opportunity to find hidden black holes. The Swift discovery of a new black hole candidate is significant, as only around 20 dynamically confirmed black holes are known to exist in our galaxy. Due to their expected changes in accretion state and their brightness, X-ray novae are excellent laboratories to study changes in the transfer of material from a companion star to a black hole.

Common Energetics: Black Hole Jets in AGN and GRBs

Black holes are more than passive prisons of light and matter in the universe: They are capable of accelerating some matter just outside the point of no return (the event horizon) to near-light speeds, creating jets of particles. Thus, black holes are the ultimate particle accelerators, producing collimated, relativistic jets that can best the energies reached in the Large Hadron Collider by orders of magnitude. These jets have been observed in a diverse range of black hole systems spanning from stellar mass (~10 $M_\odot$) to supermassive scales (~10^5–10^{10} $M_\odot$) in the bright flashes of gamma-rays known as gamma-ray bursts (GRBs), in the miniature versions of quasars lurking in our galaxy known as microquasars, and in the centers of some active galaxies (called active galactic nuclei, or AGN).



The relation between the collimation-corrected gamma-ray luminosity L and the kinetic power Pjet for AGN and GRBs. AGN and GRBs follow correlations that are consistent, within the uncertainties, with the best-fit model obtained from the joint data set (solid line, shaded regions: 2σ confidence band). The yellow data points correspond to XRF 020903 and GRB 090423, limits which not taken into account in the statistics.



Rodrigo Nemmen discusses the common energetics of AGN and GRB jets at the Sciences and Exploration Directorate New Year's Poster Party, Jan. 30, 2013. Francis Reddy

One outstanding question is how the properties of jets scale with mass from stellar to supermassive black holes. There is evidence that jets behave in similar ways in microquasars and radio-loud AGN. However, a clear connection between AGN and GRBs has not been established yet.

Rodrigo Nemmen, Sylvain Guiriec and Neil Gehrels of ASD's Astroparticle Physics Laboratory, together with colleagues from other institutions, searched the literature for observations that can be used to characterize the energetics of jets produced by black holes with a broad range of masses. They obtained estimates of the jet radiative output and the kinetic power for a sample of 234 AGN and 54 GRBs where the jet is closely aligned with our line of sight and therefore the observed emission is completely dominated by the jet due to beaming effects.

In order to quantify the radiative output of black holes jets, they used gamma-ray luminosities observed with the Swift and Fermi satellites and other instruments; they used radio as well as X-ray observations to estimate the kinetic power carried by accelerated particles. Nemmen and collaborators found that relativistic jets show the same coupling between the total power carried by the jet and the power radiated away across the mass scale—a universal scaling for the energetics of jets—regardless of the different environments and accretion flow conditions around the black hole. The researchers also calculated how efficiently the jets convert energy to light and found that the radiative efficiency averages ~15 percent, a value which is quite high. These findings were published in Science.

The similarity in the energetics of AGN and GRBs suggests that there is a single fundamental mechanism that produces relativistic jets in the universe. These results may help theorists better understand the process of jet formation, how jets produce radiation, and how the outflow of energy may affect the surrounding space.

1FGL J1018.6-5856: The First Gamma-ray Binary Discovered with Fermi

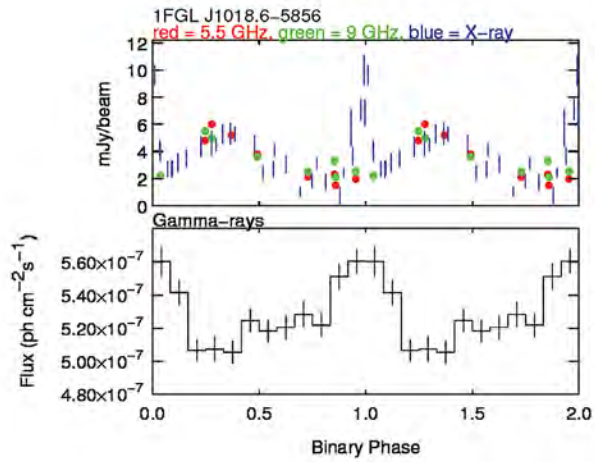
Gamma-ray binaries are closely related to X-ray binaries and also are expected to contain neutron stars or black holes. However, unlike X-ray binaries, gamma-ray binaries are extremely rare. Generating gamma-rays requires exceptional conditions, such as the shock formed between a jet from a black hole or stellar wind from neutron star and the wind of a normal companion star. However, evolutionary models predict that high-mass X-ray binaries go through a gamma-ray bi-

nary phase early in their lifetimes, when the neutron stars in these systems are rotating very rapidly. Hence, perhaps tens of gamma-ray binaries should exist in our galaxy. Only a handful of sources were known or suspected to be gamma-ray binaries before the launch of the Fermi Gamma-ray Space Telescope, which confirmed these identifications.

Using data from the Large Area Telescope (LAT) aboard Fermi, a large team led by Robin Corbet (UMBC/CRESST and NASA Goddard), Chi Cheung (Naval Research Lab) and Matthew Kerr (Stanford University) discovered the first completely new gamma-ray binary to be found with the satellite. The team identified a 16.6-day signal in the gamma-ray emission from the source, known as 1FGL J1018.6–5856, and this lengthy period made the scientists suspect the possibility of a binary system.

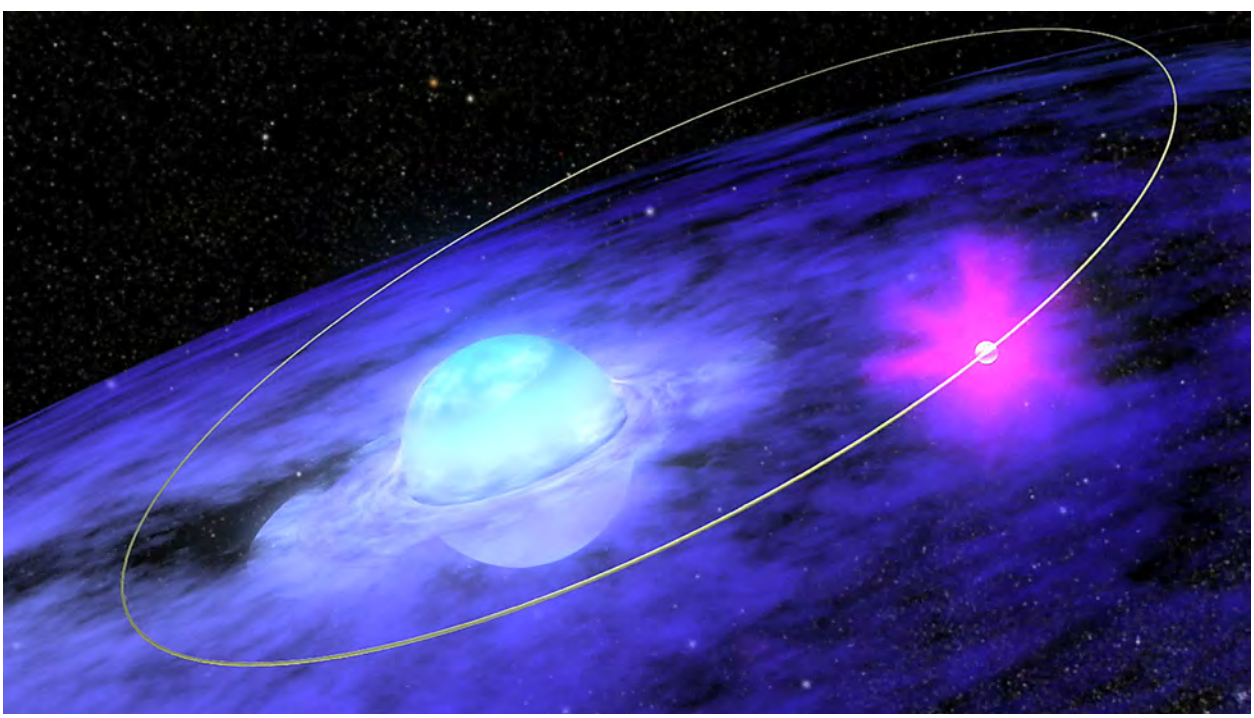
The team obtained X-ray observations from NASA's Swift satellite and radio observations with the Australia Telescope Compact Array, located near Narrabri in New South Wales, showing the presence of coincident X-ray and radio sources that also vary on a 16.6-day time scale. The data allowed identification of a potential optical counterpart, a star with a spectral classification of O6V((f)), which is very similar to the normal star found in the gamma-ray binary LS 5039.

The properties of 1FGL J1018.6–5856 are consistent with a scenario where the neutron star's wind interacts with the O star's wind to form a shock, where



Top: Radio (red, green) and X-ray (blue) light curves of the gamma-ray binary 1FGL J1018.6-5856 folded on a 16.6-day period, which is thought to be the system's orbital period. For clarity, the folded light curve is repeated. Bottom: The gamma-ray light curve of 1FGL J1018.6-5856 measured with the Fermi LAT folded on the 16.6 day period. Two identical cycles are also plotted for clarity. This light curve is not background subtracted.

particles become boosted to high energies by Fermi acceleration. Light from the O star can then undergo inverse Compton scattering up to gamma-ray energies. Changes to the gamma-ray emission seen at Earth occur either because the system has an eccentric orbit or



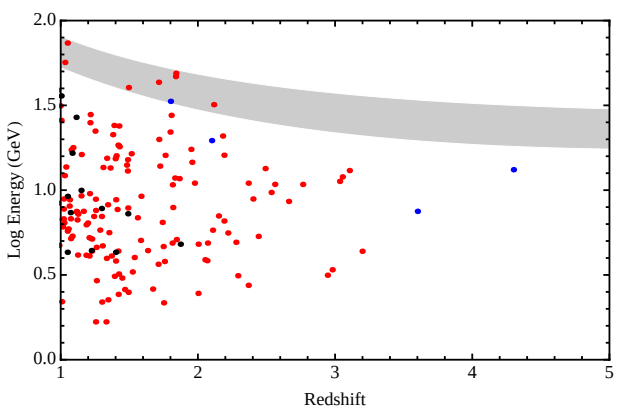
An artist's impression of a gamma-ray binary. A rapidly rotating neutron star orbits an early-spectral-type star. Gamma rays are produced by the interaction of stellar winds from the two objects.

through geometric effects as the neutron star orbits the massive primary companion.

If evolutionary models for gamma-ray and X-ray binaries are correct, then we can expect additional systems of this type to be found with Fermi's LAT. Corbet and his colleagues continue to search LAT data for signs of periodic gamma-ray modulation from other similar sources. The sensitivity of this search continues to improve with additional LAT observations, which holds the promise of additional discoveries.

Determining the Intergalactic Photon Density and the Gamma-ray Opacity of the Universe Using Deep Galaxy Survey Data

One of the key problems in high-energy astrophysics is the determination of the opacity of the universe to gamma-rays produced in very distant astronomical objects, such as active galactic nuclei and gamma-ray bursts. This opacity is the result of the annihilation of high-energy gamma-ray photons caused by collisions with ultraviolet, optical and infrared photons in intergalactic space. When such interactions occur, both photons annihilate into an electron and a positron. The cross section for this process has been accurately calculated using a branch of modern physics known as quantum electrodynamics. Since the cross section is known, the remaining piece of the problem is the determination of the low-energy photon density in intergalactic space as a function of both wavelength and redshift. These photons are produced overwhelmingly in galaxies by stars and re-radiation of starlight by dust.



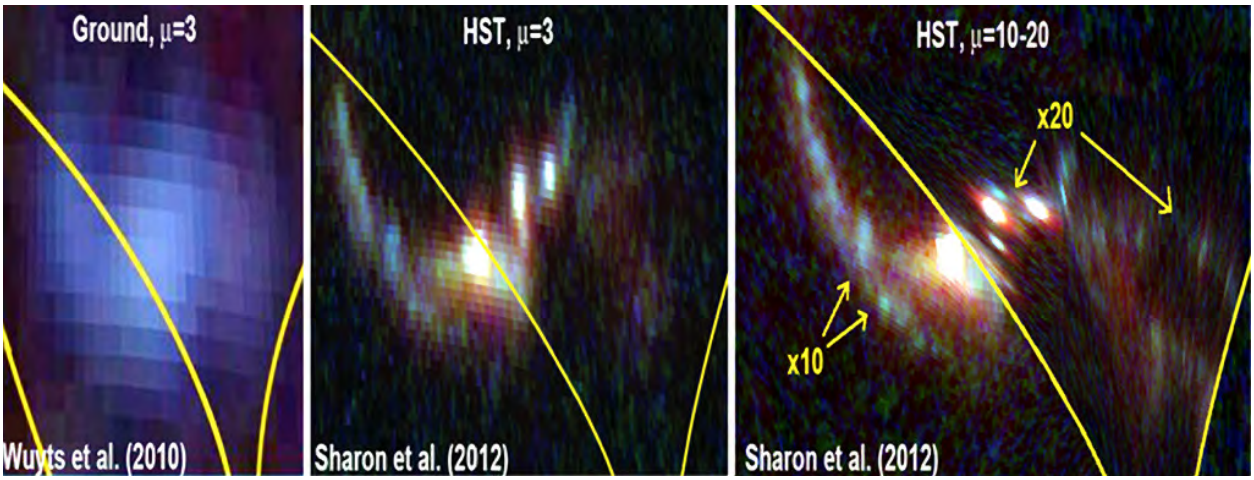
The plot shows Fermi data on the highest-energy photons observed from individual sources at a given redshift. Black and red dots denote blazars (BL Lac objects and flat spectrum radio quasars, respectively) and blue dots denote gamma-ray bursts. The gray band shows the error of the calculated opacity for reducing the transmission of gamma-rays of a given energy from a source at a known redshift by a value of 1/e, taken from a forthcoming paper by Stecker, Malkan and Scully.

In recent years, there have been many deep surveys of large numbers of galaxies performed from space using Hubble Space Telescope instruments—the Wide Field and Planetary Camera 2, Wide Field Camera 3, the Advanced Camera for Surveys, and the Near IR Camera and Multi-Object Spectrometer—the Galaxy Evolution Explorer, the Spitzer Space Telescope, as well as ground-based galaxy surveys from Keck and other telescopes. The results from these surveys now cover galaxy emission from millimeter to ultraviolet wavelengths. They map the history of this emission over a redshift range from 8 to the present time in the UV and over from redshift 2 or 3 at longer wavelengths.

By using the collected observational results of these recent galaxy surveys, Floyd Stecker and collaborators Matthew Malkan of UCLA and Sean Scully of James Madison University (formerly a Goddard postdoc) have been able to determine both the history of the photon density in intergalactic space and thus the opacity of the universe to gamma rays in the energy range that the Fermi Gamma-ray Space Telescope is now exploring. Because of their new approach, they were also able to place empirically based uncertainties on their determination of the photon density of the intergalactic background light from galaxies, as well as on their determination of the gamma-ray opacity of the universe. These uncertainties were determined from the observational uncertainties in galaxy luminosity densities using Monte Carlo techniques. Previous approaches to the gamma-ray opacity problem have relied on more theoretical modeling with various assumptions involving stellar population synthesis models, stellar initial mass functions, unknown amounts of dust extinction, and poorly known stellar metallicity-age modeling for different evolving galaxy types.

The Fermi collaboration and ground-based Air Cherenkov telescope groups have been trying to determine the amount of gamma-ray opacity as a function of energy and redshift through studies of the high-energy gamma-ray spectra of a class of active galactic nuclei known as blazars. Stecker and collaborators Michael Salamon and O. C. de Jager suggested this method 20 years ago following the launch of the EGRET gamma-ray telescope aboard the Compton Gamma-Ray Observatory and its discovery of a bright gamma-ray flare in the blazar 3C 279.

It will be interesting to see how the determinations from the two different methods described above compare. Should these determinations diverge, it



This figure, taken from Wuyts et al. (2010) and Sharon et al. (2012), illustrates how increasing lensing magnification dramatically improves the morphological detail observed. Each panel shows a reconstructed source-plane image of the multiply lensed galaxy RC 0327; that is, the galaxy's true morphology corrected for lensing distortion. The left panel shows why ground-based images are too blurry to measure where stars form in distant galaxies. The middle panel shows that HST with a mild (3x) lensing boost can resolve three bright star-forming clumps. The right panel shows that a strong (10-20x) lensing boost resolves at least ten different star-forming clumps.

could indicate evidence for either the additional of new physics or additional astrophysical processes. One such suggested possibility could be the development of a component of secondary gamma-rays along the line-of-sight to a gamma-ray source produced by interactions of ultrahigh-energy protons from the source, giving an additional component of gamma-ray photons. Another possibility could be a decreased apparent opacity caused by the interesting suggested new physics process known as photon-axion oscillations. (The axion is a particle postulated to solve the "strong charge parity problem" in quantum chromodynamics.) Since an oscillating photon-axion superposition, when in the axion state, does not pair-produce, the effective gamma-ray opacity along the line-of-sight to a gamma-ray source is reduced.

The figure, known as a Fazio-Stecker plot, shows the error band of the calculated opacity for reducing the gamma-ray transmission of gamma-rays of a given energy from a source at a known redshift by a value of 1/e, taken from the paper of Stecker, Malkan and Scully. It also shows Fermi data on the highest-energy photons observed from individual sources at a given redshift, with black and red dots denoting different types of blazars and blue dots denoting gamma-ray bursts.

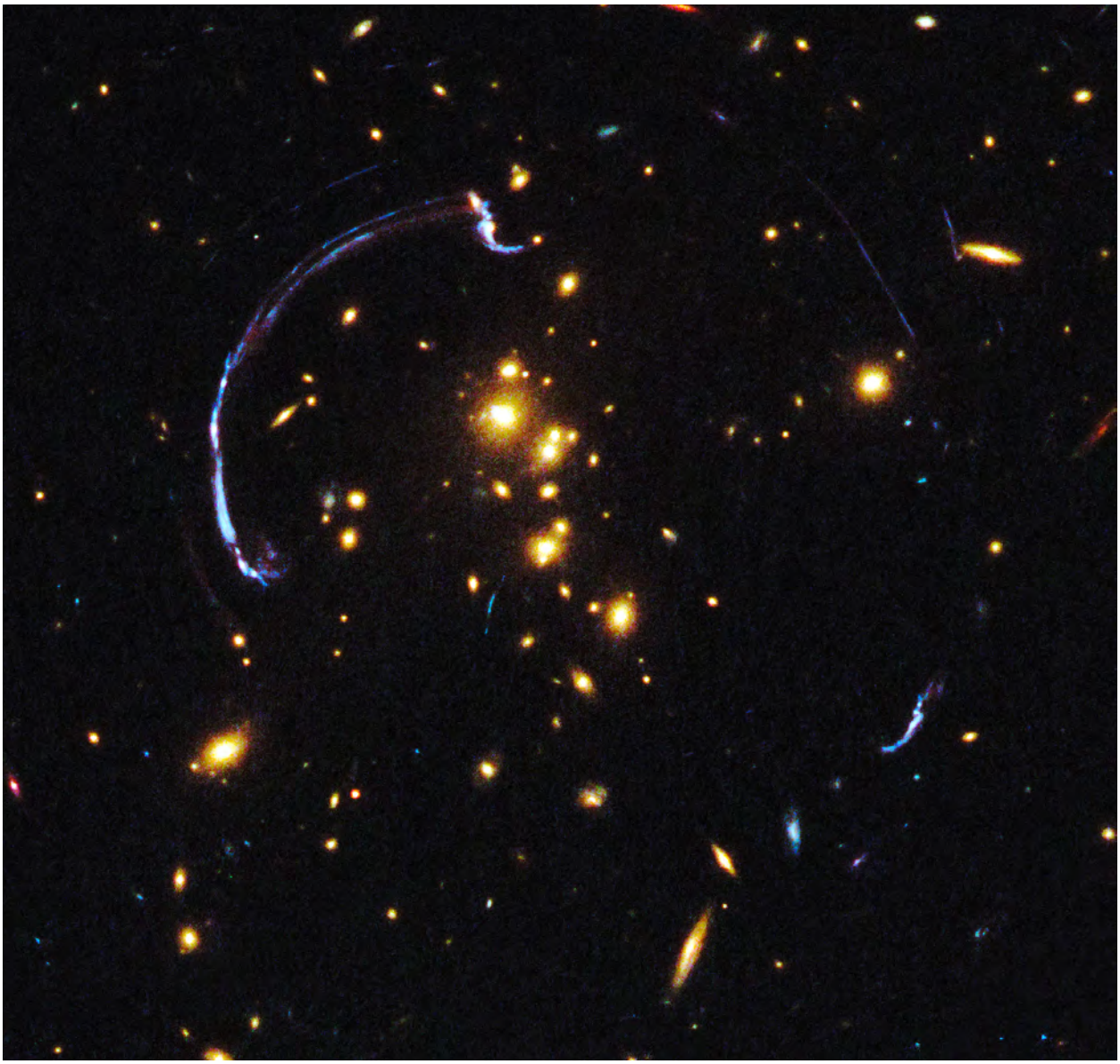
The work of Stecker, Malkan and Scully on the determination of the intergalactic photon density and gamma-ray opacity is accepted for publication in The Astrophysical Journal in the near future.

Zooming in on Star Formation in Distant Galaxies

The Hubble Space Telescope provides some of our sharpest views of the distant universe. Hubble can resolve physical scales down to 1,700 light-years (530 parsecs) at redshifts between 1 to 3. Unfortunately, this is not sufficient to resolve star-forming complexes as large as the largest found in the Milky Way (Carina, with a diameter of 650 light-years or 200 parsecs.) As a result, the places where stars form in distant galaxies, with sizes of at most hundreds of parsecs, cannot be resolved by Hubble under normal circumstances.

Jane Rigby of the Observational Cosmology Lab and her collaborators Michael Gladders (University of Chicago), Keren Sharon (University of Michigan), and Eva Wuyts (MPE) are changing the rules of the game by using Hubble to target galaxies that have been gravitationally lensed. Massive clusters of galaxies act as natural telescopes that bend and magnify the light of background galaxies. Typical magnifications of 10 to 50 permit star-forming regions in $1<z<3$ galaxies to be resolved down to 50- to 150-parsec scales.

The team demonstrated this technique by obtaining Hubble Cycle 18 observations (PI Rigby) of one of the most striking examples of gravitational lensing, a nearly 90-degree arc of light in the galaxy cluster RCS2 032727-132623. Hubble's view of the distant background galaxy is significantly more detailed than could ever be achieved without the help of the gravi-



The galaxy cluster RCS2 0327 presents one of the most striking examples of gravitational lensing, where the gravitational field of a foreground galaxy bends and amplifies the light of a more distant background galaxy. The light from a galaxy nearly 10 billion light-years away has been warped into a nearly 90-degree arc by the galaxy cluster, which lies at about half its distance. The image of the background galaxy is more than three times brighter than typically lensed galaxies. This natural-color image was taken in March 2011 with the Hubble Space Telescope's Wide Field Camera 3.

tational lens. The distorted image of the galaxy is repeated several times in the foreground lensing cluster, as is typical of gravitational lenses. Sharon modeled the gravitational potential of the cluster, and reconstructed what the galaxy would really look like if it weren't being lensed (Sharon, Gladders, Rigby et al. 2012). In ground-based images, the lensed galaxy resembled a two-armed spiral galaxy. Instead, the much sharper Hubble images revealed that the lensed galaxy is actually two galaxies in the process of merging. Each galaxy in the merger is chock-full of regions of star formation that glow like Christmas tree lights, each much brighter than any star-formation region in our Milky Way galaxy.

The team is now studying these individual star-forming regions, and has determined seldom-measurable physical conditions (extinction, metallicity and abundance pattern, density, ionization field strength) through spectroscopy obtained through NASA time on the Keck II telescope (Rigby et al. 2011, *Astrophys. J.*, 732, 59). These individual star-forming regions also show prominent signatures of outflowing winds, driv-

en by supernovae, which the team is studying using the Magellan telescopes (Rigby et al., in preparation.) The team is also studying the kinematics of how the gas is moving, using NASA time on Keck (Wuyts et al., in preparation)

Now that these researchers have thoroughly studied the nature of star formation in RCS 0327, they have begun a systematic survey of star formation down to 50- to 150-parsec scales in more than 70 lensed galaxies with redshifts between 1 and 3. Their approved 107 orbit Cycle 20 Hubble program (PI Gladders) will target 37 lensing galaxy clusters selected from the Sloan Digital Sky Survey to have prominent lensed arcs in this redshift range. Since many of these clusters contain more than one bright lensed arc, the program will survey more than 70 lensed galaxies. The goals are to determine the morphology and fundamental spatial scales of star formation in galaxies at the epoch when most stars formed.

The first two of the clusters were observed in late 2012; the rest will be observed by Hubble in 2013. Two programs with Warm Spitzer (PIs Gladders and Rigby) are measuring the total number of stars in these lensed galaxies, which complements the measurements from Hubble of the current star-formation rate. Ongoing follow-up spectroscopy with Magellan and Keck are determining metallicities.

This full dataset will reveal, for the first time, how the buildup of oxygen in galaxies depends on the past and present star-formation rates.

Wide-field Spatio-spectral Interferometry

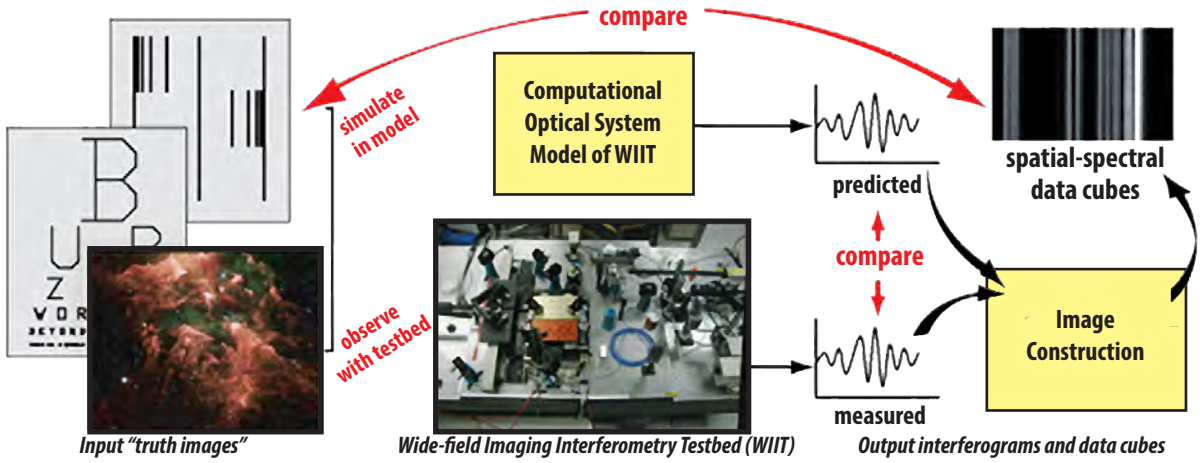
A team led by Dave Leisawitz (Science Proposal Support Office) and including Stephen Rinehart and Rick Lyon in ASD has continued to advance this broadly-applicable technique toward Technology Readiness Level (TRL) 6. The technique, sometimes called "double Fourier" interferometry, yields integral field spectroscopic data based on measurements obtained with a spatial interferometer and a single beam-combining instrument. The instrument is a modified Fourier Transform Spectrometer. Wide-field spatio-spectral interferometry is particularly well suited to far-infrared applications and lies at the heart of the SPIRIT and SPECS mission concepts studied by NASA during the past decade, and the European Far-Infrared Interferometer (FIRI) mission concept. This novel technique was first described in the astronomical literature by Mariotti and Ridgway in 1988 and developed to its present maturity level, TRL 5, in a Goddard lab, with APRA funding, over the course of the past decade.

Recent technical progress was reported in a series of papers presented at the SPIE conference on Astronomical Telescopes and Instrumentation in the Netherlands in July 2012. Leisawitz et al. summarized the project and described the importance of wide-field spatio-spectral interferometry to future far-IR missions deemed important by the infrared community.

Sensitive, high-resolution imaging and spectroscopy is essential to achieve several science goals prioritized in the 2010 Decadal Survey. Lyon et al. described and reported recent results based on our developing spatio-spectral "image" synthesis algorithm. Bolcar et al. described the Calibrated Hyperspectral Image Projector (CHIP), which our team assembled based on a NIST prototype and integrated into the Wide-field Imaging Interferometry Testbed (WIIT) in 2012. CHIP enables the projection of astronomically realistic spatial-spectral scenes into the testbed.

During the past year, data acquisition with WIIT in Goddard's Advanced Interferometry and Metrology (AIM) Lab, a world-class facility, became routine, and several experiments were run, yielding several hundred gigabytes of high-quality data. In the AIM Lab, WIIT is functionally equivalent to a space-based interferometer: instrumental error terms dominate, and environmental effects are negligible. What's more, the instrument is very well understood. A high-fidelity optical system model of the testbed was used to produce synthetic interferograms, and it was shown that they closely match data obtained in the lab. The instrumental visibility loss in the WIIT testbed is in excellent agreement with a theoretical estimate of the visibility loss, and the individual loss terms are well understood. Noise in the data is dominated by photon statistics and matches expectations. These important milestones on the road to TRL 6 were all achieved during the past year.

Three summer interns and a longer-term co-op student, ranging in education from high-school senior to senior undergraduate, gained valuable experience and made significant contributions to this project during the past year. We're proud of their recent curricular achievements. Ms. Melody Liu, our two-time summer intern, graduated from high school and is now a freshman at MIT. Mr. Elliot Teichman graduated from the University of Maryland with an undergraduate degree in astronomy and joined Teach for America to help educate underserved high school students. Mr. Daniel Liss was awarded his second patent, graduated from high school, and is now a freshman at Columbia University. And our three-term co-op student from McMaster University, Mr. Evan Sinukoff, is now pursuing a doctorate in astrophysics at the University of



To reach TRL 6, we will systematically apply an error-tracking experimental approach in which increasingly complex, more astronomically realistic test scenes are observed, and different observing modes are explored to learn the practical limitations of wide-field spatio-spectral interferometry. This will also enable quantitative understanding of how each instrument design parameter impacts the quality of the synthesized hyperspectral image cube.

Hawaii. Each of these students learned enough that they could teach a good lesson on interferometry.

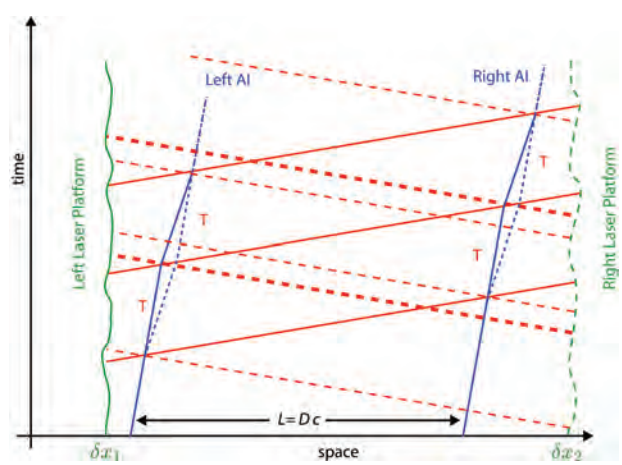
Comparing Atom and Light Interferometers as Detectors of Gravitational Waves

The detection and measurement of gravitational waves (GWs) from astrophysical and cosmological sources is recognized as one of the most promising sources for new information about the Universe and has been a goal of experimental physicists for nearly half a century. Space-based instruments such as the Laser Interferometer Space Antenna (LISA), which would observe the GW Universe in the source-rich milliHertz frequency band, have been identified as a priority for NASA Astrophysics but have yet to be implemented due to funding constraints.

Recently, GW detectors based on multiple Atom Interferometers (AIs) connected by long-baseline laser links have been proposed in the literature as alternatives to traditional light interferometers such as LISA. These AI designs exploit the quantum-mechanical wave nature of ultra-cold atom clouds to make precise measurements of the GWs effect on the laser phase.

John Baker and Ira Thorpe of the Gravitational Astrophysics Laboratory performed a comparative study of LISA-like light interferometers and AI interferometers for space-based GW detection. They developed a theoretical framework in which both types of detectors could be simultaneously described and calculated the influence of several types of fundamental noise, including fluctuations in the laser frequencies used to perform the long-baseline interferometry and non-gravitational accelerations of the interferometer mirrors.

The result of this comparison is that AI-based instruments and light-based instruments are identically affected by laser frequency noise and similarly affected by acceleration noise (*Phys. Rev. Lett.* 108, 211101, 2012). This suggests that viable AI-based mission concepts will have similar mission parameters (number of baselines, length of baselines, laser frequency noise requirement, and acceleration noise requirement) and therefore similar costs, assuming the payload costs per baseline are similar.



A space-time diagram of a single-baseline gravitational wave detector using two atom interferometers (AIs) shows the interaction of laser pulses (red) emitted from a spacecraft (green) with cold atom clouds (blue). The diagram was used to analyze the effects of noise sources, such as fluctuations in laser frequency and spacecraft acceleration, on gravitational wave sensitivity.

Research and Development

Suborbital

Super Trans-Iron Galactic Element Recorder (Super-TIGER)

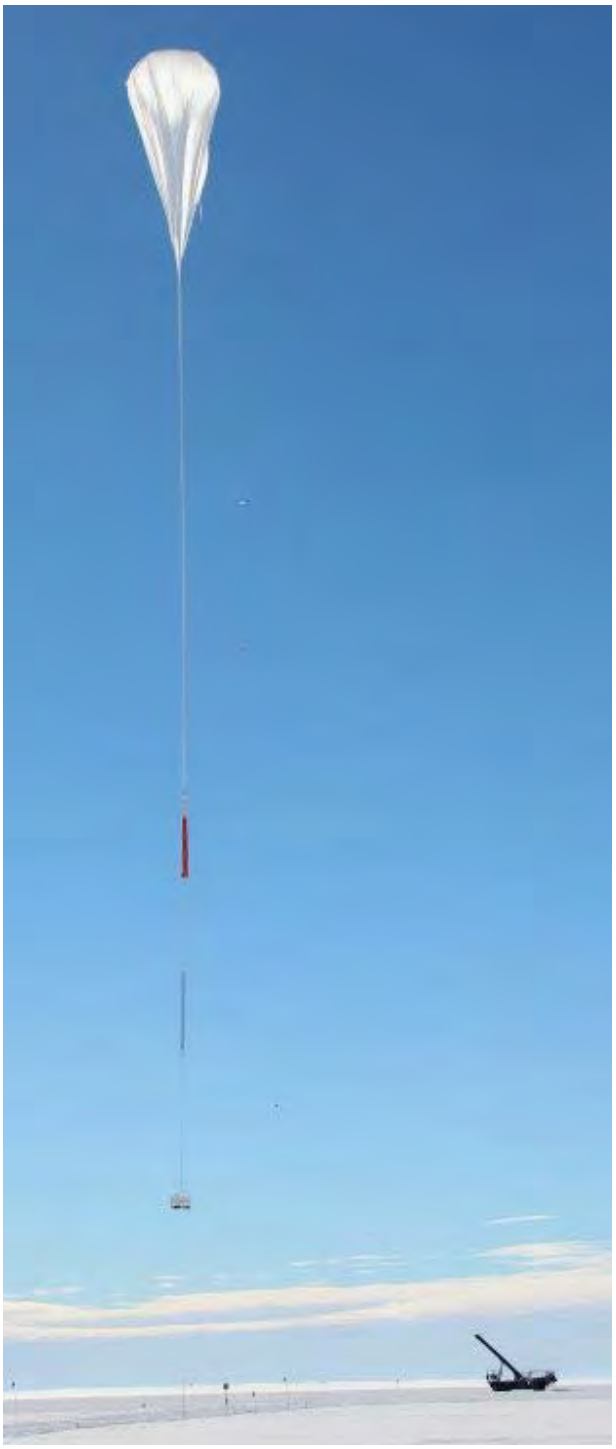
Super-TIGER, a new, large-area balloon-borne instrument for long-duration Antarctic balloon flights, launched on its first flight from Williams Field, McMurdo Station at 15:45 EST on Saturday, Dec. 8, 2012 (09:45 NZST, Sunday, Dec. 9). It began its second orbit of Antarctica on Dec. 26.

The Super-TIGER collaboration includes Washington University in St. Louis (PI, W. Robert Binns), Goddard, Caltech, and JPL. The Goddard team includes John Mitchell, Eric Christian, Georgia De Nolfo, Thomas Hams, Jason Link, Kenichi Sakai, and Makoto Sasaki.

Super-TIGER measures the individual abundances of elements over the range $30 \leq Z \leq 42$ with high statistical accuracy to test and clarify the emerging model of cosmic-ray origin in OB associations and models for atomic processes by which nuclei are selected for acceleration. Exploratory measurements with lower statistics will extend to $Z = 60$. Super-TIGER will also measure, with excellent statistical precision, the energy spectra of the more abundant elements $14 \leq Z \leq 28$ at energies $0.8 \leq E \leq 10$ GeV/nucleon. These measurements will provide a sensitive test of the hypothesis that microquasars or other phenomena could superpose features on the otherwise smooth energy spectra.

Super-TIGER is based on experience with the smaller TIGER instrument that was flown from Antarctica in 2001 and 2003 for a total of 50 days and produced the first measurements of individual element abundances for $_{31}$Ga, $_{32}$Ge, and $_{34}$Se. Three layers of plastic scintillator and two Cherenkov detectors, one with an acrylic radiator and one with a silica aerogel radiator, determine the charge and energy of

Super-TIGER suspended from the Columbia Scientific Balloon Facility's launch vehicle, The Boss, on flight day.



Super-TIGER immediately after launch on Dec. 8, 2012.

incident nuclei. A scintillating optical fiber hodoscope gives particle trajectories to enable corrections for pathlength through the detectors, detector response maps, and interactions in the atmosphere and in the instrument.

Super-TIGER during integration in the assembly building at Williams Field, showing the two instrument modules and the lightweight gondola.

Super-TIGER uses two independent instrument modules, each with a 1.15 m × 2.3 m active area, giving a total detection area of 5.4 m^2. Each module is only 60 cm thick to maximize its geometric acceptance. The detector layout and minimal column density give an effective geometry factor of 2.5 m^2 sr at Z = 34, over four times larger than TIGER. The second flight of Super-TIGER is planned for 2014. In two approximately 30-day flights, Super-TIGER will achieve nearly an order of magnitude improvement in statistics compared to TIGER.

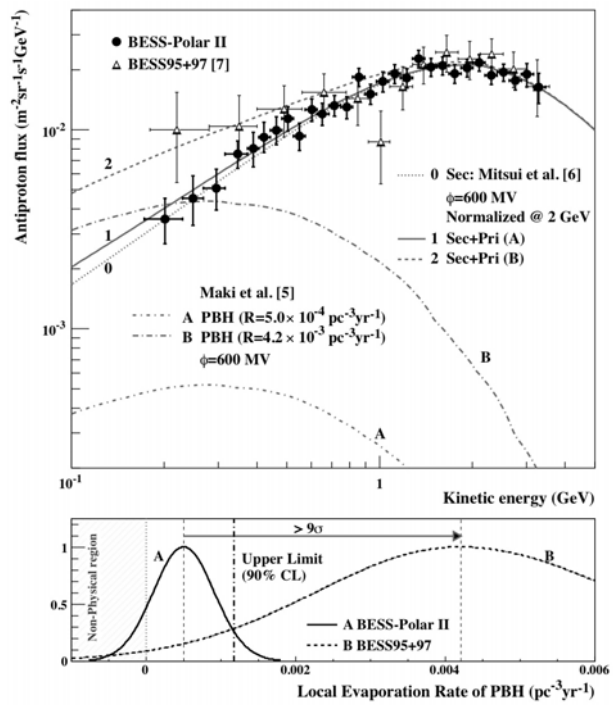
Goddard is responsible for the acrylic and aerogel Cherenkov detectors, the scintillators, the mechanical structure of the instrument and payload, integration and testing, and logistics. In 2012, the final components of the instrument and payload were completed and integration was carried out at Goddard. The instrument then underwent thermal-vacuum testing at the NASA Plum Brook facility in Ohio and final integration and compatibility tests at the Columbia Scientific Balloon Facility in Palestine, Texas. Antarctic integration began at Williams Field in late October, leading to the Dec. 8 launch.

Balloon-Borne Experiment with a Superconducting Spectrometer - Polar (BESS-Polar)

BESS-Polar was developed for sensitive investigations of the nature of the dark matter and the apparent dominance of matter over antimatter using long-duration balloon flights over Antarctica. The collaboration is co-led by Goddard (Dr. John W. Mitchell) and KEK (High Energy Accelerator Research Organization, Dr. Akira Yamamoto) and ASD team members are Mitchell, Makoto Sasaki, Kenichi Sakai, and Thomas Hams.

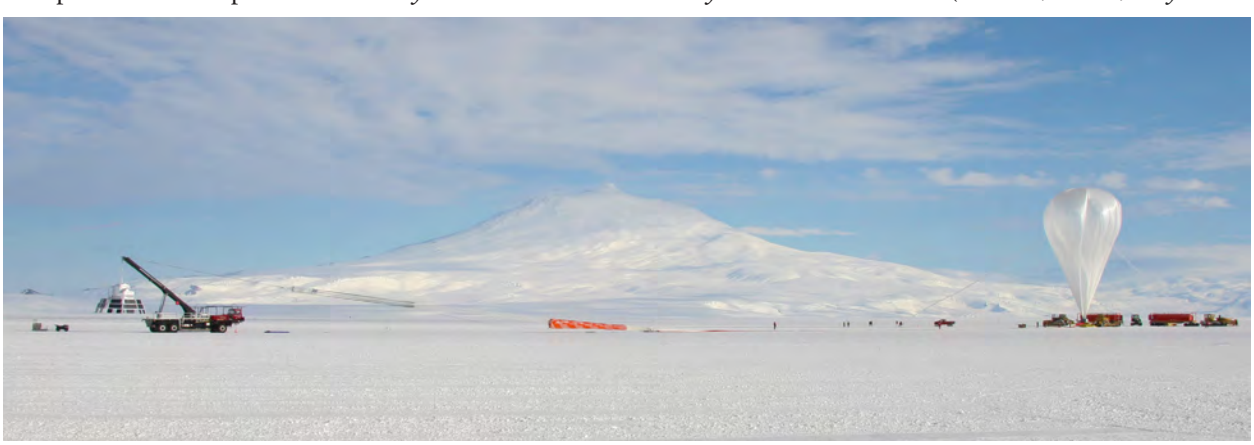
BESS-Polar uses the basic design concept of the exceptionally productive BESS instrument that made nine conventional one-day northern-latitude balloon flights between 1993 and 2002. BESS-Polar, in common with the original BESS, uses a solenoidal superconducting coil, thin enough for particles to easily penetrate, filled with a drift-chamber tracking system with low multiple scattering. This provides a wide opening angle and large geometric acceptance, ideal for rare-particle measurements. Detectors to measure the charge and velocity of incident particles, including time-of-flight detectors and an aerogel Cherenkov counter, form partial cylinders around the magnet. BESS-Polar uses refined instrumental techniques with exposure greatly increased by long-duration polar balloon flights. The threshold energy is halved by thinning the magnet and detectors, moving the Cherenkov counter below the magnet, eliminating the pressure vessel, and adding a time-of-flight hodoscope within the magnet bore. These changes lower the mass that particles have to traverse by a factor of four compared to BESS.

BESS antiproton spectra in 1995 and 1997, near solar minimum, indicated a possible low-energy excess over secondary predictions, perhaps resulting from evaporation of small (~5 × 10^{11} kg) primordial black holes by Hawking radiation. To investigate this intriguing possibility further required much more exposure at solar minimum, when the signature of a primary source would not be smeared by solar modulation. BESS-Polar I flew 8.5 days from McMurdo Station, Antarctica, in 2004 at a time of low but significant solar activity. BESS-Polar II flew near solar minimum in 2007–2008 with the magnet energized for 24.5 days. From the BESS-Polar II data, 7,886 cosmic ray antiprotons between 0.17 and 3.5 GeV satisfied the most rigorous analysis requirements. The results and initial interpretation were published in *Physical Review Letters* (K. Abe, et al., *Phys. Rev. Lett.* 108, 051102). Some of the secondary models fit the BESS-Polar II spectrum well and a primary component is not needed. The likelihood of antiprotons from primordial black hole evaporation was quantified and excludes, by over nine sigma, the slight possibility of primary antiprotons suggested by BESS 1995/1997 data. Within statistics, BESS-Polar II found no evidence of primary antiprotons from primordial black holes.

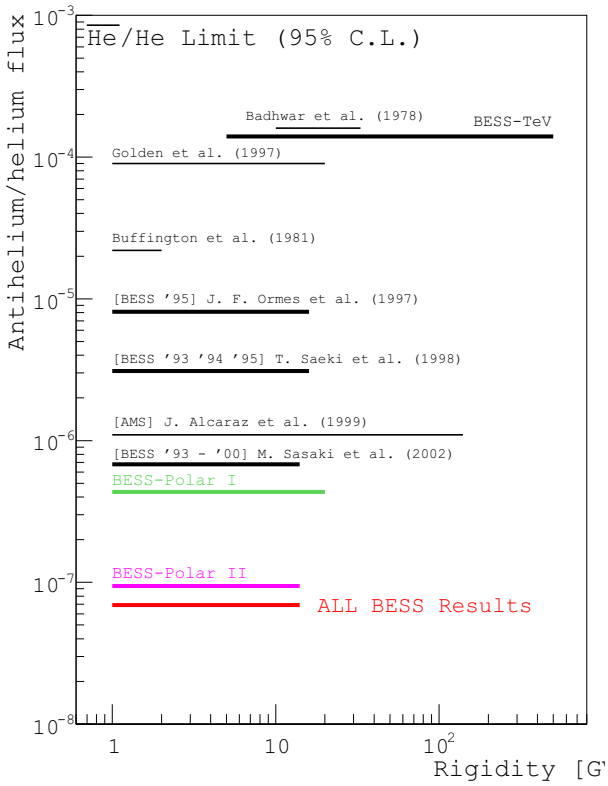


The high-precision low-energy antiproton spectrrum measured by BESS-Polar II shows no evidence of primary antiprotons from evaporation of primordial black holes.

BESS-Polar II data was also carefully searched for evidence of antihelium and the results were published in *Physical Review Letters* (K. Abe, et al., *Phys. Rev.*



BESS-Polar II just before launch in December 2007 from Williams Field, McMurdo Station, Antarctica, with the Mount Erebus volcano in the background.



The combined BESS/BESS-Polar upper limit to the possible ratio of antihelium/helium in cosmic rays is stronger by more than three orders of magnitude than the first-reported limits. The BESS program finds no evidence of antinuclei with |Z|≥2 in the cosmic radiation or, by implication, in the cosmological neighborhood.

Lett. 108, 131301). Between 1 and 14 GeV, 4×10^7 helium nuclei were identified, but no antihelium. The resulting upper limit on the antihelium/helium ratio is 9.4×10^{-8} (at 95 percent confidence). Combining this with data from all other BESS flights, including BESS-Polar I, gives an upper limit of 6.9×10^{-8}, the most stringent limit to date. With this report, the BESS collaboration has made the upper limit on the antihelium/helium ratio stronger by more than three orders of magnitude compared to the first limits reported. In recognition of the importance of these results, the *PRL* paper was selected as a *PRL* Editor's Suggestion and was featured in an APS Highlight.

Led by Goddard, the collaboration is modifying BESS-Polar to measure light isotopes, particularly Be, to relativistic energies. The ratio of radioactive ^{10}Be to stable ^{9}Be acts as a radioactive clock measuring the storage time of the cosmic rays in our galaxy and, by employing time-dilation, can measure the fraction spent in the galactic halo. BESS-Polar is uniquely capable of making these important measurements. The BESS-Polar magnet, which had to be partly disassembled in the field as part of the BESS-Polar II recovery has been reassembled and is now at Goddard. The magnet was run to full field in Japan and cryogen lifetime tests will be carried out at Goddard in 2013.

Cosmic Ray Energetics and Mass (CREAM and ISS-CREAM)

The balloon-borne CREAM instrument was developed for direct measurements of cosmic-ray spectra $1 \leq Z \leq 26$ at total energies greater than 10^{11} eV to test models of cosmic-ray acceleration. In addition, CREAM measurements of the energy-dependent abundance ratios of secondary cosmic-ray species to their primary progenitors test models of cosmic-ray transport and storage in our galaxy. The CREAM collaboration includes the University of Maryland (PI, Eun-Suk Seo), Goddard, Pennsylvania State University, Northern Kentucky University, and Ohio State University, as well as collaborators in Korea, France, and Mexico. ASD team members are John Mitchell and Jason Link.

A large exposure (geometric acceptance multiplied by time) is needed to measure the energy spectra of the most common elements to energies approaching the spectral "knee" (~10^{15} eV). At these energies, most measurements have been based on the detection by ground-based instruments of the showers of particles produced by interactions of primary cosmic rays in the atmosphere and the identity of the incident particle is only inferred. Direct measurements by CREAM provide direct information on cosmic-ray composition, as well as the calibration data required to interpret air-shower results. CREAM has flown six times over Antarctica, accumulating 162 days of exposure.

The combined CREAM and airshower data test models of Fermi shock acceleration of cosmic rays in supernova remnants. Standard models for this mechanism predict single-power-law spectra until a rigidity-dependent acceleration limit is reached. Above this "knee" the all-particle spectrum steepens, accompanying a progressive composition change with increasing energy from dominance by light elements to dominance by heavier elements. CREAM has reported spectra that depart from single power laws, hardening above 200 GeV/nucleon, with the proton spectrum slightly steeper than those of helium and heavier nuclei. Among proposed explanations for these results are the effects of a nearby supernova remnant, or distributed reacceleration within an OB association.

CREAM measures the charge of incident nuclei using a plastic scintillator timing detector and a silicon pixel detector. Depending on the energy and species of the incident particle, its energy is measured by a

The CREAM instrument during balloon inflation for an Antarctic flight.

silica-aerogel Cherenkov camera (CREAM-III, IV, V, VI), a transition radiation detector (CREAM-I), and a tungsten-scintillating optical-fiber calorimeter (all versions). A new transition radiation detector has been developed for CREAM by CERN (Switzerland) and JINR (Russia) to enable improved measurements of secondary-to-primary ratios. Goddard responsibilities are an acrylic Cherenkov detector for rapid particle identification to trigger the instrument on nuclei heavier than He and a scintillating optical-fiber penetration detector that aids triggering on high-energy events and gives a reference time for the timing scintillators.

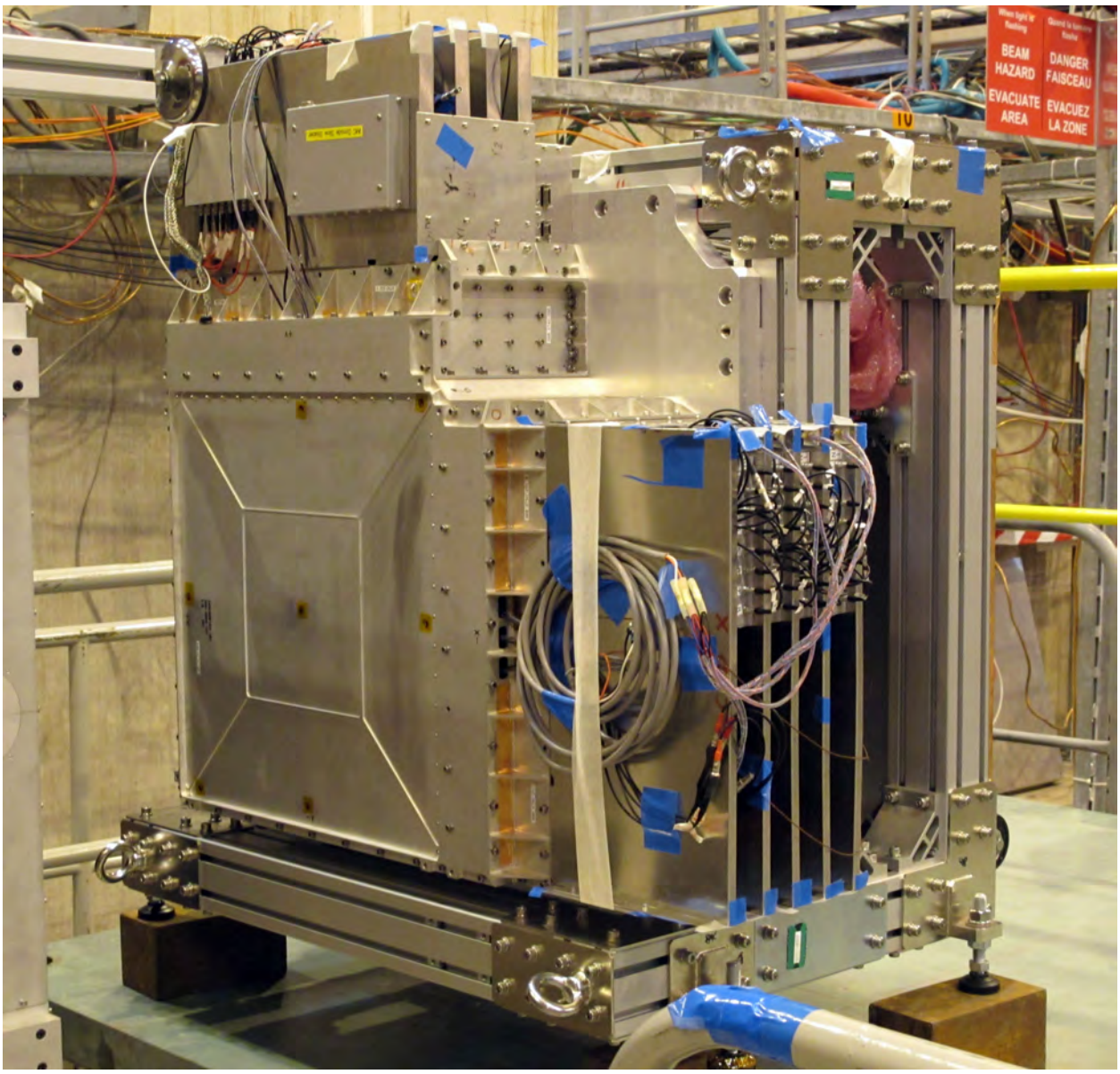
The current focus of the CREAM collaboration is the development of a version of the instrument, ISS-CREAM, to fly on the JEM-EF facility on the ISS. Launch is planned for 2014 on the SpaceX Dragon. Goddard, Pennsylvania State University, and Northern Kentucky University are developing a new detector for ISS-CREAM to help enable measurements of high-energy electrons by helping distinguish electrons from the far more abundant protons. This uses a boron-loaded plastic scintillator to measure neutrons produced in particle cascades in the calorimeter. Because more neutrons are produced in hadronic cascades than in electromagnetic showers of the same energy, the neutron count is a sensitive discriminator to determine whether a shower was initiated by a hadron, such as a proton or atomic nucleus, or by an electron or gamma ray. A prototype of the Boronated Scintillator Detector (BSD) was tested with a pulsed neutron source at Goddard and in accelerator beams at the CERN Super Proton Synchrotron. These tests showed that the BSD exceeds its predicted performance. Engineering of the mechanical structure and read-out electronics at Goddard is nearing completion, and the flight model will be constructed in 2013.

Calorimetric Electron Telescope (CALET)

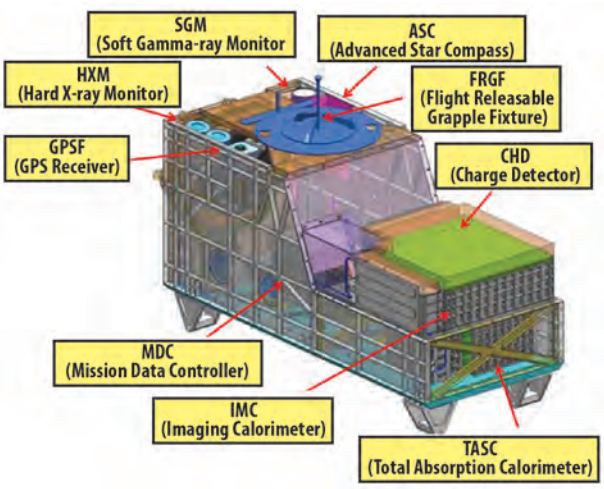
CALET is a new mission for the Japanese Experiment Module-Exposed Facility (JEM-EF) on the Interna-

tional Space Station, manifested for HTV-5 (H-II Transfer Vehicle 5) in 2014. CALET will measure the high-energy spectra of electrons, nuclei, and gamma-rays to address outstanding questions, including signatures of dark matter, the sources of high-energy particles and photons, and the details of particle acceleration and transport in the galaxy. CALET is a JAXA project (PI Shoji Torii, Waseda University) that includes researchers from Japan, the U.S., Italy, and China. The CALET-U.S. team of Louisiana State University, Goddard, Washington University in St. Louis, and the University of Denver are working in CALET instrument development, testing, instrument modeling, flight operations, flight data processing and science analysis. The ASD team of John Mitchell, Thomas Hams, John Krizmanic, Alexander Moiseev, and Makoto Sasaki are responsible for the instrument simulation and performance model, technical support for instrument development, and accelerator testing and calibration.

CALET's Main Telescope uses a deep-imaging particle calorimeter for superior energy resolution and excellent separation between hadrons and electrons and between charged particles and gamma rays. The Main Telescope has a field-of-view of ~45° from the zenith and a geometric acceptance of 0.12 m^2 sr. A



The engineering model of the CALET Main Telescope during the 2012 beam test at the CERN SPS. The zenith surface of the detector is pointed to the left in this picture to accept the incoming particle beam.



The CALET mission module for the JEM-EF. The CALET Main Telescope is made up of the charge detector (CHD), imaging calorimeter (IMC) and total absorption calorimeter (TASC).

charge detector (CHD) subsystem at the top of the telescope measures the charge of incident particles and functions as an anti-coincidence detector for gamma-ray measurements. The calorimeter is divided into an imaging calorimeter (IMC) section that provides tracking and accurately determines the starting point of showers, and a total absorption calorimeter (TASC) section that measures total particle energy. The IMC contains ~3 radiation lengths (Xo) of tungsten interspersed between eight x-y layers of scintillating optical fibers read out by multi-anode photomultipliers. Most electrons and photons will initiate showers in the IMC, which measures the starting point of the shower and its development until it enters the TASC. The TASC is a stack of lead tungstate (PWO) crystals arranged in x-y layers to track the axis of the shower. Each crystal is read out by a photodiode and an avalanche photodiode to give excellent resolution over the wide range of scintillation light signals produced in the PWO by particle showers with different energy, incident angle, and interaction points. The TASC has a total thickness of 27 Xo and collects the total energy in the shower with a leakage of only a few percent for electrons.

CALET is focused on investigating the high-energy total electron spectrum into the trans-TeV energy range. These measurements have the potential to identify, for the first time, the signature of high-energy particles accelerated in a local astrophysical engine and subsequently released into our galaxy. Electrons lose energy rapidly by synchrotron and inverse Compton processes. The distant-source spectrum is expected to be relatively featureless, falling approximately as E^{-3} and softening rapidly above 1 TeV. Electrons with TeV energy must have been accelerated within about 10^5 years and can have diffused at most a few hundred parsecs. The electron lifetime and the diffusion distance decrease rapidly with energy. Detection of electrons with energy significantly above 1 TeV would indicate the presence of a nearby source and the arrival directions of these electrons should also show detectable anisotropy. Individual sources might also produce features in the spectrum at lower energies. CALET will resolve discrepancies among recent results from balloon experiments (BETS, ATIC, PPB-BETS), space experiments (Fermi, PAMELA) and ground-based air Cherenkov telescope observations (HESS).

High-energy electrons and positrons may also be produced by dark-matter annihilation. CALET will search for signatures of dark-matter-annihilation-producing features in the electron or gamma-ray spectra. Together with measurements at the Large Hadron Collider, details of the spectra of high-energy cosmic-ray electrons and positrons may hold the key to revealing the nature of dark matter.

The spectra of primary cosmic-ray nuclei, and the important secondary elements such as boron, hold the key to understanding galactic particle transport at very high energy. CALET will measure the B/C ratio with precision to about a decade in energy beyond current results, and thereby test many of the models currently proposed. CALET will also extend the measurements of the spectra of cosmic ray nuclei from hydrogen to iron, with high resolution, into the region of the spectral "knee" around of 10^{15} eV to investigate possible structure and energy-dependent composition changes.

CALET will perform a gamma-ray all-sky survey, complementing Fermi and HESS observations, to detect intense high-energy sources, study the diffuse component, and search for new regions of emission. CALET includes a low energy (7 keV–20 MeV) gamma-ray burst monitor. GRB measurements are also extended to high energy using the Main Telescope.

Construction of the instrument and spacecraft are nearing completion. An engineering model of CALET was tested at the CERN (European Organization for Nuclear Research) Super Proton Synchrotron (SPS) in September/October 2012 using proton and electron beams up to 400 GeV in energy. These high-precision, high-statistics tests showed that the instrument provides the needed discrimination between cosmic-ray electrons and the far more numerous protons, and has an energy resolution of a few percent for electrons. Tests at the SPS with heavy-ions from a fragmented Pb beam are scheduled for January/February 2013. Mitchell is responsible for co-leadership of these tests and for accelerator beam tuning and development.

In 2012, CALET was awarded the status of "Recognized Experiment" by CERN, with increased access to CERN facilities and services.

X-ray Quantum Calorimeter (XQC), Micro-X, and DXL Sounding Rockets

The X-ray Quantum Calorimeter (XQC) is a broadband, non-dispersive X-ray spectrometer built to study the soft X-ray background in the band from 0.05 to 2 keV. The ASD research team members include Porter, Kelley, Kilbourne, and Eckart. Collaborating institutions include the University of Wisconsin at Madison, the University of Miami, and Yale University.

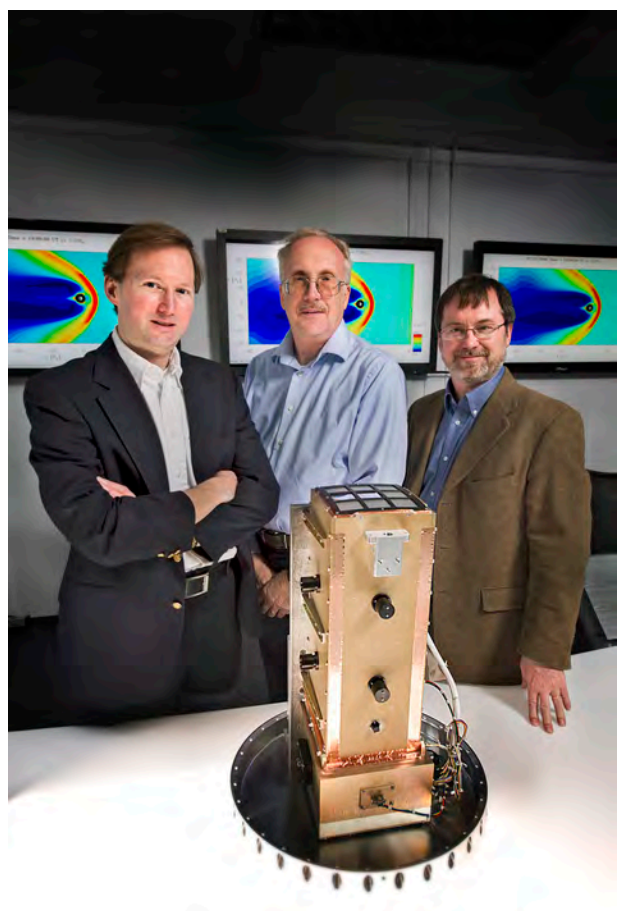
The spectrometer was built to differentiate the spectral components that are thought to make up the ubiquitous soft X-ray background, including emission from the Local Bubble, the Galactic halo, and solar-wind charge exchange in the exo-atmosphere and the heliosphere. The superposition of these temporally and spatially variable sources can create a complicated spectral picture that requires high-resolution spectroscopy to unwind. Detailed spatial maps first were made with sounding rockets, then with ROSAT, and the first high-resolution spectra in the 0.25 keV band were made with the DXS shuttle-attached payload that used a scanning dispersive spectrometer.

The XQC, however, is the first broadband non-dispersive, high-resolution spectrometer to probe the entire X-ray-emitting range, from M-shell Fe emission at 70 eV up to 2 keV, where the diffuse emission becomes dominated by unresolved extragalactic sources. In addition, the XQC payload is the first—and currently, the only—X-ray calorimeter array that has flown in space.

The XQC spectrometer is based on a 36 pixel X-ray calorimeter array that was designed and produced at Goddard. Each pixel in the calorimeter array is relatively large at 2mm × 2mm, and has an energy resolution at O VII Ka of better than 8 eV FWHM. The detector array is operated at 50 mK using a small adiabatic demagnetization refrigerator built at the University of Wisconsin and Goddard. The payload does not use an X-ray optic since this would significantly reduce the grasp of the experiment, but is instead collimated to a one-steradian field of view.

The XQC has flown five times since 1995, with the most recent flight in November 2011. The fourth and fifth flights used a detector array with four times the collecting area of previous flights and is based on technology developed for the Astro-E2 program. The data from the fifth flight is currently being processed, but preliminary results show significant contributions from C IV, O VII, OVIII, Fe XVII, and Fe XVIII. Previous flights have placed constraints on certain types of dark matter, and have detected and placed limits on Local Bubble emission from M-shell transitions in Fe IX, X, and XI. Flight six of the XQC is planned for early-2013 and will incorporate further mitigations against contamination of the outer filter, a serious problem for flights four and five.

The Micro-X payload is designed to be the first X-ray calorimeter payload using focusing X-ray optics. It uses significant design heritage from the XQC program, including a very similar adiabatic demagnetization refrigerator. However, the detector and readout technology are derived from the IXO program. The ASD research team members include Porter, Kelley, Kilbourne, Bandler, Adams, Eckart, Smith, Serlemitsos, and Soong. Collaborating institutions include the University of Wisconsin at Madison, MIT, the University of Florida, and the National Institute of Standards and Technology. The Micro-X payload will use a 121 pixel (11 × 11) X-ray calorimeter array with



The STORM wide-field X-ray camera and its principle scientists, planetary scientist Michael Collier (left), heliophysicist David Sibeck (center), and astrophysicist F. Scott Porter.

The DXL/STORM mission team poses in front of the White Sands Missile Range launch pad before the payload's Dec. 12, 2012, flight.

superconducting transition-edge (TES) thermistors operating at 50 mK. It is designed to have an energy resolution of 2 eV (FWHM) across the energy band from 0.05 to 2 keV. The Micro-X payload will use a focusing optic designed and produced at Goddard for the SXS sounding rocket that flew in 1989 and is the predecessor of the optics used for BBXRT, ASCA, Astro-E2, and Astro-H.

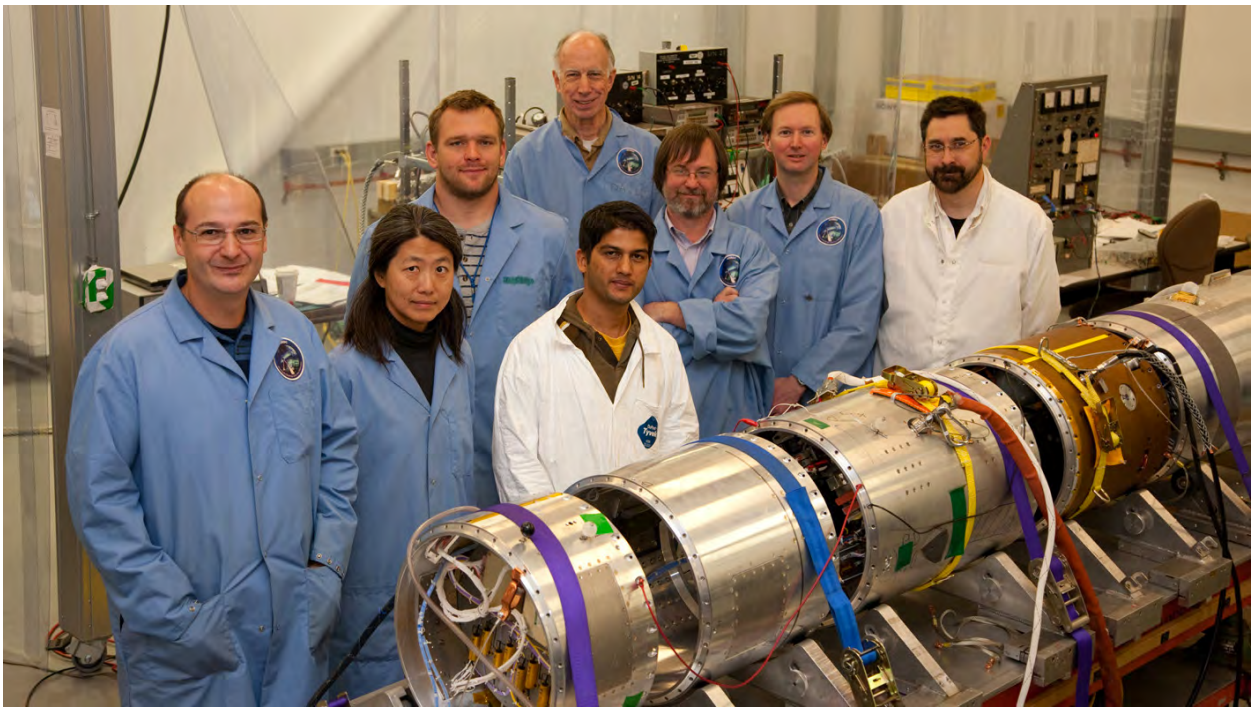
The Micro-X payload is scheduled to fly in late 2013 to observe the bright eastern knot of the Puppis A supernova remnant. The detector array is designed and produced by GSFC and will be read out using a cryogenic SQUID multiplexer and room-temperature electronics jointly developed by GSFC and NIST. GSFC has already provided the refurbished SXS X-ray optic with 200 cm^2 collecting area at 1 keV and a 2.5 arcmin PSF.

Micro-X will provide some of the first detailed high-resolution spectra of a supernova remnant, with about 40,000 counts expected during the flight. The payload will be the first opportunity to utilize high-spectral-resolution, broadband, spatial-spectral imaging, and will provide a glimpse of what we can expect from Astro-H and future, larger scale, calorimeter instruments.

The DXL payload utilizes an old payload repurposed for new science. It is now widely believed that a significant component of the soft X-ray background results from the interaction of the solar wind with neutral atoms within our solar system. Observing from low Earth orbit, we have seen significant emission from the solar wind interacting with exospheric neutral hydrogen (magnetospheric emission), and also the solar wind interacting with interplanetary hydrogen and helium (heliospheric emission). These two sources have very different spatial and temporal signatures, but are both the result of charge-exchange recombination, where a highly ionized solar wind ion removes an electron from a neutral species, emitting photons, including X-rays, as it relaxes to its ground state. The DXL payload contains two 800 cm^2 proportional counters built in the late 1970s at the University of Wisconsin to map the soft X-ray background. However, DXL will use the same large-grasp instrument to spatially disentangle the heliospheric from the magnetospheric charge-exchange emission and compare the results to modern spatial and temporal models of solar wind charge exchange.

The DXL project brings together scientists from several disparate fields who have a strong interest in these phenomena. ASD scientists include Porter, Snowden, Kuntz, Chiao, and Thomas who have a strong interest in the soft X-ray background and in understanding the solar wind charge-exchange contamination of many soft X-ray observations with ROSAT, Chandra, XMM, Suzaku, and soon, Astro-H. This is in partnership with Goddard collaborators Sibeck (Space Weather Laboratory) and Collier (Solar System Exploration Division), who have a strong interest in the interaction between the solar wind and Earth's exosphere to understand the critical boundary layer that drives much of space weather. The PI institution is the University of Miami, with additional collaborating institutions: University of Kansas, the University of Wisconsin, and Leicester University.

The DXL payload also includes a Goddard-provided instrument, STORM, as a technology demonstration. STORM is a microchannel-plate X-ray detector with a wide field of view (10 × 10 degree) Lobster-eye slumped microchannel-plate optic. This is a prototype instrument for a full-scale magnetospheric charge exchange X-ray imager, and DXL is the first space-flight demonstration of this technology. The



The DXL/STORM payload and science team during horizontal integration testing at White Sands Missile Range in December 2012.

STORM instrument was developed at GSFC by ASD scientists Porter, Snowden, Kuntz, Chiao, and Thomas with collaborators Collier, Sibeck, and the University of Leicester.

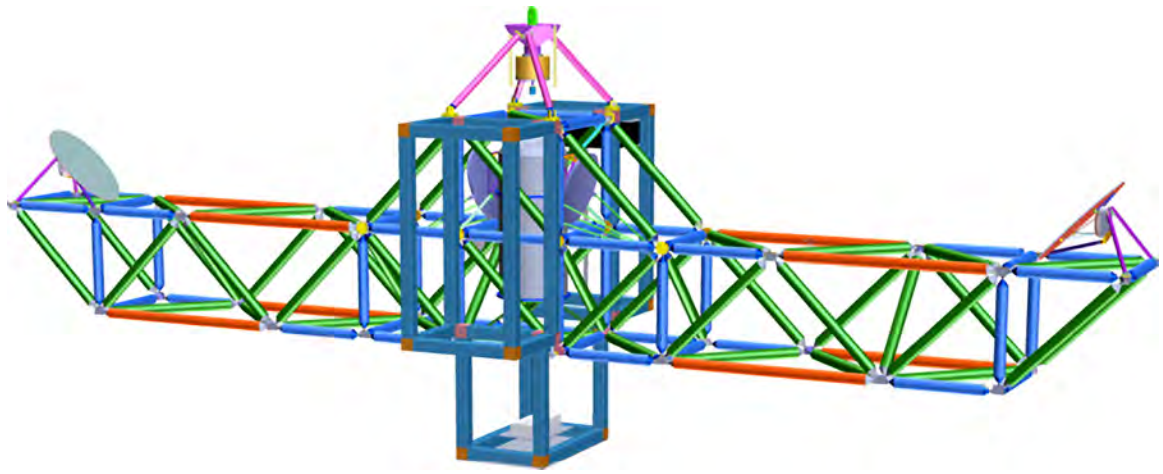
The DXL and STORM payloads successfully flew on Dec. 12, 2012. DXL clearly observed charge exchange from interplanetary helium in the helium focusing cone. STORM also clearly observed cosmic soft X-ray emission. Both instruments performed flawlessly and landed without damage.

The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

Astronomical studies at infrared wavelengths have revolutionized our understanding of galaxies, stars, and planets, as well as their origins. But further progress on major questions is stymied by the inescapable fact that the spatial resolution of single-aperture telescopes degrades at long wavelengths. Exciting physical processes lurk below our current far-infrared (FIR) resolution, including clustered star formation, powerful interactions between normal matter and monstrous black holes at the cores of galaxies, and the formation of planetary systems. Interferometry is a path to high angular resolution in the FIR, making it a potent tool for scientific discovery.

The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) is an 8-meter boom interferometer to operate in the FIR (30–90 μm) on a high-altitude balloon that was selected for funding under the ROSES/APRA program in 2010. The long baseline will provide unprecedented angular resolution (~0.5") in this band. These wavelengths are inaccessible from the ground; the high atmospheric transmission at balloon altitudes, in combination with BETTII's unique double-Fourier instrument will allow spectral resolution of up to $R \equiv \lambda/\Delta\lambda \sim 200$. By combining these capabilities, BETTII will provide spatially-resolved spectroscopy on astrophysically important sources. BETTII's first flight will isolate the far-infrared emission from forming stars in cluster environments, allowing us to tightly constrain models of cluster formation.

The BETTII project is now two years old, and over the past year, the design of both the instrument and gondola has been completed. In June 2012, the BETTII team held a Preliminary Design Review where the overall system design was presented, discussed, and outstanding design elements were identified. Since then, additional subsystem reviews have taken place to demonstrate that individual component systems are sufficiently developed to initiate procurements. This included a full instrument review in October 2012. A



In 2012, the design of BETTII's gondola and instrument were completed. A pair of mirrors spaced 8 meters apart collect infrared light from the same object. Combining these two signals with an instrument called an interferometer yields the same resolution as a single 8-meter telescope. BETTI's first flight is planned for spring 2015.

small number of actions were identified from this review, and procurement of long-lead items including the helium-3 refrigerator and the instrument cryostat has begun. In addition, the metering truss was constructed over summer 2012, and testing of the mechanical behavior of this assembly is now underway. The BETTII team has also generated a Master Equipment List and is in the process of developing a complete, detailed test plan that works from the level of individual components all the way to the full system. Many of the individual components have been purchased or manufactured, and testing of these components is underway. We anticipate that all major components well be in hand in 2013, and both components and subsystem testing will be under way.

In addition, over summer 2012, a cadre of students developed the BETTII RUBBLE experiment. RUBBLE is an experimental star camera using off-the-shelf components and open-source software. It is designed to achieve subarcsecond pointing accuracy on balloon platforms. While a number of star cameras have been flown on balloon payloads previously, RUBBLE is both more accurate and less expensive, and we envision presenting it as an open-source package so that other scientists building balloon payloads can benefit from the design. RUBBLE will fly as a hitchhiker on the BOBCAT experiment in 2013; it is currently complete and undergoing tests in the laboratory.

A successful flight of BETTII will pave the way for future space interferometry by demonstrating key technologies, including wide-field phase referencing for image reconstruction and the technique of double-Fourier interferometry. A traditional Michelson interferometer uses a single detector and has a field of view determined by the size of the individual light collecting apertures. By using a detector array, one observes interferograms corresponding to multiple contiguous primary beams simultaneously on different pixels. This technique—wide-field double-Fourier interferometry—has been demonstrated on a laboratory test bed but never in a flight-like environment.

The first flight of BETTII is planned for spring 2015. Data acquired with BETTII will be complementary to observations with space observatories such as Herschel and the James Webb Space Telescope, exploring the FIR wavelength range with unprecedented high angular resolution. These data will be powerful tools for understanding star formation in clusters. Further, BETTII will validate technologies and retire risks for future space interferometers, such as the Space Infrared Interferometric Telescope.

The BETTII project is a collaboration between NASA's Goddard Space Flight Center, the University of Maryland, and Cardiff University with assistance from the Far-Infrared Telescope Experiment team in Japan. The BETTII team includes ASD scientists Stephen Rinehart, Rich Barry, Dominic Benford, Dale Fixsen, Bill Danchi, Johannes Staguhn, Robert Silverberg (Emeritus), as well as David Leisawitz (Science Proposal Support Office), Christine Jhabvala (Instrument Systems & Technology Division) and Lee Mundy (UMCP). The project also has had contributions from a UMCP graduate student (Maxime Rizzo) and a number of undergraduates from multiple institutions. Information on BETTII interns can be found on the BETTII website: http://asd.gsfc.nasa.gov/bettii/

Technology Development

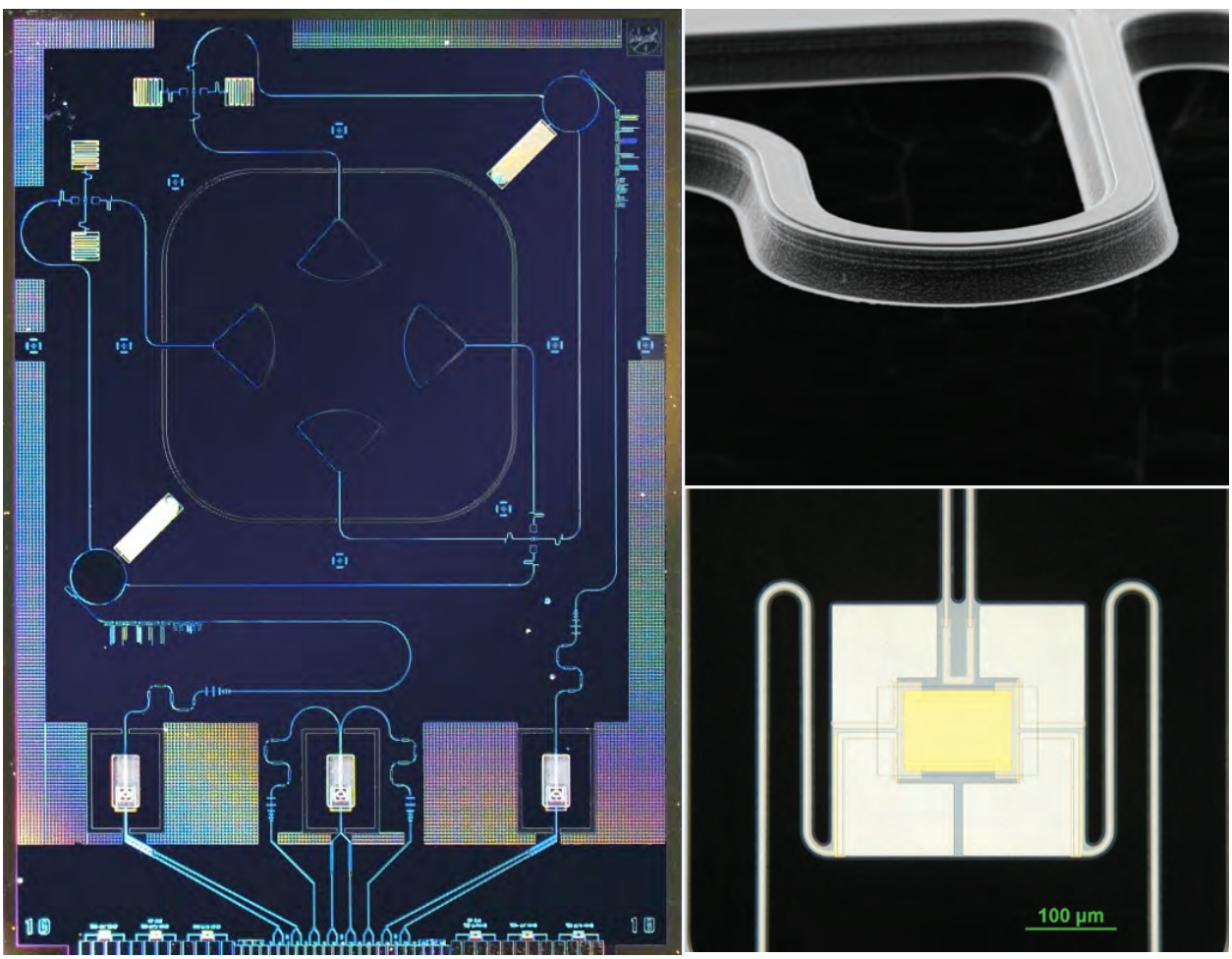
Detecting CMB Polarization

Recent advances in cosmology hint that the universe underwent a brief period of rapid expansion called inflation early in its history. If inflation occurred, the gravitational waves it produced would have polarized the cosmic microwave background (CMB) in a particular pattern. To measure this faint signal requires the development of instruments with high sensitivity, control over systematic effects, and multiple frequencies for removal of polarized galactic foregrounds.

Ed Wollack, David Chuss, Karwan Rostem, and Harvey Moseley in ASD's Observational Cosmology Laboratory, along with team members Kevin Denis, Thomas Stevenson, and Kongpop U-Yen in Goddard's Applied Engineering and Technology Directorate, are developing detectors for measurement of the polarization of the CMB. These devices are waveguide-coupled and employ Transition-Edge Sensing (TES) bolometers realized on a mono-crystalline silicon substrate. Fully-integrated detectors have been fabricated.

In the sensor concept, radiation from the feedhorn is coupled onto superconducting microstrip circuitry using a planar ortho-mode transducer and subsequently filtered and detected on chip. This design is amenable to the large focal planes a satellite mission will require. The team is currently optimizing the sensor design for compatibility with suborbital test platforms. This involves tailoring the device response via the thermal conductance, transition temperature and time constant.

This group also has designed sensors operating at 40 and 90 GHz that will be integrated into the Cosmology Large Angular Scale Surveyor (CLASS)



Left: A CLASS 40-GHz-detector microwave circuit is shown. Opposite probe antennas (center) couple to a common polarization on the sky once a waveguide and feedhorn are connected. The signal in each polarization is filtered to define the band before thermally coupling to a TES. Right (top): Scanning electron micrograph image of one of the silicon legs that supports the TES membrane. Right (bottom): The TES thermally-isolated membrane. The TES is is the rectangle in the center of the image.

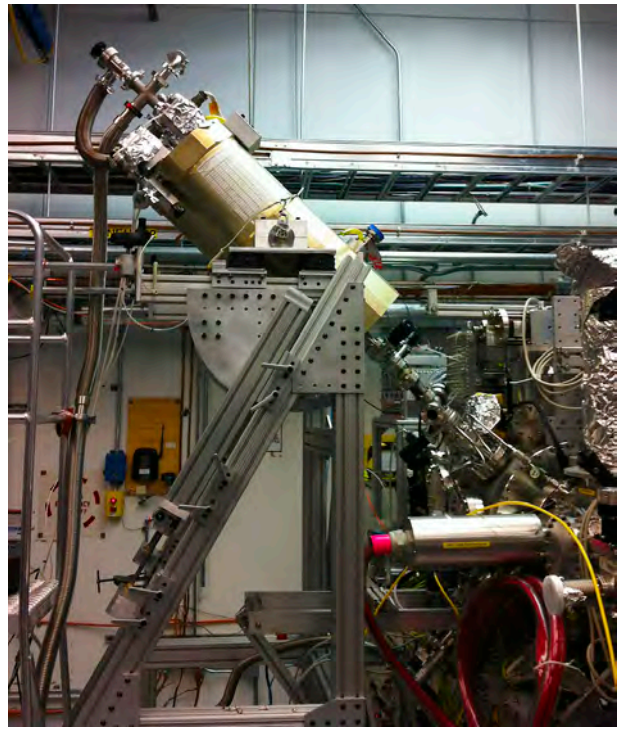
instrument, a project led by Johns Hopkins University that will be deployed in Chile's Atacama Desert. CLASS observes polarization of the CMB at the largest angular scales in order to avoid contamination from gravitational lensing. The instrument employs variable-delay polarization modulators (VPMs, also developed at Goddard) in concert with the polarization sensitive detectors in order to encode and separate the faint polarized astrophysical signature from instrumental effects.

Laboratory Astrophysics Using an X-ray Microcalorimeter with an Electron Beam Ion Trap

Our laboratory astrophysics program is designed to simulate astrophysical plasmas in the laboratory in order to benchmark and provide guidance to the atomic codes that form the basis of the spectral synthesis models used in X-ray astrophysics. These models are used to relate spectra observed from an astrophysical object to conditions in the source, including temperature, ionization-equilibrium, composition, density, turbulence and bulk motion. This work is fundamentally important as high-resolution spectroscopy becomes the dominant tool in exploring the physics of X-ray-emitting objects.

This has already started with the observation of bright point sources with the high-resolution dispersive spectrometers on Chandra and XMM/Newton. It will become critically important with the upcoming Astro-H and IXO/Athena, which will produce a detailed, high-spectral-resolution image with every observation. Our program is designed to validate and correct the accuracy of the spectral synthesis models in controlled ground-based experiments, giving us confidence that we have correctly ascribed observed spectral features to known conditions in the astrophysical source.

The basis of our program is a high-resolution, non-dispersive, X-ray calorimeter spectrometer, a suite of very-high-resolution dispersive spectrometers, and the Electron Beam Ion Trap (EBIT) plasma generator at the Lawrence Livermore National Laboratory (LLNL). ASD scientists include Porter, Kelley, Kilbourne, Adams, Smith, and Leutenegger. Other collaborating institutions include Stanford University and the National Institute of Standards and Technology. The LLNL EBIT can produce nearly any plasma conditions, from low-charge states in light elements to bare uranium with electron beam energies of up to 200 keV. Nearly any charge state of any astrophysically interesting element can be produced, either as a pure charge state or in a Maxwellian distribution at known temperature.



The XRS/EBIT microcalorimeter spectrometer attached to an EBIT at the Linac Coherent Light Source. This experiment performed some of the first measurements of X-ray photoexcitation in highly charged ions in the laboratory, providing critical laboratory tests of astrophysical plasmas.

Non-equilibrium ionization conditions can also be produced with almost any astrophysically interesting ionization parameter. Typical measurements in our program include spectral-line identification, absolute cross sections, recombination, charge-exchange recombination, and cross sections in thermal and non-thermal distributions. Measurements are related back to theory, the results of atomic calculations, and to the standard X-ray spectral synthesis models used in X-ray astrophysics.

A key instrument in these measurements is a broadband high-resolution X-ray calorimeter instrument provided by Goddard beginning in 2000 and now on its third revision. This system has been operated almost continuously for the past 9.5 years. It has produced well over two dozen peer-reviewed articles, and it has made critical measurements of absolute cross sections in L-shell Fe and Ni, as well as charge-exchange measurements in S, C, O, and Fe. Many investigations are ongoing. Recent emphasis has been a detailed look at L-shell charge exchange,

mostly with sulfur and iron, as a function of ionization state, a key component of magnetospheric charge exchange for which there exists no predictive theory. Magnetospheric and heliospheric charge exchange are key components of spatially, spectrally, and temporally variable foreground emission which complicate observations of, for example, the soft X-ray background, warm-hot intergalactic medium, and clusters of galaxies. Charge-exchange emission is also very diagnostic and if observed in a celestial source can provide key information on the composition, ionization state, and relative velocity of both the donor and acceptor species. Our laboratory investigation is unique in the world at providing the first controlled high-resolution spectra of charge exchange in astrophysical elements and is geared to provide information to guide the development of a predictive atomic theory, especially for the key L-shell emission which dominates local charge exchange.

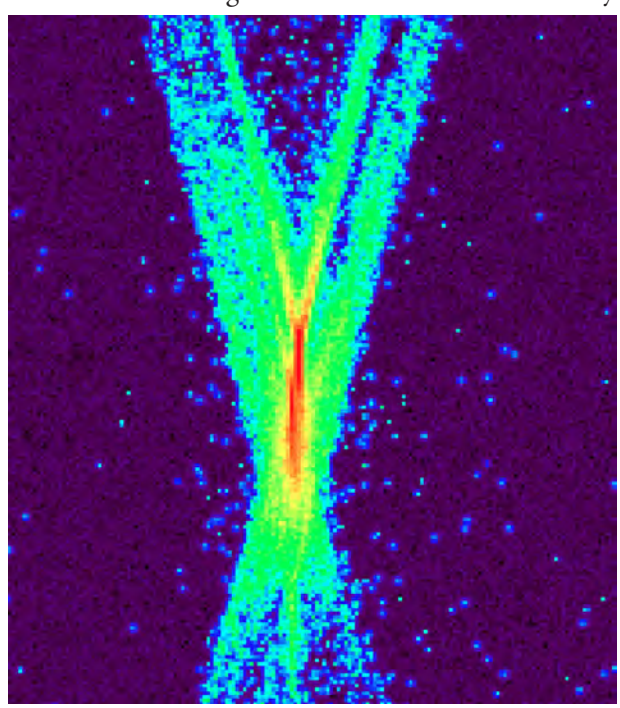
Goddard first installed an X-ray calorimeter instrument at the LLNL EBIT facility in the summer of 2000, the XRS/EBIT, based on the engineering-model detector system for the Astro-E observatory. The system was significantly upgraded using technology developed for Astro-E2 in 2003. A dedicated facility-class instrument designed from the ground up for laboratory astrophysics was installed in 2007. The current instrument, dubbed the EBIT Calorimeter Spectrometer (ECS), utilizes a 32-channel X-ray calorimeter array from the Astro-E2 program installed in a long-lifetime automated laboratory cryostat that enables continuous experiments for up to 70 hours with a two-hour recharge. The detector array is populated with 16 mid-band (0.05–12 keV) X-ray absorbers with 4.5 eV FWHM resolution at 6 keV, and 16 high-band (0.1–100 keV) X-ray absorbers with 30 eV FWHM at 60 keV.

In addition to operating the ECS, we recently (spring 2011 and spring 2012) refurbished the XRS/EBIT spectrometer to perform photoexcitation measurements at the SLAC Linac Coherent Light Source (LCLS). In this experiment we combined a portable EBIT, the XRS/EBIT spectrometer, and a monochrometer with the LCLS light source to breed and observe X-ray emission from photoexcitation in highly charged ions. This resulted in a recent letter to Nature (Bernitt et al. 2012), with ASD scientists Porter and Leutenegger as co-authors.

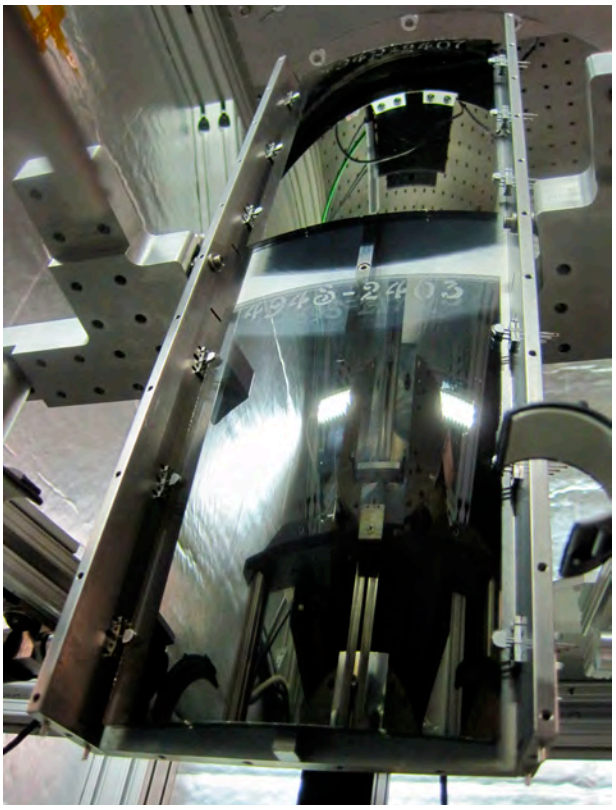
We are currently designing and constructing the fourth-generation instrument that will be based on detector technology from the IXO/Athena development program. It will be installed in a completely automated cryogen-free cryostat. This fourth-generation instrument is dubbed the Transition-Edge Microcalorimeter Spectrometer (TEMS) and will be composed of a checkerboard hybrid of 128 low-band (0.05–1 keV) pixels with 0.8 eV resolution at 1 keV, and 128 mid-band (0.05–10 keV) pixels with 2.0 eV resolution at 6 keV. In addition, there will be a 64-channel high-band array (0.1–200 keV) with 30 eV resolution at 60 keV. The TEMS instrument will become the workhorse instrument in our laboratory astrophysics program to make sure that our measurements and understanding of atomic processes are ready to interpret the spectra we will obtain with Astro-H and future observatories. TEMS will be installed at the EBIT facility in late 2013.

Next Generation X-ray Optics

X-ray optics is an essential and enabling technology for future X-ray astronomical missions. It is characterized by three quantities: angular resolution, effective area per unit mass, and production cost per unit effective area. This development, led by Dr. Will Zhang of the X-ray Astrophysics Laboratory, is a collaborative effort of scientists and engineers from ASD and Goddard's Applied Engineering and Technology Directorate, as well as SGT and Ball Aerospace. Its objective is to develop a telescope-manufacturing process that achieves the highest angular resolution possible while maximizing the effective area per unit mass and minimizing the cost per unit effective area, advancing by at least an order of magnitude the state of the art of X-ray



An image from the mirror module made using 7.9 keV X-rays generated by a copper target.



This X-ray mirror module containing three co-aligned and bonded parabolic-hyperbolic mirror pairs. This module has been subjected to X-ray imaging performance tests in a 600-m long X-ray beam line before and after vibration and thermal-vacuum environment tests, demonstrating that this technology is at TRL 5.

telescope construction represented by the three currently operating missions: Chandra, XMM-Newton, and Suzaku.

This development effort uses the segmented design approach. The technique is scalable and suited to building telescopes of any size—small ones for Explorer missions as well as large ones for flagship missions. The key steps of the process include: fabrication, coating, and measurement of mirror segments, and alignment and integration of mirror segments into modules.

The development effort is multi-pronged, investigating two methods for fabricating mirror substrates: precision glass slumping and the polishing and lightweighting of monocrystalline silicon. The precision glass slumping is a replication technique and has been developed for the former International X-ray Observatory mission (IXO). It is a mature and inexpensive process and has been demonstrated to be capable of making mirror substrates at the 7-arcsecond level, enabling the manufacture of 10-arsecond-resolution telescopes. The polishing and lightweighting of monocrystalline silicon is a new method under development that has the potential of making diffraction-limited X-ray mirrors, enabling a future telescopes with angular resolution comparable to, or better than, Chandra's 0.5 arcseconds.

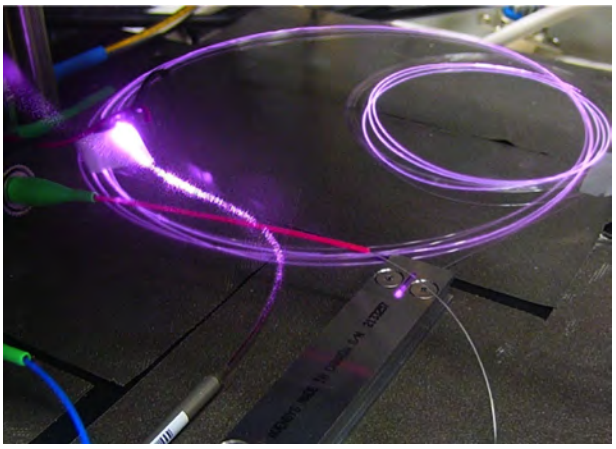
The team is investigating both magnetron sputtering and atomic layer deposition (ALD) for coating thin X-ray mirrors to achieve the maximum possible reflectivity while minimizing figure distortion caused by coating stress. Both processes have been demonstrated to work on experimental samples. In 2012 they will be applied on full-size mirrors.

As part of their effort to develop a method of aligning and integrating mirror segments into a module, the team has built up a small laboratory in the Goddard Optical Test Site. The laboratory has a very stable thermal environment, with temperature variation less than 0.1° C over several days. In 2011, they repeatedly aligned and bonded single pairs of parabolic and hyperbolic mirror segments, achieving X-ray images better than 10 arcseconds and demonstrating the technique is well suited for making 10-arcsecond modules. In 2012, they successfully applied this technique to co-align and bond three pairs of mirror segments, demonstrating that these modules can pass both X-ray performance tests and environment tests. In 2013 they expect to further refine the alignment and bonding technique to construct technology-development modules that contain more than 3 parabolic-hyperbolic mirror pairs.

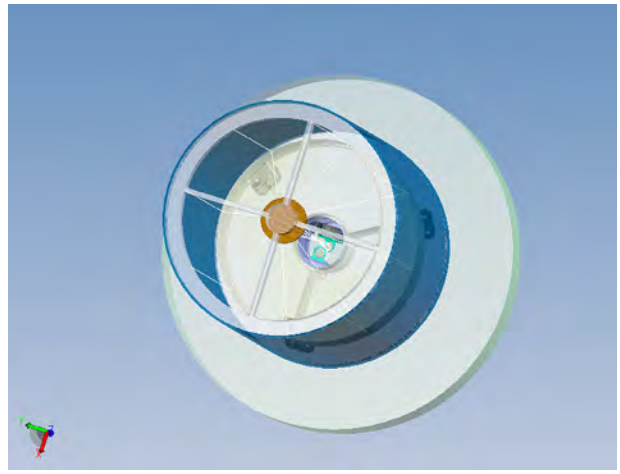
Technology Development for Gravitational Wave Missions

The technologists of the Gravitational Wave Astrophysics Branch continued to study key and enabling technologies for space-based gravitational wave detection in 2012. These efforts were led by branch scientists Camp, Livas, Numata, Stebbins, and Thorpe with help from both contract and civil-servant engineers. The technology-development efforts also provided educational opportunities for several students, including high school student Alex Dalzell and graduate student Darsa Donelan (U. Florida). Results from 2012's technology development work were presented at several conferences, including the IEEE Aerospace Conference, the 9th International LISA Symposium, and the 39th COSPAR General Assembly.

The biggest change for 2012 was the expansion of possible mission architectures that resulted from the dissolution of the NASA/ESA partnership on the Laser Interferometer Space Antenna (LISA) mission and the subsequent re-scoping of gravitational wave missions in both the U.S. and Europe. Livas, Steb-



A high-power ytturbium fiber amplifier in action



This mechanical model of the on-axis telescope design, showing the spider and tertiary mirror, enables quantitative evaluation of estimated performance against requirements.

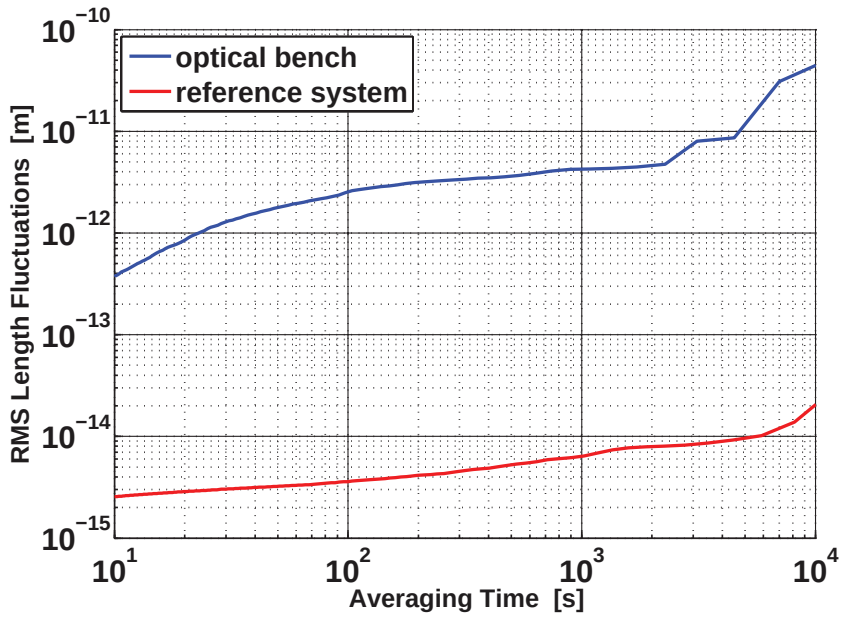
bins, and Thorpe played vital roles in the execution and documentation of the Gravitational-Wave Mission Concept Study, which considered a variety of potential mission concepts and evaluated their cost, risk, science impact, and technologies. While the study concluded that the most effective mission concepts were those implemented with LISA-like architectures, there were some significant differences (e.g., laser power, telescope size, etc.) that will influence future technology development. A related effort to produce a Gravitational Wave Technology Development Plan is currently under way and is expected to conclude early in 2013.

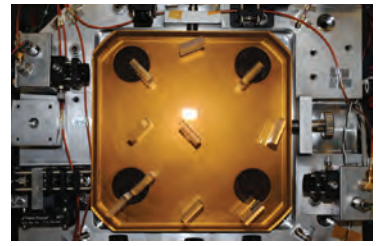
In addition to developing technologies for a future U.S.-led gravitational wave mission, branch technologists are studying potential contributions to ESA's New Gravitational-Wave/Evolved LISA (NGO/eLISA) mission concept, which expects to respond to an upcoming call for large missions in ESA's Cosmic Visions Programme.

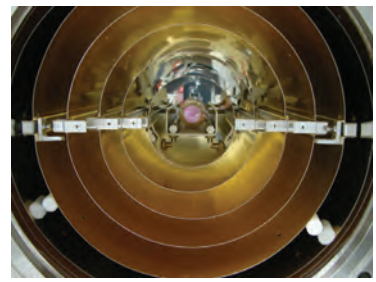
Fiber laser/amplifier development. Laser technology for the telecommunications industry has undergone dramatic advances in the past decade. Lasers and optical amplifiers based on bulk optics have been replaced by technologies such as fiber lasers and amplifiers, waveguide devices and semiconductor lasers. These components naturally fit into the precision laser systems needed for interferometric gravitational wave missions: They have high mechanical robustness, high reliability, compact form factor, and high wall-plug efficiency. Numata and Camp are pursuing an all-fiber/waveguide space laser solution based on the MOFA (master oscillator fiber amplifier) configuration, namely, a waveguide-based oscillator followed by a pre-amplifier and a power amplifier. In 2012, detailed noise measurements of the power amplifier system were completed. The differential phase noise is reduced by a factor ~4 by adopting a highly-doped short large-core fiber and is now on the LISA requirement level. Numata and Camp, with a support from Redfern Integrated Optics (RIO, California), have also continued the development work on planar-waveguide external cavity diode laser (PW-ECL) as a possible alternative to traditional NPROs and fiber lasers. By 2011, 1550-nm PW-ECL was proven to have enough robustness for spaceflight. As a result, it was adopted as a light source of the OpTIIX metrology system in 2012. Also in 2012, RIO started development work on 1064-nm version of PW-ECL, primarily for the LISA mission. Its first sample will be delivered to GSFC in early 2013 and will be tested together with the Yb pre- and power-amplifier as an all-waveguide-based laser system.

Telescope structure stability. A telescope is needed for gravitational wave measurements to increase the light-transfer efficiency between distant spacecraft. Since the telescope lies in the interferometric path, it is critical that the optical path length through the telescope remain stable at the picometer level. Livas, together with engineering support from GSFC and testing support from postdoctoral fellow Josep San-Juan and undergraduate Danila Korytov (U. Florida) completed testing to confirm that the dimensional stability is limited by thermal effects in the environment and that the structure will meet requirements in the expected on-orbit environment.

Telescope development and scattered light suppression. Many of the requirements for a realistic telescope for a space-based gravitational wave mission may be satisfied by an optimized Cassegrain-style telescope of modest size (0.2 m) and wavefront quality of $\lambda/30$. The gravitational wave measurement application requires two additional requirements—picometer







The measured upper limit on pathlength fluctuations of the optical bench demonstration prototype are about 25 times smaller than the diameter of a hydrogen atom.

pathlength stability and very low scattered light performance— that impose conflicting requirements on the telescope design. The picometer-level pathlength stability favors an on-axis telescope design, and the scattered light performance favors an off-axis design. Livas, together with collaborators John Crow (543), Joe Howard (551), Len Seals (551), Petar Arsenovic (551), and Ron Shiri (551) have been studying the design options and recently commissioned an industrial partner to do a focused design and engineering study that includes an explicit consideration of design-for-manufacturing requirements, an expertise that the Goddard team does not have. As part of the design study, Shiri and Seals are studying the feasibility of using amplitude masks similar in design to those developed for exoplanet research for scattered light suppression. The masks would be implemented with carbon nanotube technology developed by John Hagopian (551). An experimental test program to verify the performance of these masks is planned in parallel with the feasibility study. The next step after the design study will be to place an order for a prototype telescope, and then verify by testing that it meets the requirements, including scattered light performance and pathlength stability. The pathlength stability testing will be conducted in collaboration with the University of Florida.

Optical bench construction. The missions under study in Europe and the U.S. detect gravitational waves by monitoring distance fluctuations between widely-separated, freely-falling test masses using laser interferometry. The optical structures used to perform this interferometry must be stable at the picometer level to ensure that they do not introduce disturbances that would corrupt the measurement. An innovative technique known as hydroxy-catalysis bonding has been applied in Europe to produce the optical benches for the technology demonstrator mission LISA Pathfinder. Thorpe is leading an effort funded by the Goddard IRAD program to build a small optical bench containing a frequency stabilization reference using the hydroxy-catalysis technique. The team consisting of A. Preston (Laser Remote Sensing Laboratory), L. Miner (Instrument Systems and Technology Division, Optics Branch), and K. Norman (SGT) successfully completed construction of the bench and have begun performance testing of the frequency reference. Preliminary results show an upper-limit RMS length stability of ~4 picometers over averaging times of 1000s. This limit is about 1000x worse than the best measurements made by the GSFC group with their reference cavities (~6 femtometers at 1000s), which are constructed using a different technique that is not as suitable for spaceflight as hydroxy-catalysis bonding. The group is currently working to characterize and indentify the excess noise in the optical bench system and determine what portion is due to the structure itself. For comparison, a Hydrogen atom has a diameter of about 100 picometers and a proton has a charge radius of ~1 femtometer.

This prototype quadrant photoreceiver packaged for compatibility with the LISA Pathfinder optical bench meets the requirements for making picometer displacement measurements and nanoradian anglular measurements.

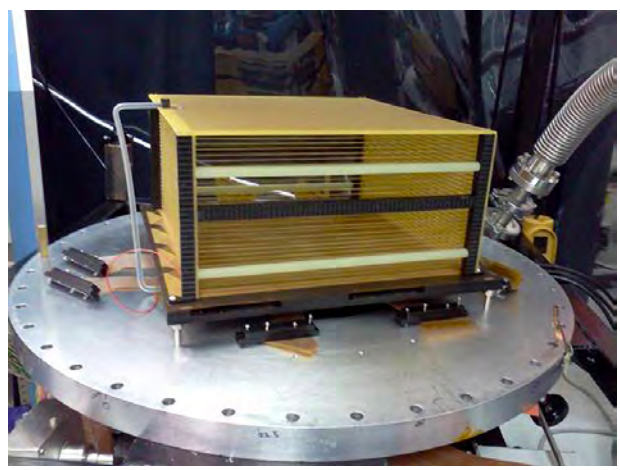
Photoreceiver development. Space-based gravitational wave detectors will use quadrant photoreceivers to detect the interferometric signals and measure the motion of drag-free test masses in both angular orientation and separation. A custom photoreceiver with a 1.0-mm-diameter quadrant photodiode and the associated electronics has been developed through the Small Business Innovative Research (SBIR) program. Demonstrated device performance shows an equivalent input current noise of better than 1.8 pA/√Hz below 20MHz and a 3 dB-bandwidth of 34 MHz, which meets nominal requirements. The SBIR contract formally concluded in March with the delivery of four packaged quadrant photoreceivers. Device level characterization of the noise and bandwidth of the receivers is in progress. The next steps include spatial scanning of the photodiode surfaces, measurement of inter-quadrant cross-talk, and system-level differential wavefront-sensing angle measurements. The photoreceivers may find near-term application in the Gravity Recovery and Climate Experiment (GRACE) follow-on mission now under development, and there may be requirements for larger diameter detectors with similar noise performance.

Three-Dimensional Track Imager Detector for Gamma-ray Imaging with Polarization

Stanley Hunter, with Georgia DeNolfo, Seunghee Son, and Michael Dion, continue the development of the Three-Dimensional Track Imager (3-DTI) for a future gamma-ray telescope with the goal of providing optimum angular resolution and polarization sensitivity in the medium-energy (5–500 MeV) gamma-ray range.

The 3-DTI is a large-volume time-projection chamber (TPC) capable of three dimensional tracking and momentum measurements used for particle identification. A two-dimensional micro-well detector (MWD) serves as a spatial readout and multiplication stage while the third coordinate is obtained from the drift time of the primary charge through the gas volume. Each well of the MWD, 200 μm diameter on 400 μm centers, is an active gas proportional counter with gas gain of ~10^4. Negative ion drift is utilized to reduce the drift velocity and diffusion allowing for the large TPC volume. Development of the 3-DTI technology is funded by NASA/APRA. The team's accomplishments this year include:

1. Drs. Son and Dion made major improvements in our UV laser micro-machining facility allowing various machining techniques to be tested. Plasma cleaning and reactive ion etching of the MWD substrates are being investigated as a means to increase the MWD gain.



30 × 30 × 15 cm³ 3-DTI prototype; the 30 ×30 cm² MWD can be seen between the wires and supports forming the 15-cm tall drift volume. The flex-circuit connections between the MWD electrodes and the charge-sensitive front-end electronics have not been connected. The front-electronics and high-voltage supply for the drift grid are located below the aluminum plate.

The Quasi-Monoenergetic 6 MeV Gamma Facility at Goddard's Geophysical and Astronomical Observatory (GGAO) site. This facility utilizes the D-T neutron generator, extending from the activation loop on the left side of the 1.8 × 1.8 × 0.9 m^3 block of granite, to irradiate water via the $^{1}6O(n,p)^{16}N$ reaction with 14.2 MeV neutrons. The 7.13-second half-life of the ^{16}N allows the water to be pumped to the decay loop on the right side of the granite block where it decays to $^{16}O^*$ that quickly de-excites producing 2.742, 6.129, and 7.117 MeV gamma rays. The granite block shields the decay loop from the background radiation produced by the n,p reaction and neutron interactions in the granite.

2. Dr. Dion designed, fabricated and tested MWDs with a small post projecting from the anode. The increase in detector gain was not realized due to defects in the post fabrication. Additional work continues.
3. The second-generation transient digitizer readout system was fabricated and initial testing completed. This "streaming mode" readout essentially eliminates the 3-DTI readout dead time. Development of the streaming mode software was begun by Teresa Sheets and will be continued with FY13 IRAD funding to demonstrate gigabit per second processing required to process the raw streaming mode data. Final testing and integration with the 30 cm 3-DTI prototype is continuing.
4. A Quasi-Monoenergetic 6 MeV Gamma Facility was developed at Goddard's Geophysical and Astronomical Observatory (GGAO) site. This facility takes advantage of the D-T neutron generator and 1.8 × 1.8 × 0.9 m^3 block of granite at GGAO to provide a low background source of 2.742, 6.129, and 7.117 MeV gamma rays.
5. An APRA proposal, "Optimization and Testing of the 3-DTI for Medium-Energy Gamma-Ray astrophysics," was submitted but not selected for continued funding. A new proposal will be submitted in FY13.
6. Publications:

Development of a telescope for medium-energy gamma-ray astronomy. Stanley D. Hunter, Peter F. Bloser, Michael P. Dion, Georgia A. DeNolfo, Jason Legere, Mark L. McConnell, Suzanne F. Nowicki, James M. Ryan, Seunghee Son, and Floyd W. Stecker. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84430F, doi:10.1117/12.925216

Development of a quasi-monoenergetic 6 MeV gamma facility. Suzanne F. Nowicki, Stanley D. Hunter, Julia G. Bodnarik, Michael P. Dion, Ann M. Parsons, Jeffrey Schweitzer, and Seunghee Son. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844337, doi: 10.1117/12.925473

Development of a quasi-monoenergetic 6 MeV Gamma Facility at NASA Goddard Space Flight Center. S. F. Nowicki, S. D. Hunter, A. M. Parsons. *Nucl. Instrum. Methods Phys. Res. Section A* 705, 111, doi: 10.1016/j.nima.2012.12.066

Projects

Scientists assigned to NASA flight projects play vitally important roles during all phases of a mission's life cycle—from the development of science requirements, to concept and technology development, formulation and eventually operations. The Project Scientist works with project managers, engineers, NASA Headquarters, the mission science team (or science working group) and the wider astronomical community to assure a successful outcome. Nearly half of the scientists in ASD serve NASA either as a Project Scientist (PS) or as a Deputy Project Scientist (DPS), Mission Scientist (MS), Instrument Scientist (IS), Principal Investigator (PI), Deputy PI, and more. The top-notch science that flows from ASD missions is a testament to the knowledge, hard work and dedication that the division's technical staff brings to these roles.

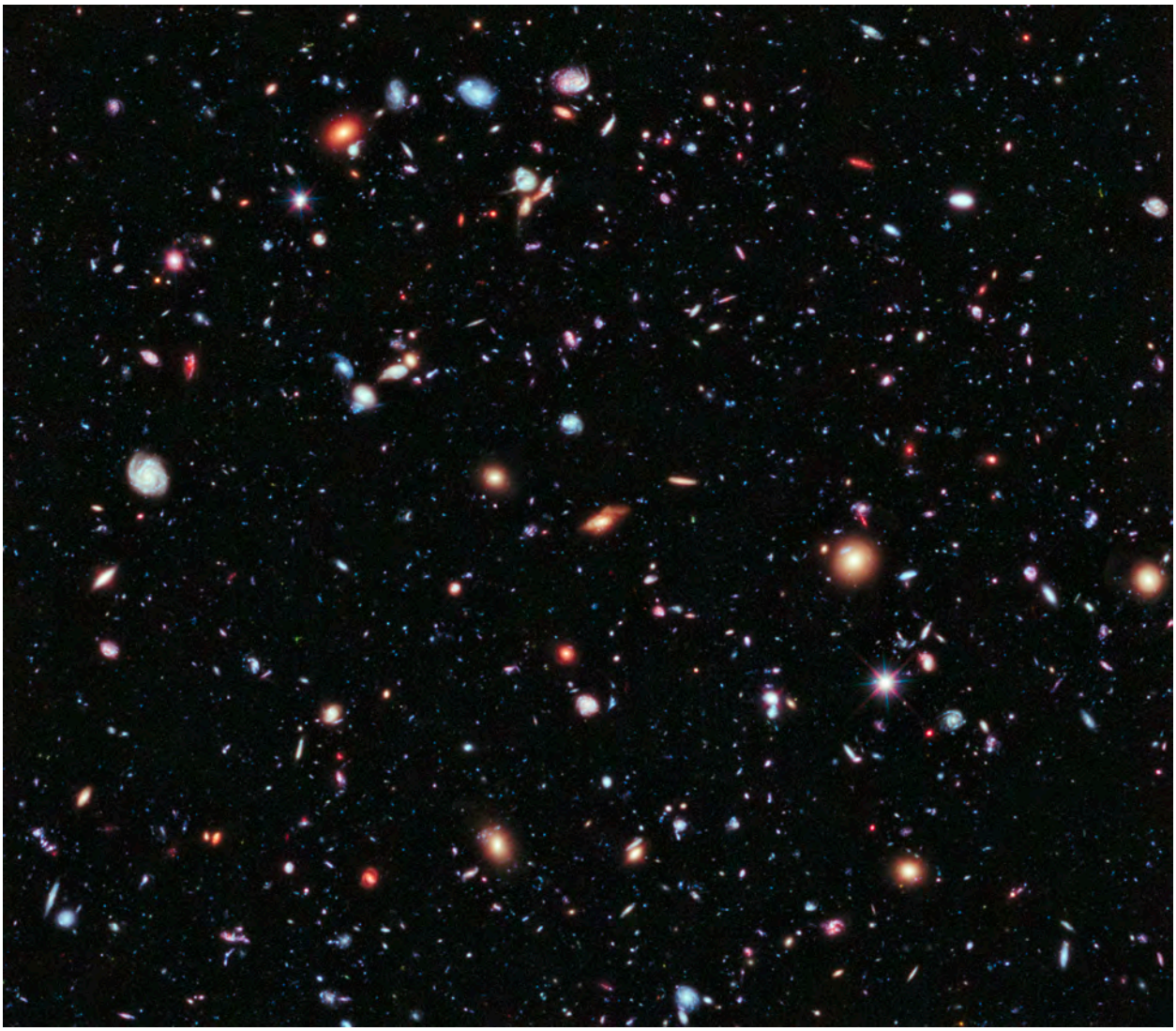
Project Scientists	
ACE	Tycho von Rosenvinge
Astro-H	Robert Petre (PS)
SXS Instrument	Rich Kelley (PI)
Balloon Program	Jack Tueller (PS), John Mitchell (DPS)
Cosmic Origins	Dominic Benford (Chief Scientist), Susan Neff (Deputy)
X-ray Mission Concept Study	Robert Petre (Study Scientist), Andy Ptak (Deputy)
Explorer Program	Neil Gehrels (PS)
GEMS	Tim Kallman (PS), Jean Swank (PI), Keith Jahoda (DPI), Joe Hill (IS)
Fermi	Julie McEnery (PS), Liz Hays (DPS), Neil Gehrels (DPS), Dave Thompson (DPS)
HEASARC	Alan Smale (Director), Lorella Angelini (DPS)
HST	Jennifer Wiseman (PS), Ken Carpenter (Operations PS), Padi Boyd (Operations DPS), Jeff Kruk (Observatory PS)
Gravitational Wave Mission Concept Study	Robin Stebbins (Study Scientist), Jeffrey Livas, James (Ira) Thorpe and John Baker (Deputies).
JWST	John Mather (PS), Jon Gardner (DPS), Mal Niedner (DPS for Technical), Matthew Greenhouse (ISIM PS), Bernard Rauscher (DPS for ISIM), Mark Clampin (Observatory PS), Charles Bowers (DPS for Observatory), George Sonneborn (Operations PS), Jane Rigby (DPS for Operations), Randy Kimble (DPS for I&T), Amber Straughn (DPS for Communications and Public Outreach)
JWST microshutters	Harvey Moseley (PI)
NASA Engineering Safety Center	Ed Wollack
Physics of the Cosmos	Ann Hornschemeier (Chief Scientist), Alan Smale (Deputy)
WFIRST study	Neil Gehrels (Study Scientist), Jeff Kruk (Instrument Scientist)
RXTE	Tod Strohmayer (PS)-Mission Completion in Jan 2012
Sounding Rockets	Scott Porter (DPS)
Suzaku	Rob Petre (PS), Lorella Angelini (DPS)
Swift	Neil Gehrels (PI), Scott Barthelmy (DPI)
WISE	Dave Leisawitz (MS), Dominic Benford (DMS)
WMAP	Ed Wollack (PS)
XMM	Steve Snowden (PS)

In Operation

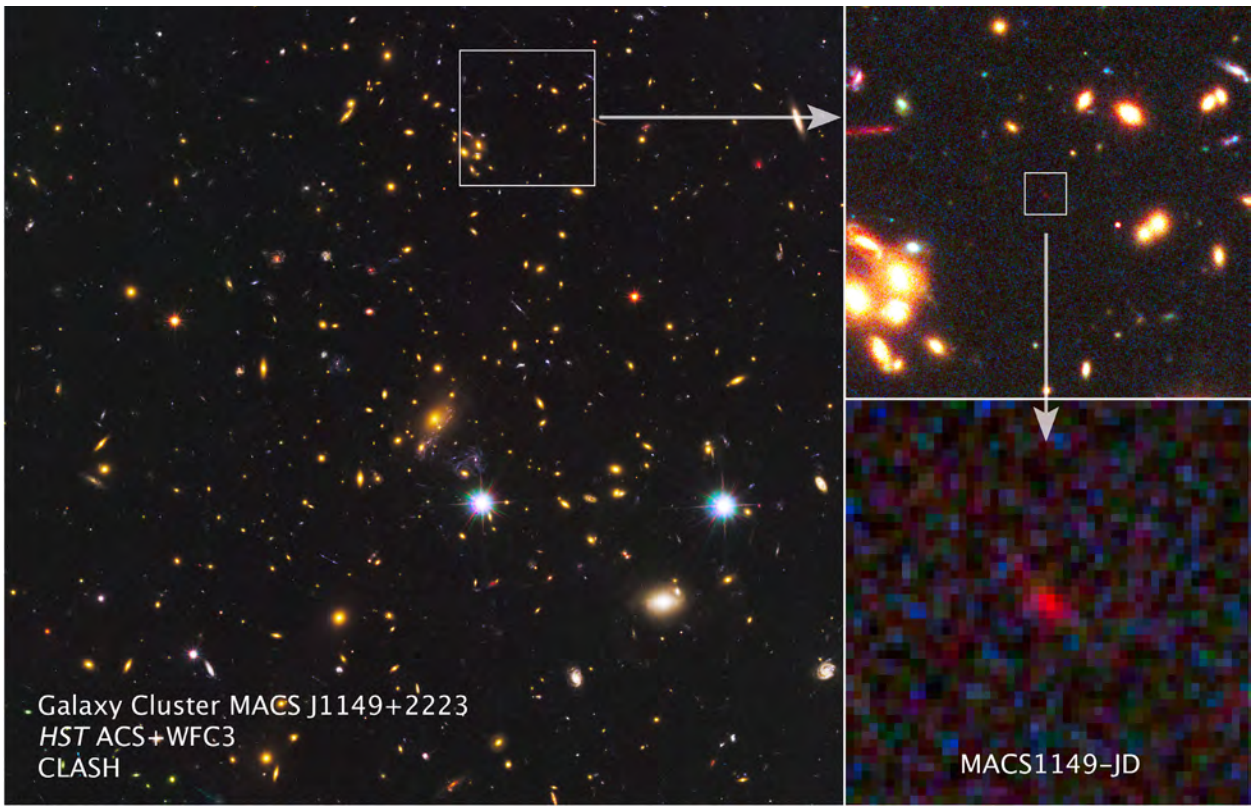
The Hubble Space Telescope

Hubble's science return soared in 2012, even three years after the historic final space shuttle servicing mission SM-4. This is largely because its superb instrument suite has made Hubble more scientifically powerful than ever. The flagship Wide-Field Camera 3 (WFC3), developed at Goddard, continues to push the forefront of astrophysics. In particular, its infrared channel provided images of ultra-high-redshift galaxies never seen before, with high-sensitivity deep fields including the Extreme Deep Field (XDF), assembled from combining archival images of a patch of the Hubble Ultra-Deep Field from a decade of observations. The year culminated with the phenomenal announcement from Richard Ellis and his team of an entire population of galaxies now detected between redshifts of 8 and 12, reaching back to just a few hundred million years after the Big Bang. This population reveals infant galaxies that have yet to evolve into more metal-rich environments and larger structures that more mature galaxies display. These observations are obvious bridges to the James Webb Space Telescope, which will be able to pick up proto-galaxies in detail from the very early universe at even higher redshifts.

Extremely distant galaxies were also drawn into view by careful imaging of massive galaxy clusters, which can gravitationally lens and magnify the light



The Extreme Deep Field (XDF), a new, improved portrait of mankind's deepest-ever view of the universe. The photo was assembled by combining 10 years of Hubble photographs of a patch of sky at the center of the original Hubble Ultra Deep Field. The image uses data from the Advanced Camera for Surveys and the visible and infrared channels of Wide Field Camera 3.



With the combined power of NASA's Spitzer and Hubble space telescopes, as well as a cosmic magnification effect, astronomers have spotted what could be the most distant galaxy ever seen. Light from the young galaxy captured by the orbiting observatories first shone when our 13.7-billion-year-old universe was just 500 million years old. The far-off galaxy existed within an important era when the universe began to transition from the so-called cosmic dark ages.

from distant galaxies beyond. One such infant galaxy with redshift of nearly 10 was spotted in Hubble images from the Cluster Lensing and Supernova Survey with Hubble (CLASH) program, and corroborated by observations from the Spitzer Space Telescope. Light from this galaxy fragment started its journey only a few hundred million years after the Big Bang.

CLASH, with principle investigator Marc Postman, is one of Hubble's Multi-Cycle Treasury (MCT) programs. These flagship programs are designed to capture data and rich scientific return for studies that require hundreds of orbits, multiple years, and diverse teams to accomplish. The MCT programs, started in Cycle 18 of Hubble's Guest Observer (GO) program to support the goal of maximizing Hubble's science return in its remaining years, reached full throttle in 2012, with most observations completed, preliminary science results released, and the development of science products and tools well underway. The other programs include the Panchromatic Hubble Andromeda Treasury (PHAT) program (PI Julianne Dalcanton), the Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey (CANDELS) program (PIs Sandra Faber and Harry Ferguson), and the Supernova Follow-Up program of Adam Riess, using data from the CLASH and CANDELS programs. MCT data have no proprietary period and are made available immediately to the scientific community for diverse scientific uses.

Careful dynamic HST observations of our neighboring Andromeda galaxy also revealed a prediction astounding enough to inspire a NASA-sponsored televised press conference: The Andromeda and Milky Way galaxies will collide head-on, in 4 billion years.

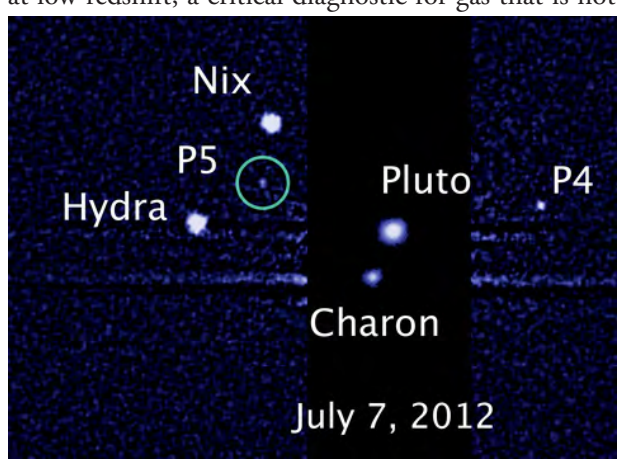
Within our own galaxy, exoplanets continued as a field of highest interest. One particularly important new HST exoplanet observation revealed the first known "waterworld", GJ 1214b, a super-Earth sized exoplanet that has an atmosphere containing significant amounts of water.

Hubble continues to break records regarding scientific return. In 2012, Hubble reached the milestone of its 11,000th published paper, an accomplishment unique to this mission. But of even more import was the publication of 836 papers in refereed journals in 2012. This is the highest yearly total ever for HST (or

An artist's concept of the night sky in a few billion years, as the Andromeda and Milky Way galaxies close in. Roeland van der Marel of the Space Telescope Science Institute (STScI) and his team used careful Hubble measurements of Andromeda's motion along with computer simulations to predict the future cosmic merger.

any mission), surpassing last year's previous HST record and even 2010's output by more than 100 papers! Both of these achievements demonstrate the increasing productivity of the mission, even several years after the last servicing mission, as well as the community's interest in the rich data provided by the MCT programs and the growing data archive. Over 80 papers have been published to date based on MCT data alone.

The Project Science Office for HST at Goddard continued its science leadership with ASD scientists Jennifer Wiseman as Senior Project Scientist, Kenneth Carpenter as Operations Project Scientist, Patricia (Padi) Boyd as Deputy Operations Project Scientist, and Jeffrey Kruk as Observatory Project Scientist. Project Scientists worked with Goddard Project Management and engineering teams as well as STScI science and technical staff throughout the year, on issues ranging from oversight of the telescope proposal selection and time allocation reviews to technical status meetings. They also served on organizing committees for, and participated in, meetings convened to improve the science productivity of HST and to discuss the future of UV astronomy itself. Two particular technical accomplishments from this cooperation were an adjustment in the detector lifetime position for spectra within the Cosmic Origins Spectrograph (COS), vastly improving sensitivity and capability of COS for years to come, and the extension of COS operation at FUSE-quality resolution down to 900 Angstroms. This wavelength range enhancement enables new science never before accessible to HST, providing access to deuterium abundance outside the local bubble, and O VI in our galaxy and intergalactic medium (IGM) at low redshift, a critical diagnostic for gas that is not



Another moon for Pluto: Hubble has now detected several previously unknown moons of the dwarf planet, bringing the current total to five. The growing knowledge of the distribution of debris around Pluto is helping chart a safer course for New Horizons, a probe on its way to study Pluto and the Kuiper Belt.

The Tarantula Nebula in 30 Doradus is the brightest star-forming region visible in a neighboring galaxy and home to the most massive stars ever seen. The image was taken to celebrate Hubble's 22nd anniversary in 2012.

hot enough to be observed in X-rays but too hot to be observed by other mean; most of the IGM is thought to be in this phase. Molecular hydrogen absorption measurements are now also enabled as a critical diagnostic for the most abundant molecular component of the universe.

The team also worked with STScI to produce the annual *Science Year in Review*, reviewed and advocated healthy science support in the mission budget, and reviewed all science press releases for the mission. Of particular note in 2012 was the cooperative HST project and STScI preparation and presentation of the HST Senior Review proposal to NASA HQ, the first time Hubble has been evaluated by the Senior Review of Operating missions in over 15 years. By presenting the outstanding forefront science discoveries, the mission goals, and the streamlining of operations, HST received an outstanding evaluation and full support from NASA for continuing the mission unabated.

Hubble's discoveries in 2012 included yet another moon of the icy dwarf planet Pluto, bringing the total known to five, and adding to the two that were already discovered by Hubble. While these detections are interesting in their own right, they also are providing input toward the strategy of another NASA mission, the New Horizons probe heading to Pluto and the Kuiper Belt. The detection of multiple moons around Pluto is now actually becoming a matter of concern for New Horizons: the region around Pluto may be laden with abundant debris even smaller than these moons, but large enough to damage the passing probe. Data from Hubble is therefore crucial to mapping out the probable distribution of circumplanetary material around Pluto, based on the planar distribution of the recently

detected moons. This information is guiding mission engineers to chart a safer course for New Horizons as it nears the Pluto system, and demonstrates the importance of Hubble for support of other missions as well.

As the Hubble continued on at its most scientifically powerful and productive pace of all time, we celebrated the mission's 22nd birthday with a breathtaking view of the star-formation mecca in the heart of 30 Doradus, known as the Tarantula Nebula. The image comprises one of the largest mosaics ever assembled from Hubble photos and includes observations taken by WFC3 its and Advanced Camera for Surveys, an example of how Hubble's instruments, used together, can further enable breathtaking results that inspire both science and awe.

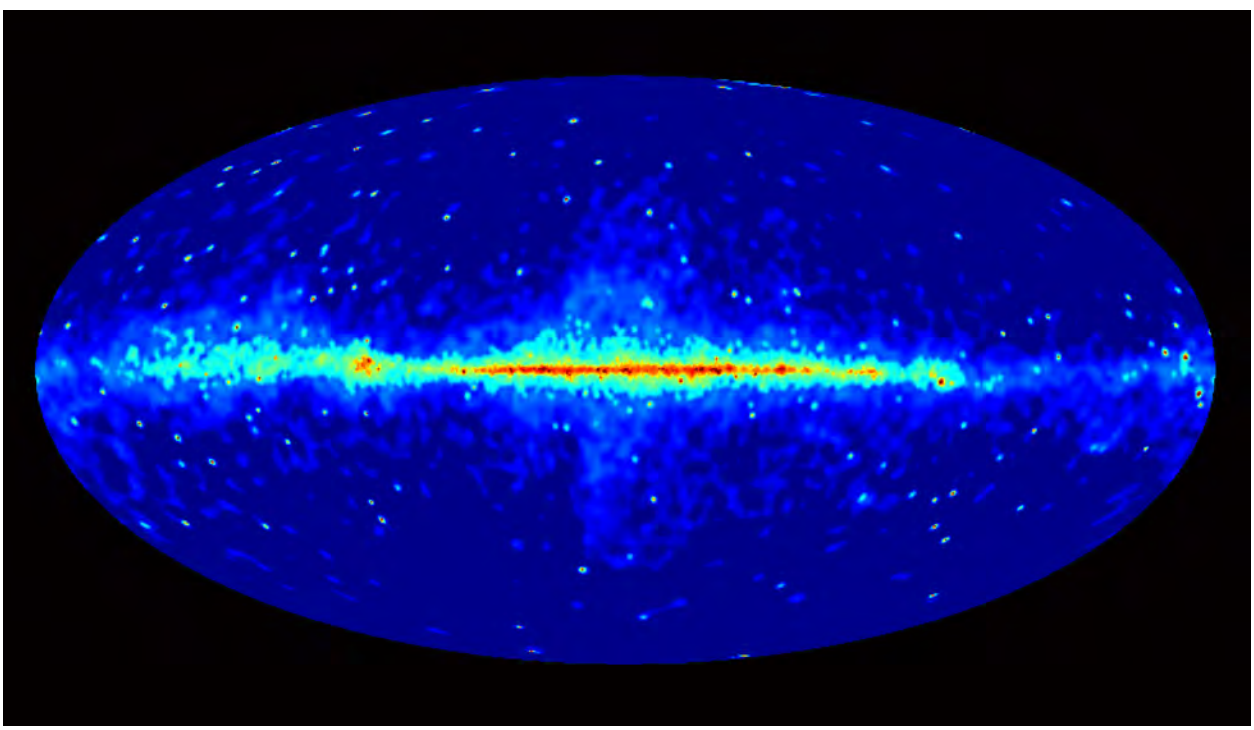
Fermi Gamma-ray Space Telescope

Science

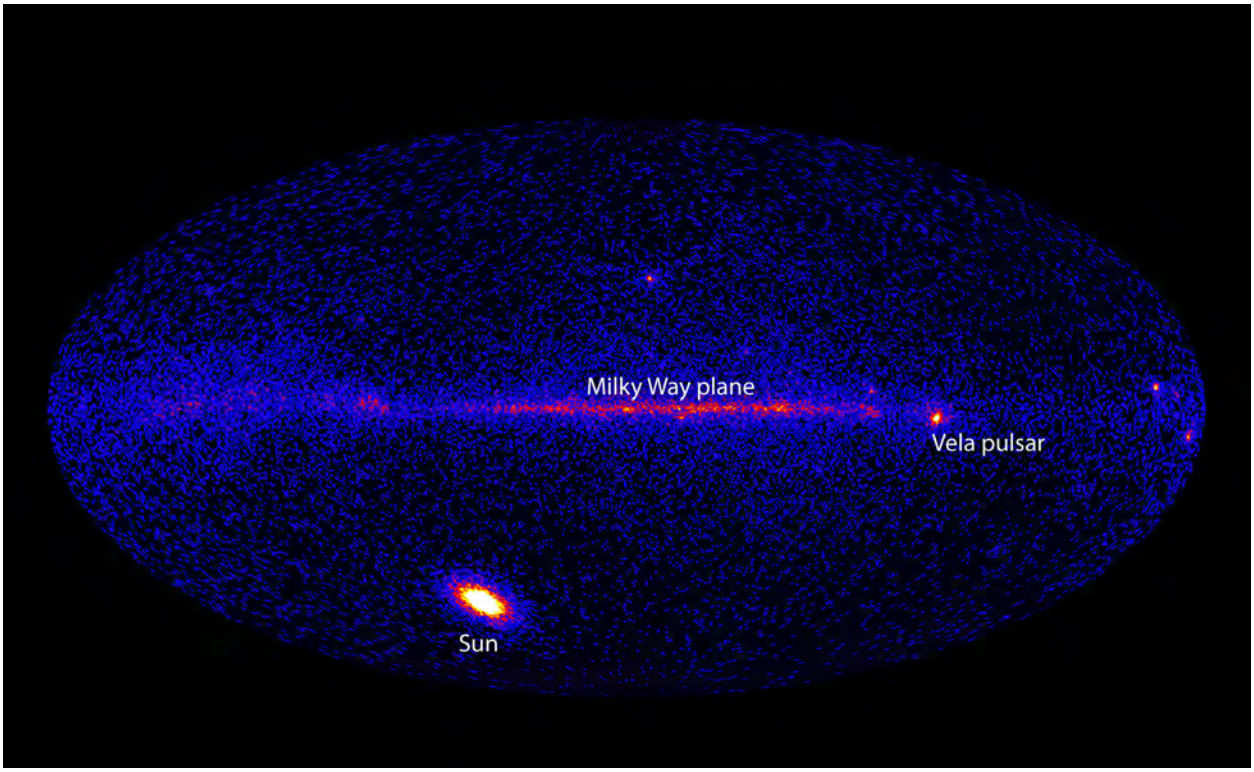
This year brought the results of Fermi's first Senior Review with the welcome news that the mission will continue operations into the extended phase beginning in late 2013. This marks the high quality of scientific output across the teams and the gamma-ray user community and supports ongoing discoveries as monitoring continues, observations deepen, and all levels of analysis increase in sophistication. David Thompson and Judith Racusin with Seth Digel made core contributions to the science submission and also authored an article on Fermi for *Physics Today*.

Supernova remnants (SNRs), a notable class of gamma-ray emitter and potential source of high-energy cosmic-ray particles, continue to be a prolific area of research for the Fermi team, particularly as exposure increases above 10 GeV, where the Large Area Telescope (LAT) has more resolving power. In the two brightest SNRs seen with the LAT, the data reveal the characteristic signature of pion decay, demonstrating that protons are accelerated to high energy and confirming previous hints of this feature found by AGILE. John Hewitt, Theresa Brandt, and Fabio Acero have been active in studies of individual SNRs. Brandt, Hewitt, Acero, and Jamie Cohen have also made key contributions to a LAT catalog of supernova remnants, a large project to systematically characterize gamma-ray emission in the vicinity of known radio remnants and to study the population within a multi-wavelength context.

The LAT also carries out direct studies of local high-energy cosmic rays. Alex Moiseev continues studies of cosmic-ray electrons measured with the



This smoothed map presents they sky from 10 GeV to >300 GeV, a new energy window being explored by Fermi's LAT. Brighter colors indicate brighter gamma-ray sources. As the LAT builds exposure, faint sources and features emerge, and new flaring sources appear while others fade. Numerous sources along the plane of our galaxy as well as far from it are visible. The large Fermi bubbles can be seen extending from the galactic center in the middle of the map



On March 7, 2012, the sun emitted a very strong flare that dominated the gamma-ray sky, outshining the brightest persistent source by 100 times.

LAT while David Green with Brandt and Liz Hays is extending that work to heavy ions.

Gamma-ray pulsars have offered new challenges for observations and puzzles for theory. Ozlem Celik, Elizabeth Ferrara, Megan DeCesar, and Thompson made key contributions to the second Fermi LAT pulsar catalog, a major effort describing the properties of 117 pulsars. DeCesar and Alice Harding focused on constraining pulsar emission scenarios through the modeling of gamma-ray pulsar lightcurves. Harding received the 2012 John C. Lindsay Memorial Award for Space Science for understanding of pulsars, through theoretical studies and interpretation of data from the Fermi mission. Harding's contributions continue as explanations are sought for the first observation that emission from a young pulsar, the Crab, extends above the energies where currently favored models suggest cutoffs.

Beyond our galaxy, Davide Donato, Thompson, Julie McEnery, Jeremy Perkins, Roopesh Ojha, Michael Dutka, and Bill McConville have been pursuing studies of Active Galactic Nuclei (AGN). Numerous Astronomer's Telegrams have resulted from AGN flares spotted by Donato, Ojha, Dutka, and Tonia Venters while working as LAT Flare Advocates. Ojha and Dutka continue to work closely on correlations with the southern hemisphere radio VLBI program TANAMI.

Thirteen new LAT-detected GRBs were discovered during 2012, and Donato, Sylvain Guiriec, Dan Kocevski, McEnery, Racusin, and Sylvia Zhu contributed to GRB detection infrastructure, follow-up notification, and burst advocate shift work. Additional gamma-ray burst studies focused on correlations and populations (Guireic, Kocevski, Racusin, Eleonora Troja, Zhu, Rodrigo Nemmen, and McEnery).

Some fascinating flares originate much closer to Earth. The sun continues to be active in gamma rays and produced a very bright flare that was featured as an Astronomy Picture of the Day on March 15.

Theoretical studies involving Fermi results in addition to pulsars include work by Nemmen (working with Neil Gehrels), which shows a correlation between kinetic power and gamma-ray luminosity for AGN and gamma-ray bursts; the study appeared in *Science* December. Venters continues to study the extragalactic background in gamma rays and possible implications for intergalactic magnetic fields.

Outreach to the Scientific Community

McEnery and Hays organized the second Fermi Gamma-ray Summer School with support from many

members of the local group and the Fermi Science Support Center (FSSC). McEnery, Brandt, and Hays worked closely with the local organizing committee for the Fourth Fermi Symposium. Goddard served as host institution for a LAT collaboration meeting in September, an effort led by Racusin and Perkins. Racusin, in cooperation with the RHESSI team in the Solar Physics Lab, the FSSC, the Gamma-ray Burst Monitor (GBM) and LAT teams, organized the first Fermi Solar Data Analysis Workshop at Goddard. Racusin, Zhu, and DeCesar created a tasty representation of the Fermi spacecraft and sky map in cake form for a local celebration of the fourth launch anniversary.

Many Fermi scientists have participated in public outreach, including the Science and Engineering Exposition. Venters is leading the development of a display about Fermi for the Goddard visitor center.

Instrument and Mission Operations and Analysis

The spacecraft and instruments continue to operate without any notable degradation. Fermi successfully conducted its first propulsion maneuver to avoid a close conjunction with a defunct satellite. The GBM began taking data continuously in a time-tagged event mode useful for resolving very short timescales. Moiseev, Hays, Brandt, and Green have continued studies of the performance of the LAT Anticoincidence Detector, a subsystem built at Goddard. McEnery, Racusin, and Hays have been working closely with the spacecraft operations team and system experts at Goddard to maintain peak science performance of the observatory.

The FSSC continues to manage observatory scheduling and to respond to target-of-opportunity requests. FSSC members have been actively releasing new and updated science tools packages and making user-contributed software and data products available to the public.

Swift

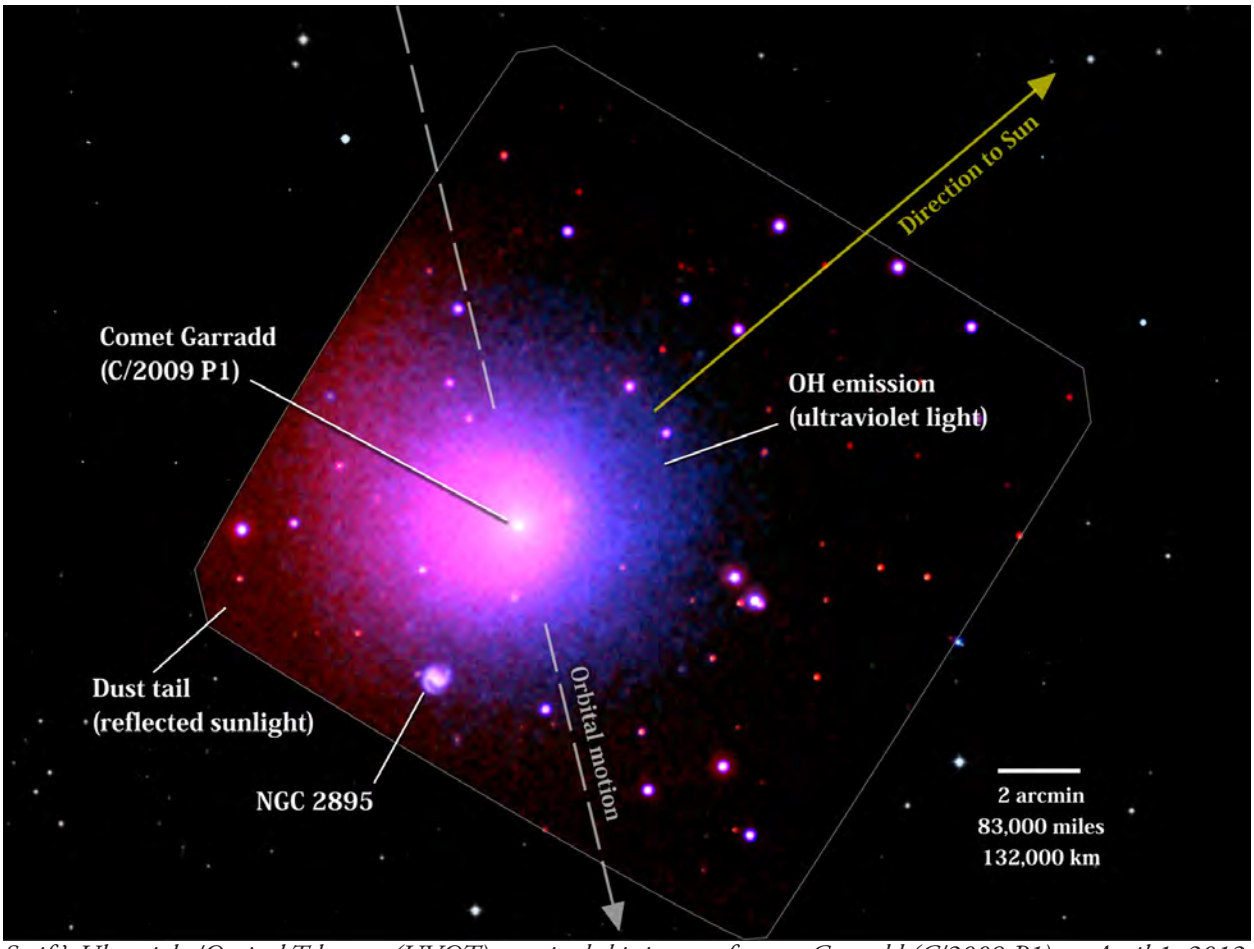
Swift is a NASA Explorer mission, with international participation, that is designed to find gamma-ray bursts and study them over a wide range of wavelengths, from gamma rays to optical light. It was launched in 2004 and is in its extended mission phase with re-entry no earlier than 2025.

Gamma-ray bursts (GRBs) are the most luminous explosions in the universe since the Big Bang. They come randomly from all directions in the sky and last from a few milliseconds to a few hundred seconds. GRBs are believed to occur in the collapse of some massive stars into supernovae or when two neutron stars merge. The details of how such intense bursts of radiation are produced are still not well understood.

There are three telescopes aboard Swift: the Burst Alert Telescope is a coded-aperture gamma-ray detector that operates between 15 and 150 keV. It detects GRBs and rapidly localizes them to approximately two arcminutes. Immediately afterward (usually within one minute) the spacecraft slews to point its two narrow-field instruments at the burst. The X-Ray Telescope measures the 0.2–10 keV X-ray flux from the GRB's afterglow and localizes the source to within two arcseconds. The Ultraviolet/Optical Telescope collects data between 1,600 and 6,000 Angstroms and provides a sub-arcsecond position for the burst. Swift distributes these positions for each GRB to other observatories within seconds of obtaining them.

In the eight years since launch, Swift has detected and localized more than 700 GRBs. Among these are more than 60 short (T90 ≤ 2 sec) and hard GRBs, about half with likely host identifications and/or redshift estimates. These observations provided support for the theory that these bursts are due to the merging of binary neutron stars. Science highlights from the last year include, among others:

- In January 2012, researchers from Clemson University detected a flaring and rapidly brightening X-ray source in the Andromeda galaxy (M31). Follow-up observations of this "ultraluminous X-ray source" (ULX) with VLA by Matthew Middleton of the University of Durham, UK, and his collaborators gave the first-ever detection of a radio-emitting jet from a stellar-mass black hole outside our own galaxy.
- On Sept. 16 and 17, 2012, BAT triggered multiple times on a previously unknown hard X-ray source a few degrees from the Galactic Center. The trigger marked the onset of a dramatic transition from the low/hard to the high/soft state of the X-ray nova Sw J1745–26, revealing a previously unknown black hole in our galaxy.
- Swift monitoring of the binary system OB2 #9 by Yael Nazé at the University of Liège in Belgium led to the X-ray detection of colliding winds from the two stars. The data indicate that Cygnus OB2 #9 is a massive binary with components of similar mass (around 50 times the sun's mass) and luminosity following long, highly eccentric orbits.
- Alain Lecavelier des Etangs at the Paris Institute of Astrophysics and his team used multi-wavelength observations of the exoplanet HD 189733b with Swift and HST. The observations revealed an X-ray flare from the star so powerful that it led to the evaporation of the planet's upper atmosphere. During this process, the Jupiter-sized planet lost around 1,000 tons of gas in the planet's atmosphere each second.



Swift's Ultraviolet/Optical Telescope (UVOT) acquired this image of comet Garradd (C/2009 P1) on April 1, 2012, when the comet was 142 million miles away, or 636 times farther than the moon. Red shows sunlight reflected from the comet's dust; violet shows ultraviolet light produced by hydroxyl (OH), a fragment of water. NGC 2895 is a barred spiral galaxy located 400 million light-years away. The UVOT image (outlined) is placed within a wider visible image of the region from the Digital Sky Survey.

• Ultraviolet and X-ray monitoring of comet Garradd (C/2009 P1) showed that the comet produced large amounts of dust and gas well before it reached the snow line. Dennis Bodewits at the University of Maryland, College Park, and his team concluded that the activity was powered by something other than water ice, which is expected to remain frozen until the comet approaches the snow line.

• Two independent Swift studies of thermonuclear Type Ia supernovae (SNe Ia) rule out the presence of massive companion stars in these systems. Peter Brown from Texas A&M and Stefan Immler from NASA/Goddard used Swift UV and X-ray observations of a large sample of young SNe Ia. The lack of any recorded UV or X-ray emission showed that the outgoing shock of the SN explosions does not plow through the winds of massive companion stars or even sun-like stars.

• On Dec. 12, 2012, Wayne Baumgartner and his colleagues from NASA/Goddard released the 70-month survey of BAT data to the public. The catalog contains over 1,200 sources, 8-band BAT spectra, and 70-month 8-band snapshot lightcurves for all sources.

• By the end of 2012, around 1,300 refereed papers had been published based on Swift results. During the last two years, the number of Swift papers exceeded that of Subaru, Gemini, and Keck, and is approaching the number of publications of the successful high-energy missions XMM-Newton and Chandra. More than half of all Swift papers are from non-GRB fields with an increasing fraction.

• During the 2012 Swift Guest Investigator (GI) Program Cycle 9, 158 proposals were received, requesting $4.3M in funds and 13.2 Ms total exposure time for 866 targets. New for 2012, proposers

interested in joint observing programs can now request Swift observing time through the Chandra and XMM-Newton GI Programs.

XMM-Newton Guest Observer Facility

ASD operates the U.S. XMM-Newton Guest Observer Facility (XMM GOF). XMM is a European Space Agency (ESA) X-ray astrophysics mission with some U.S. hardware and software contributions, and ESA allocates resources to support European XMM users but looks to the GOF to provide support to the large U.S. astrophysics community. GOF activities include facilitating the submission of GO proposals to ESA, distributing proprietary data to U.S. PIs, maintaining the full public science archive, and supplying expertise, analysis software and documentation to U.S. scientists.

The GOF works in conjunction with the ASD GOFs of other high-energy astrophysics missions (e.g., Fermi, Swift and Suzaku) to lower costs and to ensure consistency in the areas of the budget proposal process, FITS tools, database structure, web pages and archival data access. Cost savings are leveraged by sharing resources, techniques, expertise and reusing software. GOF activities cover a very wide range of endeavors in support of XMM. A U.S. XMM-Newton Users Group under the chairmanship of Prof. Craig Sarazin (U. Virginia) provides community oversight of GOF activities. Dr. Steve Snowden is the NASA Project Scientist, and with Drs. Lynne Valencic and Kip Kuntz provides science support to the U.S. astrophysics community. Brendan Perry provides software support and Michael Arida maintains the U.S. XMM archive.

Kuntz and Snowden are involved in the particle background calibration of the XMM X-ray imagers and the cross-calibration between the XMM instruments and other X-ray observatories (e.g., Chandra, Suzaku, ASCA, and ROSAT), which enhances the utility of multi-observatory data analysis. This has been a major activity over the last several years with XMM GOF participation in the International Astronomical Consortium for High Energy Calibration (IACHEC). Snowden and Kuntz have developed the XMM-Newton Extended Source Analysis Software (XMM-ESAS) package which is now fully implemented within the mission software suite. This package significantly simplifies and improves the accuracy of data reduction for extended objects and the diffuse X-ray background.

Valencic maintains the ABC and D Guides which provide an introduction to the scientific analysis of XMM-Newton data, updates the XMM publication list on a quarterly basis—there are now ~1.3 refereed XMM publications per day, and a total of over 4,000! She began work this year verifying the Observation IDs in the publication list database to ensure all data sets were correctly identified. She also supports the implementation of XMM-Newton analysis software within the Hera data analysis system, and has developed extensive data analysis scripts, which can be either used in the Hera system or downloaded to a user's machine. These streamline data reduction and make XMM-Newton data more accessible to the non-X-ray astronomy community.

Kuntz maintains (by periodic updates to include recent observations) the Optical Monitor (OM) source catalog (Kuntz et al. 2008, *Publ. Astron Soc. Pacific*, 120, 740) to compliment the X-ray source catalog produced by the XMM-Newton Survey Science Centre (SSC). The database contains entries for every source detected in OM observations. Kuntz and Arida work with STScI to make the OM catalog and data available through the Mikulski Archive at Space Telescopes (MAST), considerably increasing the data availability to optical astronomers.

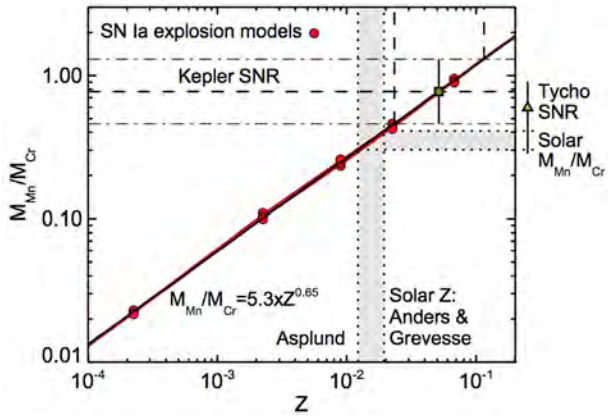
Arida maintains the XMM-Newton archive at the GSFC GOF, which mirrors all public data in the ESA XMM-Newton Science Archive (XSA) at the SOC, as well as proprietary data for U.S. PIs. This mirroring of the data reduces the high data load at the European Space Operations Center site, and provides a much faster data-transfer rate within North America, as well as allowing use of the unique capabilities of the BROWSE database and providing a direct link for the use of XMM-Newton data within the HERA data analysis system.

Perry is an integral part of the ESA XMM mission software (Standard Analysis Software, SAS) development team and also contributes original software to SAS (e.g., XMM-ESAS). He is developing Trend data, which will be available to the community in early 2013.

The XMM GOF was successful in the 2012 Senior Review process and will receive continued funding through mid-FY15 for both GOF operations and GO support. The GOF will submit a proposal to the 2014 Senior Review for continued funding through 2016.

Suzaku (Astro-E2)

Suzaku is the fifth in a series of Japanese X-ray astronomy satellites, launched by the Japan Aerospace Exploration Agency (JAXA) on July 10, 2005. Like ASCA before it, Suzaku is a joint Japan-U.S. mission,



The manganese-chromium ratio as a function of the progenitor metallicity in Type Ia supernova explosion models (adapted from Badenes et al. 2008), plotted with the measured Mn/Cr for Kepler's SNR, which indicates the super-solar metallicity of its progenitor. For comparison, Mn/Cr for Tycho's SNR is also shown.

developed by the Institute of Space and Astronautical Science of JAXA (ISAS/JAXA) in collaboration with Goddard and many other institutions.

Suzaku's scientific payload includes three co-aligned instruments, of which two are functional. The X-ray Imaging Spectrometer (XIS) consists of four imaging CCD cameras, three of which are front-illuminated (FI: energy range 0.4–12 keV) and one back-illuminated (BI: energy range 0.2–12 keV). Each XIS is located at the focal plane of a dedicated X-ray telescope (XRT). One of the three FI chips was rendered inoperable by a micrometeorite impact in December 2006; two other chips suffered lesser micrometeorite impacts but remain operational. The second functional instrument is a non-imaging, collimated Hard X-ray Detector (HXD) sensitive in the 10–600 keV band. The third instrument, the X-Ray Spectrometer (XRS), ceased operation shortly after launch due to a spacecraft design error.

The power output of the onboard solar panels has decreased over time due to radiation damage, which caused the spacecraft to enter a safe hold in late January 2012 for several days. In response, ISAS/JAXA tightened the Sun angle range of observations and turned off all non-essential components. These countermeasures have allowed continued observations using all functional instruments. As of year end, ISAS is cautiously optimistic that normal observations with Suzaku can continue for several more years.

Goddard's role in the mission includes supplying the five XRTs and the XRS "insert" (detector, blocking filters, adiabatic demagnetization refrigerator, and LHe cooler), development of data-processing software, operation of the U.S. Guest Observer Facility (GOF), and administration of the U.S. Guest Observer (GO) Program. Rob Petre is the NASA Project Scientist, Lorella Angelini is the Deputy Project Scientist, and Koji Mukai (CRESST) is the GOF Lead. Suzaku has produced an abundance of data from a wide variety of cosmic X-ray sources. Key unique Suzaku observations include: investigation into the variability of the heliospheric solar wind charge-exchange emission; discovery and measurements of lines of low-abundance metals and of radiative recombination continua in supernova remnants (SNR); broadband measurements of Galactic X-ray binaries and active galactic nuclei (AGN) to measure the reflection continuum above 10 keV and the relativistically broadened Fe K line, leading to black hole spin estimates; and measurement of cluster properties at their virial radius.

Key Project proposals, the goal of which is to carry out major, multiyear observing programs that utilize Suzaku's unique capabilities, were solicited during cycles 4-7. Ten Key Projects have been initiated, seven of which have been completed. The completed ones include a census of broad Fe lines in AGN, an extensive mapping of the Perseus Cluster of Galaxies (the brightest cluster in X-rays) to beyond its virial radius, and a deep observation of Kepler's SNR. This last has enabled the determination of Mn/Cr and Ni/Fe ratios, and led to the conclusion that the progenitor of this Type Ia supernova had a super-solar metallicity.

U.S. observers have access to 50 percent of the observing time, as well as all archival data. In the eighth observing cycle (proposal due date: Nov. 16, 2012), no new Key Project proposals were solicited due to concerns over the longevity of Suzaku; it also led to a decrease in the number of proposals submitted to 67 (from 90 in the previous several cycles), although the oversubscription factor was still about 3. Suzaku time can also be requested through the Chandra and Fermi GO programs. The Suzaku team is also collaborating with the MAXI team, following up flaring sources identified by MAXI.

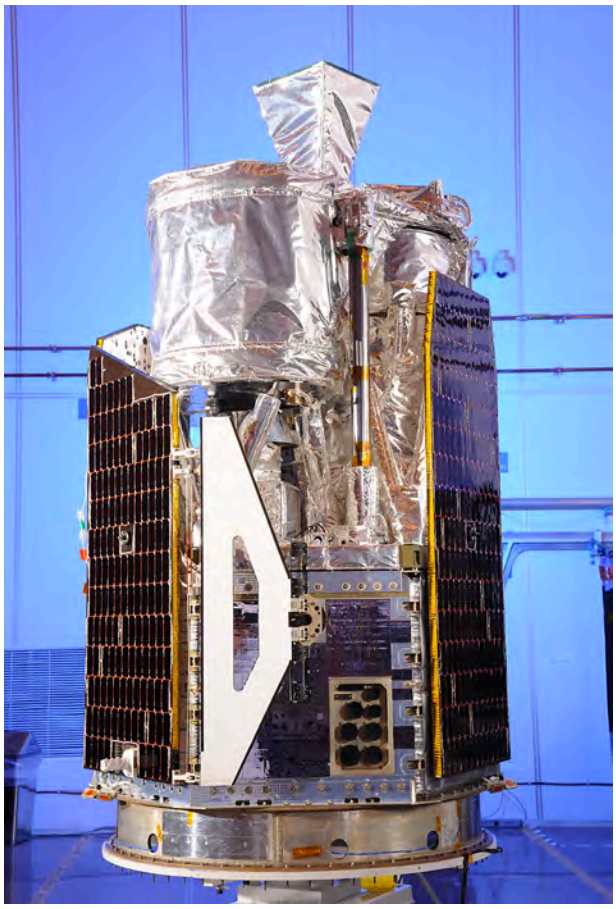
The Suzaku data center is responsible for processing and archiving the full mission data set and distribution of data to U.S. GOs; development and maintenance of proposal and observation planning tools and documentation; maintaining the calibration database; supporting proposal reviews; assisting GOs in analyzing data; and ensuring grant funds are distributed in a timely way. The data center staff consists of three full-time scientists (Koji Mukai, Kenji Hamaguchi, Katja Pottschmidt) and one programmer, plus part-time support from HEASARC staff.

Nuclear Spectroscopic Telescope Array (NuSTAR)

On June 13, 2012, NuSTAR was air-launched from the Kwajalein Atoll in the South Pacific into a circular equatorial orbit. After a successful in-orbit checkout, it began conducting observations on Aug. 1. A SMEX mission weighing less than 400 kg, NuSTAR is instrumented with two mirror modules that focus hard X-rays (3 to 80 keV) onto two CdZnTe detector arrays. The mirror modules and the detector arrays are linked with a mast that deployed from a length of approximately one meter in its stowed configuration to 10 meters once in orbit.

NuSTAR (PI Fiona Harrison, Caltech) is managed by JPL with oversight from the Explorer Program Office at Goddard. The Goddard contribution is the nearly 7,000 thin glass substrates precisely formed and qualified by a team led by William Zhang of the ASD's X-ray Astrophysics Laboratory. These glass substrates were shipped to the Danish Technical University, where they were coated with multilayers of thin films that enabled them to reflect hard X-rays. They were then shipped to Columbia University's Nevis Laboratories, where they were assembled into the two mirror modules. The CdZnTe focal plane detectors were built and qualified by a team at Caltech, and the mast by ATK. The entire NuSTAR observatory was integrated at Orbital Science Corporation at Dulles, Va.

NuSTAR's primary scientific objective is to conduct a deep survey of several square degrees of the sky to find highly obscured sources that cannot be seen in other energy bands. With its excellent energy resolution and revolutionary imaging capability in the hard X-ray band, NuSTAR also will be able to make significant contributions in understanding objects of all kinds, including active galactic nuclei, stars, supernova remnants, clusters of galaxies, starburst galaxies, and ultraluminous galaxies. In particular, it will conduct a sensitive survey of the central region of the Milky Way, where many sources are obscured by dust, making them difficult to observe in the soft X-ray band. As of year end, a large number of observations have been carried out and a large amount of data has been distributed to the NuSTAR science team, which includes members from both the U.S. and other countries. A number of ASD scientists are on the NuSTAR science team and are actively analyzing and interpreting these data, as well as playing leading roles in operating and calibrating the NuSTAR instruments. These scientists include Ann Hornscheimeier, Craig Markwardt, Andrew Ptak, Brett Lehmer, J.C. Leyder, Stacy Teng, and Jane Rigby.

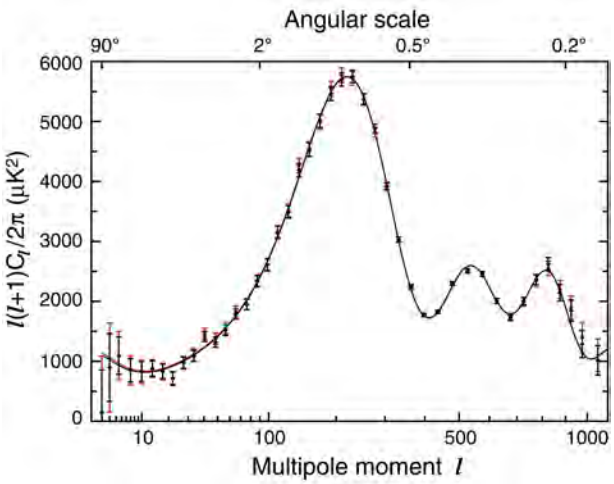


NuSTAR_launch_portrait: The fully integrated NuSTAR observatory, including the instrument and spacecraft, in January 2012. Orbital Sciences Corporation.

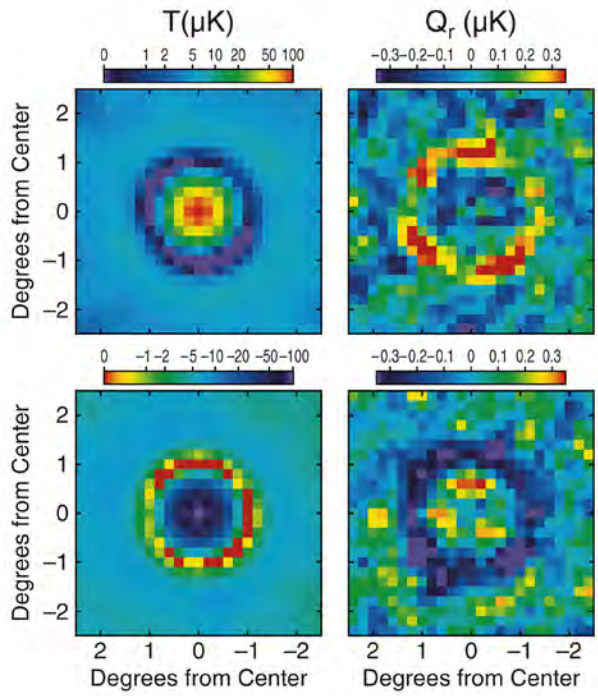
WMAP Final Results

The Wilkinson Microwave Anisotropy Probe (WMAP) has mapped the cosmic microwave background (CMB) radiation—the oldest light in the universe—and helped establish a simple and comprehensive cosmological model connecting the physics of the very early universe to the properties observed today. In this standard model, the universe is flat, homogeneous, and isotropic on large scales. The universe is composed of radiation and atoms, but is currently dominated by dark matter and dark energy. It is believed to have undergone a period of rapid inflation at its beginning, expanding by more than 50 e-foldings in a fraction of a second. The WMAP team includes ASD scientists Bennett (PI, now at JHU), Hinshaw (now at UBC), Kogut, and Wollack.

Classic papers (Peebles and Yu, 1970; Sunyaev and Zeldovich, 1970) relate the parameters of the universe's structure to the angular power spectrum. For Gaussian random-phase fluctuations, the angular power



Two estimates of the WMAP nine-year power spectrum along with the best-fit model spectra obtained from each; black represents the C-1-weighted spectrum and best fit model, while red shows the same for the MASTER spectrum and model. The two estimates differ by up to 5 percent in the vicinity of l ~ 50, which mostly affects the determination of the spectral index.



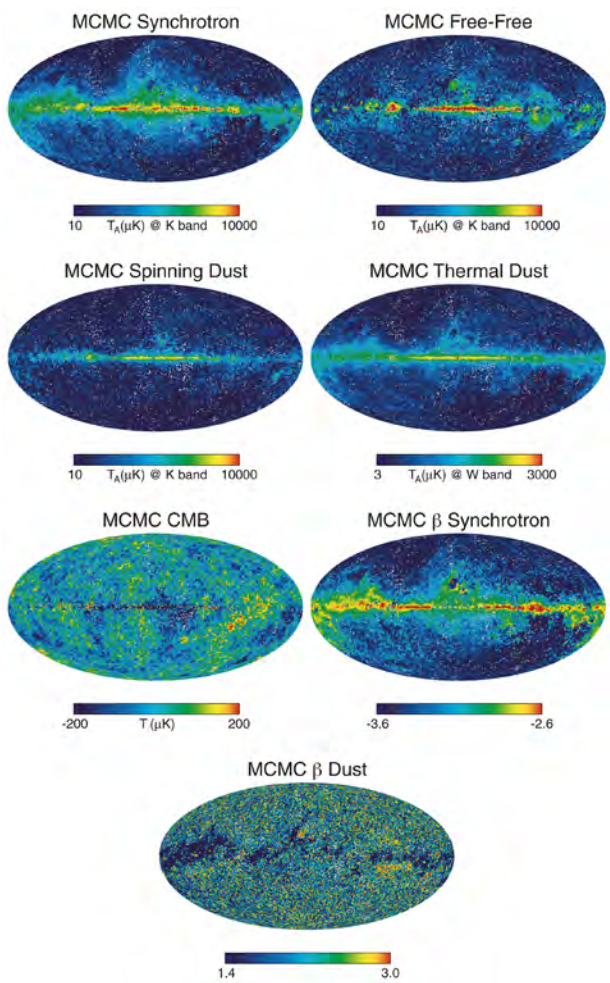
Co-added maps of temperature, T, and polarization, Q_r, smoothed to a common resolution of 0.5°, and stacked by the location of temperature extrema. (The polarization maps were not smoothed for the analysis, however.) Top-left: The average temperature hot spot. Top-right: The rotated polarization map, Q_r, stacked around temperature hot spots. Bottom-left: The average temperature cold spot. Bottom-right: The rotated polarization map, Q_r, stacked around temperature cold spots. The polarization images are color-coded so that the red ($Q_r > 0$) shows the radial polarization pattern, while blue ($Q_r < 0$) shows the tangential polarization pattern. The lines indicate polarization direction. These images are a striking illustration of baryon acoustic oscillations in the early plasma, and phase coherence in their initial conditions.

spectrum encodes the entire statistical information present in a map and thus enables the extraction of the underlying physical characteristics from the observed microwave sky. The standard ΛCDM cosmological model, defined by the six parameters, as characterized by the nine-year WMAP spectrum is provided in the table below. The matter and energy densities —$\Omega_b h^2$, $\Omega_c h^2$, and Ω_Λ—are all determined to ~1.5% precision by the data, the amplitude of the primordial spectrum is measured to within 3%, and there is now evidence for tilt in the primordial power spectrum at the 5σ level. The age of the universe as determined by WMAP, 13.74 ± 0.11 Gyr, is now known to better than one percent. This represents an overall improvement in the knowledge (of the allowable volume of the six-dimensional ΛCDM-parameter space) by a factor of 68,000 relative to the pre-WMAP observational epoch.

The final WMAP data are sufficiently sensitive to test for dark energy and provide important information without reliance on supernovae results. The combination of WMAP data with measurements of the

Best-fit ΛCDM parameters with nine-year WMAP data

ΛCDM Parameter	WMAP data only	WMAP+eCMB+BAO+H_0
Baryon density, $\Omega_b h^2$	0.02264 ± 0.00050	0.02266 ± 0.00043
Cold dark matter density, $\Omega_c h^2$	0.1138 ± 0.0045	0.1157 ± 0.0023
Dark matter density, Ω_Λ	0.721 ± 0.025	0.712 ± 0.010
Curvature perturbations, $10^9\ \Delta^2_R$	2.41 ± 0.10	2.427 ± 0.079
Scalar spectral index, n_s	0.972 ± 0.013	0.971 ± 0.010
Re-ionization optical depth, τ	0.089 ± 0.014	0.088 ± 0.013



Parameter maps from the MCMCg model fit. The top four maps are shown on logarithmic scales and the others are on linear scales. Accurate determination of the CMB close to the Galactic plane is inhibited by CMB-foreground covariance. The map for β synchrotron is evaluated at 40 GHz.

Hubble constant and of baryon acoustic oscillations (BAO) in the galaxy distribution limits the extent to which dark energy deviates from Einstein's cosmological constant. The simplest model (a flat universe with a cosmological constant) continues to represent the data remarkably well. These observations constrain the dark energy to be within 14 percent of the expected value for a cosmological constant ($w = -1.1 \pm 0.14$), while the geometry must be flat to better than 1 percent ($0.99 < \Omega_{tot} < 1.01$, 95% CL).

The final nine-year WMAP data set places new constraints on the number of relativistic neutrino species in the early universe. Neutrinos are nearly massless elementary particles that permeate the universe in large quantity but they interact very weakly with atomic matter. Nonetheless, they leave an imprint on the microwave fluctuations and the WMAP data. When taken together with the extended CMB (i.e., the eCMB data set incorporates the high-resolution observations from the South Pole and the Atacama Cosmology Telescopes), BAO, and H_0 data, one finds that the effective number of neutrino-like species is 3.55 ± 0.49. The standard model of particle physics has 3.04 effective species of neutrinos. When combined with the baryon density and primordial helium abundance (0.278 ± 0.033) the observations provide a compelling and consistent picture for the standard Big Bang nucleosynthesis scenario.

The improved sensitivity in the noise-limited polarization measurement has made possible a visual detection of the CMB polarization signal in the sky maps. When the polarization maps are dissected into regions centered on hot and cold spots in the temperature map, and then stacked, the telltale pattern of polarized rings around the spots are clearly seen.

Launched as MAP on June 30, 2001, the spacecraft was later renamed WMAP to honor David T. Wilkinson, a Princeton University cosmologist and a founding science team member who died in September 2002. Once maneuvered to its observing station near the second Lagrange point of the Earth-Sun system, a million miles from Earth in the direction opposite the sun, WMAP scanned the heavens and precisely recorded tiny temperature fluctuations across the sky. Its first results were issued in February 2003, with major updates in 2005, 2007, 2009, 2011, and with the final data release submitted for publication on Dec. 20, 2012. The WMAP mission was selected by NASA in 1996 as the result of an open competition, confirmed for development in 1997, and was built and ready for launch only four years later, on-schedule and on-budget. Having completed its mission to "take measure of our universe," its data stream has ceased and the spacecraft now resides in a parking orbit about the sun. The science team gratefully salutes the innovation of the technicians, engineers, and countless contributors to WMAP's voyage and it ultimate scientific success.

High Energy Astrophysics Science Archive Research Center (HEASARC)

The HEASARC is the primary archive for NASA missions dealing with extremely energetic phenomena, from black holes to the Big Bang. Incorporating the Legacy Archive for Microwave Background Data

Analysis (LAMBDA), HEASARC includes data obtained by missions that study the relic cosmic microwave background (CMB) as well as NASA's high-energy astronomy missions from the extreme ultraviolet through gamma-ray bands.

Since 1990, the HEASARC has been an essential element of NASA's astrophysics missions. Its archive services allow scientists to identify, display, cross-correlate, download and analyze data from a variety of past and current missions—including ASCA, BeppoSAX, Chandra, CGRO, Einstein, Fermi, INTEGRAL, ROSAT, RXTE, Suzaku, Swift, WMAP, and XMM-Newton—and provide access to a wide range of multiwavelength sky surveys, astronomical catalogs, and other resources. The HEASARC's scientific and technical staff produces several widely used software packages, provides expertise in the analysis of archived data, and helps to evolve archive interfaces to better serve the science community. The data and software standards developed by the HEASARC provide the underlying infrastructure for the interpretation of data from a wide variety of missions, substantially reducing mission costs while increasing science return.

The HEASARC archive now contains about 48 Terabytes (TB) of data, having grown by about 6 TB in 2012, and includes data from seven active missions and more than 30 space-based missions and suborbital experiments that are no longer operational. HEASARC users downloaded about 90 TB of data in 2012. Papers written using HEASARC data comprise ~10 percent of the total astronomical literature and include some of the most highly cited papers in the field.

The HEASARC Office is led by Dr. Alan Smale, who for much of 2012 also served as the NuSTAR Archive Scientist, leading the HEASARC's preparations to support pipeline processing, software distribution, and data archiving for this important Astrophysics Explorer. In September, the NuSTAR Archive Scientist role was taken over by Dr. Francis Marshall. NuSTAR was launched in June 2012, and the HEASARC will be ready to support the first public data release in 2013. Dr. Smale served as Chair of the ADEC (Astrophysics Data Centers Executive Council), lead-authored a refereed paper based on archival research, and was a co-author on three other papers.

During 2012 the HEASARC's Xamin interface, released the previous year, became the primary interface for most user queries. Xamin is now used for ~90% of the HEASARC's programmatic queries and a substantial fraction of interactive queries. Dr. Thomas McGlynn leads the development of Xamin and the maintenance of our older Browse interface. Xamin features major enhancements over Browse, notably the ability of users to save queries and query configurations for use in subsequent analyses. A major thrust over the past year has been the integration of the Xamin search and retrieval tools with the Hera data analysis tools described below. A single user account now provides access to both capabilities, and users can initiate sessions which use both tools.

The HEASARC remains a core partner in the joint NSF/NASA program to manage and operate the U.S. Virtual Astronomical Observatory. Dr. McGlynn leads the HEASARC's involvement in the VAO, and serves as the VAO Lead for Operations. He and his staff have developed applications which monitor the health of VAO and other VO services and inform responsible parties of issues as they arise. The HEASARC also plays a major role in the development of portal tools within the VO, and VO support is integrated within the major HEASARC interfaces. Both Browse and Xamin provide data using the VO cone search capability. Xamin also provides access using the much more powerful Table Access Protocol, and allows HEASARC users to query remote services using VO protocols.

In addition, McGlynn continues to manage the SkyView virtual observatory. About 4 million dynamically generated images were served by SkyView in 2012 at its website. The HEASARC also provides SkyView software as a self-contained package so that power users can run queries without directly querying the HEASARC site. SkyView provides access to SDSS, FIRST, and 2MASS data hosted at other NASA archives. Major data releases during 2012 include the WISE All-Sky Survey—a major milestone in the infrared—and a new 5-band release of Fermi all-sky data. The Fermi release greatly increases the sensitivity and effective resolution over an earlier data set. A new INTEGRAL Galactic plane survey was contributed by R. Krivonos et al. and in the radio the VLSS survey was replaced by the VLSSr reanalysis. A library of user-contributed interesting images now has more than 20,000 entries.

During 2012 Drs. McGlynn and Smale have led a security review of various elements of the HEASARC's Web presence to ensure security without compromising science utility. As a result, a number of improvements were made to the HEASARC's website.

During 2012, HEASARC programmers under the direction of Dr. William Pence coordinated two new releases of the HEASOFT data analysis software package, providing improved analysis capabilities for data from the Swift, Suzaku, and RXTE observatories. The HEASOFT package is essential for deriving new sci-

entific results from the HEASARC's large data archive. It contains about 2.5 million lines of code contained in 550 individual analysis tasks for the data from 11 high-energy missions supported by the HEASARC as well as for general analysis of astronomical data from other missions. In 2012, more than 4,000 registered external users installed the HEASOFT package on their local computers. As an alternative to installing the HEASOFT package locally, the HEASARC staff also continued to enhance the on-line Hera data analysis service which enables researchers to analyze their data with the HEASOFT package within the computing environment provided by the HEASARC over the Internet. The major focus of development has been to integrate Hera more closely with Xamin, so that researchers can seamlessly query the HEASARC archive with Xamin to locate relevant observations and then analyze the selected data using Hera, all within the same Web browser session.

Dr. Stephen Drake worked on the creation and/or updating of 120 database tables in 2012, bringing the total number of tables available to the HEASARC's Browse and Xamin interfaces to 718 unique tables. Among the newly created tables, five were new Chandra source lists and five were new XMM-Newton source lists. The others included a broad range of missions including MAXI, ROSAT, Swift, Planck and WMAP, as well as many new and updated tables of stars, galaxies, and quasars and 20 new tables of radio sources. Dr. Drake also continues to support the HEASARC's web pages and RSS feed. This feed combines feeds from projects ranging from XMM-Newton through WMAP, items such as recent calibration updates and upcoming proposal and meeting deadlines, and links to selected NASA press releases and major new science results of relevance to the HEASARC user community. In 2012, four to five new items per week appeared in the HEASARC RSS/Latest News, providing an important and timely resource to the astronomical community. Dr. Drake participated in the HEASARC's NuSTAR team, planning the ingest and distribution of these data when they become public in 2013, and also continued to serve as XMM-Newton and RXTE Archive Scientist. For RXTE, he oversaw the handover of the responsibilities for the RXTE Guest Observer Facility website to the HEASARC, following the termination of RXTE operations in January 2012. Dr. Drake was a co-author on two refereed papers published in 2012, and was appointed a member of the science team of the Neutron star Interior Composition ExploreR (NICER) mission.

Dr. Michael Corcoran continued to serve as the manager of the HEASARC Calibration Database, as Fermi and ROSAT Archive Scientist, and is also assisting with the NuSTAR mission archive. During the past year Dr. Corcoran maintained and updated the calibration database for the RXTE, Swift, Suzaku, Chandra, and Fermi missions. He helped develop two new Fermi Browse tables, worked with the Fermi LAT team to help implement full CalDB access in the Fermi Science tools, participated in weekly FSSC meetings plus telecons, and worked on documentation updates and discussions regarding Fermi calibration data. Dr. Corcoran continued to improve the implementation of the GBM response matrix generation software in the HEASARC BROWSE environment, and worked with the GBM and LAT teams to release the calibration databases for both instruments. In 2012 there were a total of 24 updates of the Swift, Suzaku, Chandra, and Fermi CalDB areas, and Corcoran performed the final update of the RXTE calibration database after mission closeout in January 2012. As CalDB manager, Corcoran implements these updates and maintains the HEASARC CalDB website, including the news archive and the RSS feed. Dr. Corcoran also worked with the NuSTAR team to incorporate the NuSTAR calibration files into the HEASARC. Corcoran writes the HEASARC Picture of the Week website, and administers a HEAPOW Facebook group which currently has over 190 members from around the world. He also maintains the Astro-Update website, used by scientists to keep track of updates to important high-energy astrophysics software packages. In 2012 Corcoran was PI of a successful Very Large Project Chandra proposal to observe the massive binary Delta Ori. He was co-author on two refereed publications, served as an editor of the proceedings of the R.H. Koch Memorial Conference, "Stars, Companions and their Interactions," which was published electronically this year by the Journal of Astronomy and Space Sciences, and published a chapter (with K. Ishibashi) for the book, "Eta Carinae and the Supernova Impostors" (ed. K. Davidson and R. Humphreys, Springer). Dr. Corcoran was invited to present a talk on research involving the variability of Eta Carinae at the XIth Hvar Astrophysical Colloquium in Hvar, Croatia, and at the "16 Years of Discovery with RXTE: A Celebration of the Mission" meeting at Goddard. Dr. Corcoran also serves as USRA director for the Center for Research and Exploration in Space Science and Technology, with oversight of 11 Ph.D. research scientists in the Astrophysics Science Division, and mentored Univer-

sity of Delaware graduate student Chris Russell, and University of Denver graduate student Jamie Lomax.

Dr. Arnaud has continued his support of X-ray astronomical data analysis tools in a variety of ways. This year he completed a major rewrite of the XSPEC models that include Compton scattering, ensuring that they all use common code and improved precision. He participated in the latest release of the HEASOFT software, which included XSPEC v12.7.1. Also included in this release was a new version of Dr. Arnaud's HEASP library, a major update replacing the previous C code with C++ (and C bindings) and a Python module created using SWIG. Since the release, Dr. Arnaud has continued to expand this library to provide better support for multiwavelength data. As part of this effort, he wrote a tool to convert Sloan Digital Sky Survey spectra into XSPEC format. Dr. Arnaud also overhauled the WebSpec interface used for simulating spectra for proposals, improving security, restructuring code, and adding new features, and provided updates to support Suzaku, XMM-Newton, and Chandra proposal rounds.

This year Dr. Arnaud took over as Treasurer of the High Energy Astrophysics Division (HEAD) of the American Astronomical Society (AAS). He attended the one-day AAS HEAD Executive Committee retreat prior to the winter AAS meeting. Dr. Arnaud was also a member of the scientific organizing committee and session chair for the Energetic Astronomy meeting in Annapolis.

Throughout 2012 Dr. Steven Sturner maintained the INTEGRAL public data archive at the HEASARC, mirroring the public data archive maintained at the ISDC in Geneva. The ISDC has public data releases approximately twice per month which are downloaded and installed in the HEASARC archive. Dr. Sturner is also the interface between the HEASARC and both the ISDC and ESA's INTEGRAL management.

Within the HEASARC, the Legacy Archive for Microwave Background Data Analysis (LAMBDA) is NASA's thematic archive devoted to serving Cosmic Microwave Background (CMB) and related data sets to the research community. LAMBDA's holdings include data from NASA's two CMB missions: the COsmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP). In 2012 the nine-year results from WMAP were released through LAMBDA. These data and scientific papers are the final results from the WMAP mission that has pioneered our understanding of cosmology. Other holdings include data from the Submillimeter Wave Astronomy Satellite (SWAS), the InfraRed Astronomical Satellite (IRAS), numerous ground and balloon-based CMB experiments, and a collection of diffuse Galactic emission maps that are needed to enable foreground subtraction from CMB data.

Under the leadership of CMB Archive Scientist Dr. David Chuss, LAMBDA continued to increase its data holdings in 2012. In support of the Decadal Survey recommendations regarding the importance of suborbital data for pioneering technology and techniques in advance of a potential Inflation Probe mission, LAMBDA has added new products from the latest ground-based CMB polarimetry experiments. These include QUIET, BICEP, and QUaD. LAMBDA is also hosting additional data from the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT). ACT and SPT are fine-scale ground-based CMB instruments that complement space-based measurements and provide exciting probes of dark matter, dark energy, and the large-scale structure of the universe. In addition, as part of its charter to provide a comprehensive data archive for the CMB, and as a complement to the SPT and ACT data archives, LAMBDA is mirroring the Planck SZ catalog.

In Development

James Webb Space Telescope

The James Webb Space Telescope (JWST) is a large (6.5m), cold (50K), facility-class, general-purpose observatory that will be launched into orbit around the Sun-Earth L2 point. It is the successor to the Hubble and Spitzer space telescopes. Its science goals include detecting the first galaxies to form in the early universe, galaxy evolution, star formation, exoplanets and objects in our solar system. Time on the telescope will be allocated to the community through annual peer-reviewed proposals in a manner similar to Hubble. The prime contractor is Northrop Grumman; the Science and Operations Center is located at the Space Telescope Science Institute. JWST is a partnership between NASA and the European and Canadian Space Agencies.

The ASD provides scientific direction for JWST through a team consisting of 11 project scientists. The Senior Project Scientist is John Mather, his deputy is Jonathan Gardner and his technical deputy is Malcolm Niedner. The other members of the team: Matthew Greenhouse (Instrumentation), Bernard Rauscher (deputy); Mark Clampin (Observatory), Charles Bowers (deputy); Randy Kimble (Integration and Test); George Sonneborn (Operations), Jane

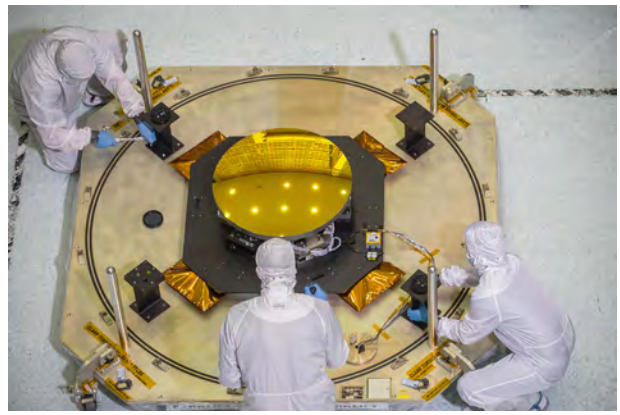
Engineers move the Fine Guidance Sensor instrument into the Goddard cleanroom after its delivery.

Rigby (deputy) and Amber Straughn (Outreach). In addition, Stefanie Milam is currently on detail from the Planetary Sciences Division to study Solar System observations with JWST. ASD science staff members are also directly involved in the provision of key flight systems for the JWST near-infrared multi-object spectrometer (NIRSpec), including its detector and microshutter array systems.

Mather chairs the JWST Science Working Group (SWG), and the Project Scientists work closely with the management and engineering teams, participating in reviews, project meetings, serving on change-configuration boards, and participating in decisions. The JWST SWG published a thorough description of the JWST science goals and technical implementation as a special issue of the refereed journal, *Space Science Reviews* (Gardner et al. 2006). It has since also updated and extended the science case in a series of white papers that include astrobiology, dark energy, exoplanet coronagraphy, exoplanet transits, first-light galaxies, resolved stellar population, solar system observations and the role of JWST in the decadal survey, *New Worlds, New Horizons*. The *Space Science Reviews* paper and the white papers are available from jwst.gsfc.nasa.gov/scientists.html. There have been two conferences for community discussion of JWST science, in 2007 and 2011.

The JWST Project is currently in development, and is conducting the Integration and Test (I&T) phase for many systems. The budget and schedule went through a replan in 2011 and the mission is now fully funded for launch in 2018; there has been no change to the budget or schedule since the replan. The Integrated Science Instrument Module (ISIM) consists of the four science instruments and nine subsystems. ISIM began its integration and testing phase in 2011 (Greenhouse, et al., 2011, *Proc SPIE* 8146, p. 8146606). In 2012, two instruments, the Mid-Infrared Instrument and the Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph were delivered to Goddard. The Near-Infrared Camera and the Near-Infrared Spectrograph are undergoing I&T for delivery in 2013. In 2012, there was a vacuum test of the cryogenic telescope simulator, which will be used to test the ISIM in the Space Environment Simulator chamber at Goddard. The first cryo vacuum test of the ISIM will take place in 2013 with the two instruments that have already been delivered; two later ISIM cryo-vacuum tests will include all the instruments and systems.

In preparation for installation of JWST's flight mirrors onto the backplane, a robotic arm practices the installation of a dummy primary mirror segment assembly onto a three cell mockup of the backplane.



JWST's flight secondary mirror undergoes inspection after its arrival at the Goddard Space Flight Center.

The ASD is directly responsible for provision of two flight systems, both within the Near-Infrared Spectrograph (NIRSpec), an instrument that is part of the ESA contribution to the mission. The Microshutter Assembly (MSA) is led by PI Harvey Moseley with contributions from a number of contractor scientists. The MSA will enable simultaneous spectra of more than 100 objects—the first time that a true multi-object spectrograph has flown in space. An initial MSA system was delivered to ESA in 2010; a replacement is currently being made. The NIRSpec detector system is also being built at Goddard, under the leadership of PI Bernard Rauscher. Moseley and Rauscher are members of the NIRSpec Science Team and will participate in their Guaranteed Time Observations.

All of the flight mirrors have been polished and coated. The secondary mirror and the first three flight primary mirror segments with their actuator supports were delivered to Goddard in 2012. The center section of flight backplane was also completed in 2012 and the two deployed side wings of the backplane will be completed in 2013. The primary mirror will be assembled onto the back plane in the Goddard clean room over the next few years.

When the primary mirror is complete and the ISIM is finished with its I&T, the two will be put together and tested in the Johnson Space Center Chamber A. The JWST project has modified the historic Chamber A for use in JWST testing by installing a gaseous helium shroud. During a test of the shroud, the Chamber reached as low as 11K. This conversion was completed in 2012, along with the Center of Curvature Optical Assembly which will be used for testing the primary mirror in the chamber.

Development of the JWST Science and Operations Center at Space Telescope Science Institute is progressing with the rest of the project. The Critical Design Review for the telescope-ground communication system was completed, along with a System Design Review for the Data Management System, which will process, calibrate and archive the science and engineering data.

Outreach to the scientific community in 2012 included a Town Hall at the American Astronomical Society winter meeting and a workshop on JWST Solar System observations at the Division of Planetary Science meeting. Public outreach and communications highlights for 2012 include a large increase in Social Media reach and impact, with more than double the followers than the previous year (over 40,000 Twitter and over 50,000 Facebook followers) and an extremely successful Reddit "Ask Me Anything" online discussion with John Mather. The project averaged four press releases and features per month and released numerous "Webb Snapshot" and other multimedia products. The outreach team and project scientists supported several large-scale outreach events, such as the Shuttle Celebration at the Intrepid Museum and the USA Science and Engineering Festival, as well as local events at the Goddard Visitor's Center, and hosted several film crews for different local, national, and international television programs. For Education,

The Johnson Space Flight Center JWST team stands in front of the massive door of the Chamber-A test facility. Chamber-A will be used to conduct a cryogenic, end-to-end optical test of JWST.

JWST partnered again in 2012 with the RealWorld/InWorld Engineering Design Challenge, in which student teams compete in both a classroom and virtual/online setting, and have online interactions and learning with JWST scientists and engineers.

Astro-H

The X-ray Astrophysics Laboratory is collaborating with ISAS/JAXA to implement an X-ray calorimeter spectrometer for the Astro-H mission. The project, headed by Richard Kelley of the X-ray Astrophysics Laboratory, is implemented as an Explorer Program Mission of Opportunity to provide key components of a high-resolution X-ray calorimeter spectrometer that will constitute one of the observatory's primary science instruments. Among laboratory scientists, Caroline Kilbourne and Scott Porter are responsible for the detector subsystem, and Peter Serlemitsos and his team of Takashi Okajima and Yang Soong are responsible for X-ray mirrors for both the SXS and the ISAS/JAXA Soft X-ray Imager (SXI). Megan Eckart and Maurice Leutenegger are developing the calibration program for the detector system. Prof. Dan McCammon of the University of Wisconsin, a long-term collaborator with the X-ray Astrophysics Laboratory and a pioneer in X-ray calorimeters, is developing a new generation of blocking filters for the instrument. Rob Petre is the U.S. Project Scientist for Astro-H.

The Soft X-ray Spectrometer (SXS) will consist of a 36-pixel X-ray calorimeter array with better than 7-eV resolution to provide high-resolution X-ray spectroscopy over the 0.3–12 keV band with moderate imaging capability. The Goddard team is to provide the detector system, adiabatic demagnetization refrigerator (50 mK operational temperature), electronics, blocking filters, and X-ray mirror, while ISAS/JAXA is responsible for the dewar system and the rest of the science instruments, the spacecraft, launcher, and mission operations. The Space Research Organization of the Netherlands (SRON) is separately providing to JAXA a filter wheel and in-flight calibration sources based on the technology originally developed by Keith Gendreau.

The dewar will be a hybrid cryogen/mechanical cooler system for redundancy, and the X-ray mirror will build on the Goddard legacy of providing lightweight, high-throughput mirrors.

Astro-H is a facility-class mission to be launched on a JAXA H-IIA into low Earth orbit in 2015. The Astro-H mission objectives:

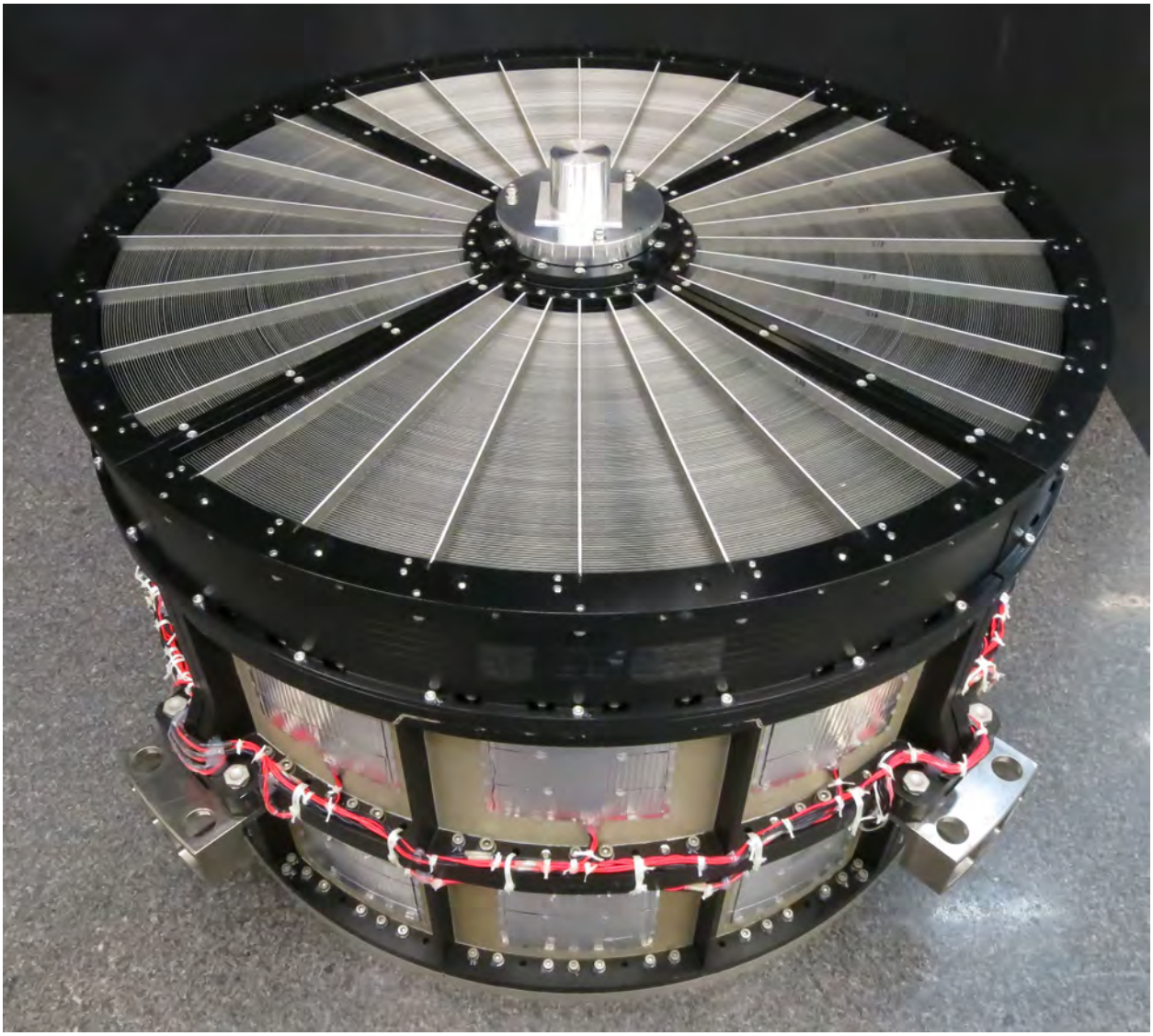
- Trace the growth history of the largest structures in the universe
- Provide insights into the behavior of material in extreme gravitational fields
- Determine the spin of black holes and the equation of state of neutron stars
- Trace shock-acceleration structures in clusters of galaxies and supernova remnants
- Investigate the detailed physics of jets

Achieving these objectives requires the SXS and three additional scientific instruments to provide a very broad, simultaneous energy bandpass. The Hard X-ray Imager (HXI) will perform sensitive imaging spectroscopy in the 5–80 keV band; the non-imaging Soft Gamma-ray Detector (SGD) extends the Astro-H energy band to 600 keV, and the Soft X-ray Imager (SXI) expands the field of view with a new-generation CCD camera.

The SXS science investigation comprises building and delivering the SXS instrumentation and carrying out a six-month observing program in collaboration with ISAS/JAXA. The baseline mission includes two years of funding for the SXS science team and support for processing and archiving the SXS data for a total of three years. An approved Science Enhancement Option (SEO) will provide the U.S. community with access to Astro-H beyond the baseline program. Under the SEO, U.S. scientists will be able to propose for Astro-H observing time and obtain grant support.

Working collaboratively with JAXA, the U.S. Guest Observer Facility will process, distribute, and archive data from all four Astro-H instruments, and provide observers with analysis tools and support. Lo-

The Astro-H/SXS engineering model dewar during tests at the Institute of Space and Astronautical Science in Japan. The unit is a complete high-fidelity model of the flight instrument containing the detector assembly, low-temperature refrigerator, aperture and electronics all provided by Goddard. The system is capable of 5 eV spectral resolution in the X-ray band and was constructed to qualify the design of the SXS for flight and identify issues that need to be addressed before finalizing the flight version.



The first of two flight X-ray mirrors built for the Astro-H mission, one of which is shown here, will be delivered to Japan in early 2013. One mirror is for the Soft X-ray Spectrometer and the other for the Soft X-ray Imager. The mirror contains over 1,600 individual reflectors, has a focal length of 5.6 m, is about 45 cm in diameter and weighs about 46 kg. This is the 21st high-throughput, low-mass X-ray mirror produced for flight by the X-ray mirror group in the X-ray Astrophysics Laboratory at Goddard.

rella Angelini is leading the design and development of this program.

There were many major accomplishments this year. These include successfully integrating the engineering model (EM) components of the SXS with the EM dewar in Japan and conducting qualification tests. These tests demonstrated that the inherent performance of the detector system in the EM dewar is capable of an energy resolution of about 5 eV (FWHM), but is degraded by vibration originating from the cryocooler compressors that produce time-variable heating of the detector stage. This problem is under investigation and several mitigations are being considered. Fortunately, this issue was caught in time to be addressed on the flight dewar system for the SXS.

In addition to the work on completing and testing the EM SXS, Scott Porter, Caroline Kilbourne and Meng Chiao have successfully completed the flight detector assembly and major components of the aperture assembly for the flight model dewar. The energy resolution of the flight detector system at the subsystem level is also about 5 eV and meets all of its other performance requirements. The system was acceptance tested and integrated with a series of X-ray sources and monchromators for characterization and calibration continuously over a period of about four months. This

was a large effort led by Megan Eckart and Maurice Leutenegger, leading to nearly 10 TB of data to be analyzed. The calibration of the flight X-Ray filters (primarily for X-Ray transmission) was also carried out at the facilities of the Brookhaven National Synchrotron Light Source by Eckart and Leutenegger, with assistance from Sarah Busch and Jan-Patrick Porst. This activity was briefly interrupted by "superstorm" Sandy, but continued successfully! The detector system will be integrated with the flight adiabatic demagnetization refrigerator later this year before going through extensive testing and then on to Japan next year. Once integrated, the dewar will be closed out and the aperture assembly components will be installed.

The first of two flight X-ray mirrors was completed by Peter Serlemitsos, Takashi Okajima, and Yang Soong, and will be delivered to Japan in early 2013. The measured performance is 1.3 arcmin (HPD), exceeding the requirement of 1.7 arcmin. The second X-ray mirror is in the final stages of assembly and will then go into performance and acceptance testing before being delivered to Japan in summer 2013.

The Astro-H Science Enhancement Option has been approved by NASA/HQ and includes activities related to data analysis, the Guest Observer (GO) program and user support. To manage and implement these activities, Lorella Angelini has established an Astro-H U.S. data center at Goddard that is working closely with Japan. The pre-launch operations, rapidly ramping up, are focused on data processing, instrument software, collection of calibration information and preparing the necessary documentation and simulation software to support the GO program for all four Astro-H instruments. The Astro-H U.S. data center will be the liaison between GOs and the Astro-H program with a help desk that will open at times near launch. Mike Loewenstein and Hans Krimm joined this activity this year and are supporting the Soft X-Ray Spectrometer and Soft X-Ray Imager instruments, respectively.

HAWC+ for SOFIA

NASA's Stratospheric Observatory For Infrared Astronomy, SOFIA, achieved its first light in May 2010. In August 2011, NASA released an Announcement of Opportunity for SOFIA second-generation instrument investigations and received 11 proposals, of which two were judged to have the best science value and feasible development plans.

The first was the High-resolution Airborne Wideband Camera Polarization (HAWC-Pol), led by PI C. Darren Dowell of NASA's Jet Propulsion Laboratory, Pasadena, Calif. This investigation planned to upgrade the far-infrared imager HAWC (PI Al Harper, University of Chicago, with a detector array for HAWC pro-

With the large door over its 2.5-meter German-built telescope wide open, NASA's SOFIA 747SP aircraft soars over Southern California's high desert during flight tests in 2010. NASA/Jim Ross.

vided by NASA Goddard) to include the capability to obtain polarimetric observations at far-infrared wavelengths. Dave Chuss from the Observational Cosmology Lab was a Co-I on this proposal.

The other was HAWC++, led by PI Johannes Staguhn of ASD's Observational Cosmology Laboratory and Johns Hopkins University. The core group included Dominic Benford, Steve Maher (also SSAI) S. H. Moseley, Elmer Sharp (also GST) and Ed Wollack, all from the Observational Cosmology Lab, and Christine Jhabvala and Tim Miller from Goddard's Detector Systems Branch. Additionally to adding optics enabling differential polarimetry, this investigation provides for a detector upgrade with two sensitive, large-format (64 × 40 pixels) TES-based Backshort Under Grid (BUG) detector arrays provided by the Detector Systems Branch. The proposal also added one additional broadband filter centered at 63 mm to the existing four FIR bands of HAWC, plus R=300 filters for all five bands, enabling fine-structure line mapping and polarimetry.

As requested by NASA, both proposals were merged, and Dowell is the PI of the combined investigation. The instrument, HAWC+, has practically the same capabilities as the one proposed in the HAWC++ investigation with the exception of the fine-structure line filters, although there is a possibility that those might be added later.

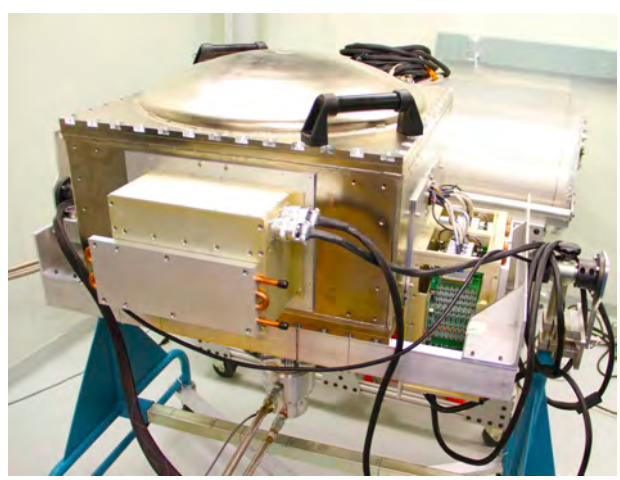
HAWC+ will give SOFIA the ability to study magnetic fields in the molecular material from which stars emerge and the ability to efficiently obtain large maps of the emission from dust. The scientific rationale for HAWC+ polarimetry arises from the fact that the far-infrared (λ = 30–300 μm) continuum dust emission from Galactic sources has been found to show linear polarization of 5 percent or greater, and that the polarization can be used to study the magnetic field in the emission regions.

Magnetic fields are known to exist throughout the universe and to be possibly a crucial ingredient in the formation of stars and molecular clouds. Only a few types of magnetic field measurement are possible. Among them, far-infrared polarimetry is particularly well suited to the study of magnetic fields in the molecular material from which new stars emerge. In addition to observing the orientation of galactic magnetic fields in dense gas in our own galaxy, HAWC+ will measure the global orientation of magnetic fields in other galaxies. These observations can address outstanding problems in galactic dynamo theory, help discriminate between theories and models for galactic winds, and help understand the FIR-radio correlation in galaxies. The phenomenon of interstellar polarization was discovered by Hall and Hiltner in 1949, but the mechanism by which grains are aligned by magnetic fields is still one of the longest-standing mysteries of ISM physics. The 2010 Decadal Survey "New Worlds, New Horizons in Astronomy and Astrophysics" stressed the importance of polarimetry in understanding the magnetic field in the report by the "Panel on the Galactic Neighborhood." In particular, they note that, "Using aligned dust as a tracer for magnetic fields requires understanding the shapes and optical properties of dust grains and how variations in the degree of dust alignment depend on local conditions in clouds." Through its winning combination of spectral coverage, sensitivity, high angular resolution, and wide field in the far infrared, HAWC+ can provide crucial tests of theories of grain alignment.

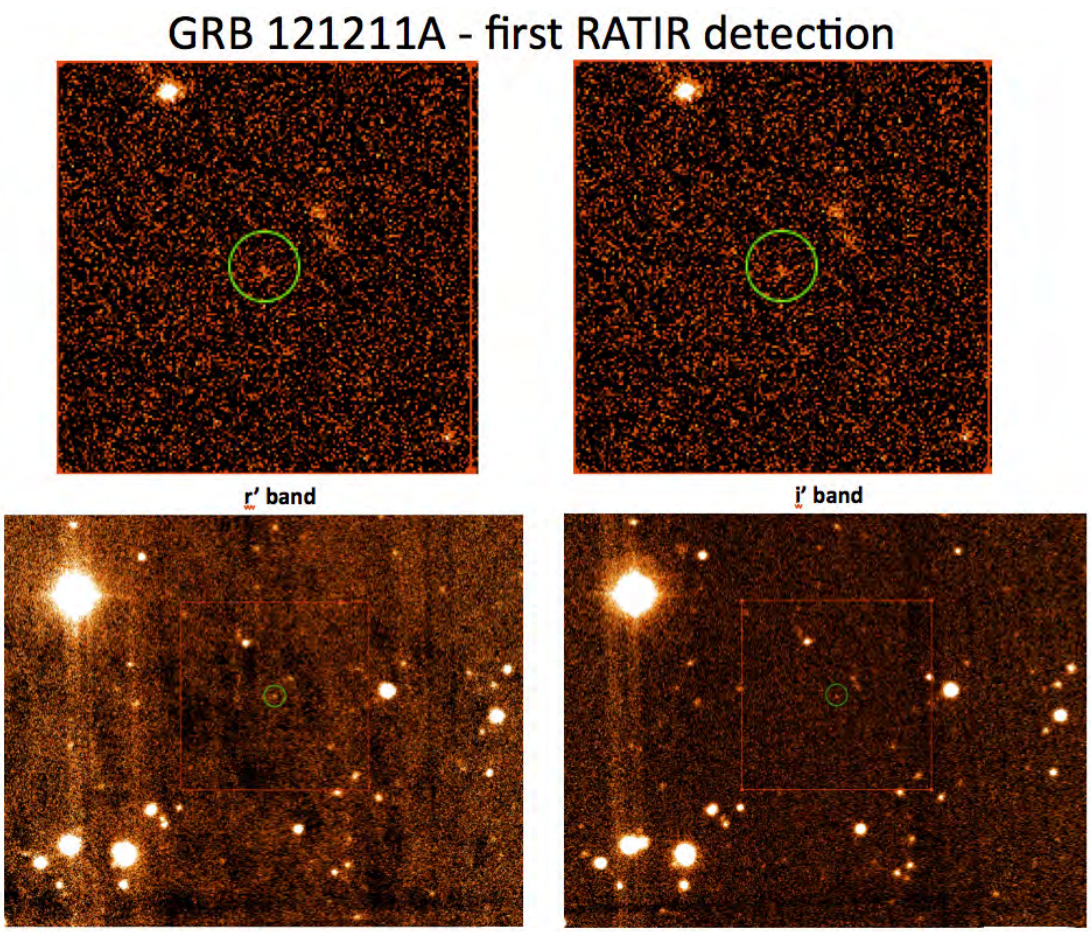
Mission and Instrument Concepts

The RATIR and RIMAS Infrared Instruments

The Reionization and Transients InfraRed camera (RATIR) is an optical/infrared imager for fast follow-up on gamma-ray bursts (GRBs) detected by NASA's Swift observatory. The project collaboration includes the University of California, Berkeley; Arizona State University (PI, N. Butler); NASA's Goddard Space Flight Center (N. Gehrels); and the Universidad Nacional Autónoma de México. The camera is designed for simultaneous image acquisition in four bands (two visible and two infrared), tailored to the primary goal of detecting "dark GRB" afterglow and prompt redshift of the burst. RATIR is permanently mounted on the 1.5-meter Johnson telescope of the Mexican



The RIMAS dewar assembled in the lab with the detector readout electronics attached.



Observatorio Astronomico Nacional on Sierra San Pedro Martir in Baja California and operates each night, supporting ancillary science that requires systematic long-term monitoring. The first GRB afterglow was detected Dec. 11, 2012.

The Rapid IMAger-Spectrometer (RIMAS) is a joint project with the University of Maryland to develop a facility instrument for the Discovery Channel Telescope (DCT) at Lowell Observatory in Flagstaff, Ariz. The DCT is a new 4-meter telescope at Lowell observatory. RIMAS covers the near infrared band and combines an imager, a low-resolution spectrometer (grism) and a high-resolution cross-dispersed echelle spectrometer. It will be used for follow-up of astronomical transient sources, including gamma-ray bursts and supernovae. The combination of a large telescope, rapid response and NIR imager/spectrometer will give unique capabilities for transient domain science. The instrument is at the final stage of development and is currently under construction.

Primordial Inflation Explorer (PIXIE)

How did the Universe begin? Humans have asked this question since our species first looked skyward. Recent progress in cosmology suggests that we may have begun to answer it. We live in an expanding Universe filled with microwave background radiation, the leftover heat from the Big Bang. In this "concordance" model, the universe is flat, largely composed of dark energy and dark matter, and seeded with density fluctuations from the early universe.

The concordance model postulates that early in its history, the universe underwent a rapid period of superluminal expansion called inflation. The exponential growth of the scale size during inflation neatly produces the observed conditions of our universe, but relies on extrapolation of physics to energies a trillion times beyond those accessible to direct experimentation in particle accelerators.

The Primordial Inflation Explorer (PIXIE) will test the inflationary paradigm by searching for the "smoking gun" signature of primordial inflation in the linear polarization of the cosmic microwave background (CMB). Quantum fluctuations in the space-time metric during inflation create a stochastic background of gravity waves, which in turn imprint a distinctive spatial signature in the CMB. The amplitude of the gravity waves depends on the energy scale at inflation. Detection of the gravity-wave signature

would establish inflation as a physical reality, provide a model-independent determination of the relevant energy, and probe physics at energies near the Grand Unified Theory scale (10^{16} GeV). The search for the inflationary signal is widely recognized as one of the most compelling questions in cosmology, endorsed as a priority for the coming decade in the 2010 Decadal Survey of Astronomy and Astrophysics, *New Worlds, New Horizons*.

PIXIE is an Explorer mission concept to detect and characterize the signature of primordial inflation. Principal Investigator Alan Kogut (665) leads a team including GSFC Co-Investigators D. Chuss, E. Dwek, D. Fixsen, S.H. Moseley, and E. Wollack. PIXIE's innovative design uses a multi-moded "light bucket" and a polarizing Fourier Transform Spectrometer to measure the differential spectrum between two co-aligned beams in orthogonal linear polarizations. PIXIE will measure the frequency spectra in 400 spectral bands from 30 GHz to 6 THz for each of the Stokes I, Q, and U parameters in each of 49,152 independent pixels covering the full sky.

The combination of sensitivity and broad spectral coverage answers exciting questions across cosmic history. PIXIE's primary science goal is the characterization of primordial gravity waves through their signature in the CMB polarization. PIXIE will measure linear polarization to sensitivity 70 nK per 1° ´ 1° pixel. Averaged over the sky, PIXIE can detect CMB polarization to 3 nK sensitivity, a factor of 10 below the minimum signal predicted from large-field inflation models. PIXIE reaches the cosmological "noise floor" imposed by the gravitational lensing below which further instrumental sensitivity is unimportant.

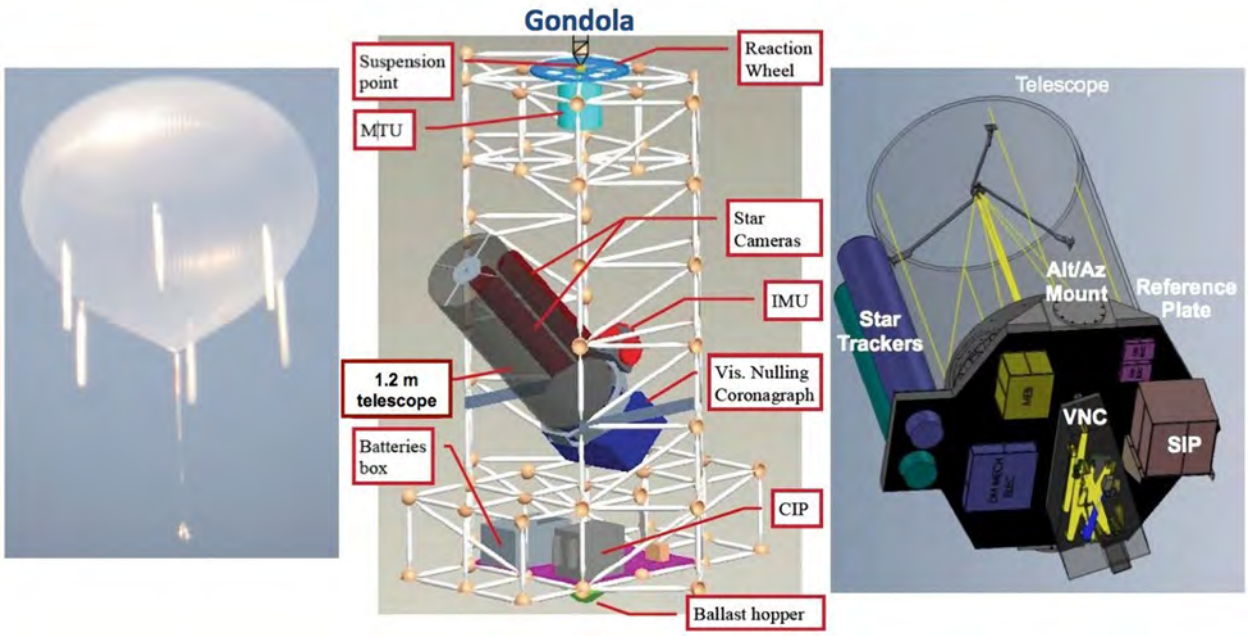
PIXIE's unique combination of high sensitivity and broad spectral coverage enables a broad range of ancillary science goals. PIXIE will measure both the temperature and ionization fraction of the intergalactic medium at redshifts 5–30 to determine the nature of the first luminous objects in the Universe. Measurements of the spectrum and anisotropy of the far-IR background test models of star formation at redshift 2–4. PIXIE determines the properties of the diffuse dust cirrus and maps the far-IR line emission from the molecules and ions that cool the interstellar medium within the Galaxy.

PIXIE was submitted to the 2011 Explorer Announcement of Opportunity. Although the mission was not selected for Phase A study, both the science and technical implementation were rated as Category 1. PIXIE can reach fundamental sensitivity limits imposed by unavoidable cosmological foregrounds, achieving key goals of NASA's planned Inflation Probe mission at a small fraction of the cost and complexity. As such, the mission retains considerable interest for NASA. The PIXIE team has been urged to re-propose at the next MIDEX opportunity.

Wide Field InfraRed Survey Telescope (WFIRST)

The Astro 2010 report, released August 13, 2010, selected the Wide-Field Infrared Survey Telescope (WFIRST) as the top priority for large space missions in the coming decade. This mission combines the dark energy science previously planned for the NASA/DOE Joint Dark Energy Mission (JDEM) project, with observing programs to obtain a census of exoplanets by means of microlensing and to obtain a wide range of near infrared surveys. The JDEM "OMEGA" mission concept was to serve as the basis for the new mission design. NASA HQ designated Goddard as the lead center for managing the WFIRST project, with significant portions of the mission assigned to JPL.

A Science Definition Team (SDT) representing the full spectrum of WFIRST science objectives was appointed at the end of 2010 to provide scientific advice on optimizing mission performance during the WFIRST pre-Phase A study, and to develop a Design Reference Mission (DRM). The Charter was revised in December 2011 to add a second DRM that did not duplicate capabilities of the recently-approved ESA Euclid mission and that further reduced cost. The SDT worked closely with scientists and engineers from the WFIRST Project Office to develop two Design Reference Missions for the Final Report, which was delivered in August 2012. This report summarized the scientific objectives of the mission, and described the expected scientific return from each of the DRM implementations. These implementations evolved significantly from the original JDEM Omega design: the 1.5m on-axis telescope was replaced with 1.3m and 1.1m off-axis telescopes for DRM1 and DRM2, respectively, and the multi-channel instrument design was replaced with a single-channel wide-field instrument. DRM1 has a collecting area comparable to JDEM OMEGA, and for both DRMs the clean point-spread function of the off-axis telescope provided significant benefits to the challenging WFIRST observing programs. The single-channel instrument concept is better-suited to the wider scientific scope of WFIRST than the multi-channel OMEGA design, which was optimized for Dark Energy observing programs. Slitless spectroscopy is provided by prisms mounted in a wheel placed in



Balloon Exoplanet Nulling Interferometer (BENI). Left: A generic balloon. Middle: A gondola with the telescope and the major subsystems labeled. Right: One design of the telescope with the VNC located beneath the optical bench.

series with the filter wheel. The SDT report is available online: http://wfirst.gsfc.nasa.gov/science/sdt_public/WFIRST_SDT_Final_Report.pdf.

The availability of two 2.4m telescopes from the National Reconnaissance Office (NRO) for use by NASA was announced in mid-2012, and an informal workshop on use of these telescopes was held at Princeton in early September. Both Neil Gehrels and Jeffrey Kruk from ASD gave presentations on the use of such a telescope for WFIRST. (A whitepaper derived from this workshop is posted on astro-ph: http://arxiv.org/pdf/1210.7809v2.pdf). A new SDT was appointed by NASA HQ in October 2012 to investigate use of an NRO telescope for WFIRST, with a report due by the end of April 2013. Neil Gehrels of Goddard and David Spergel of Princeton are co-chairs of this SDT. Weekly telecons are being held, and several face-to-face meetings are scheduled. The Mission Study Office is located at Goddard, and Telescope and Coronagraph Study Offices are located at JPL.

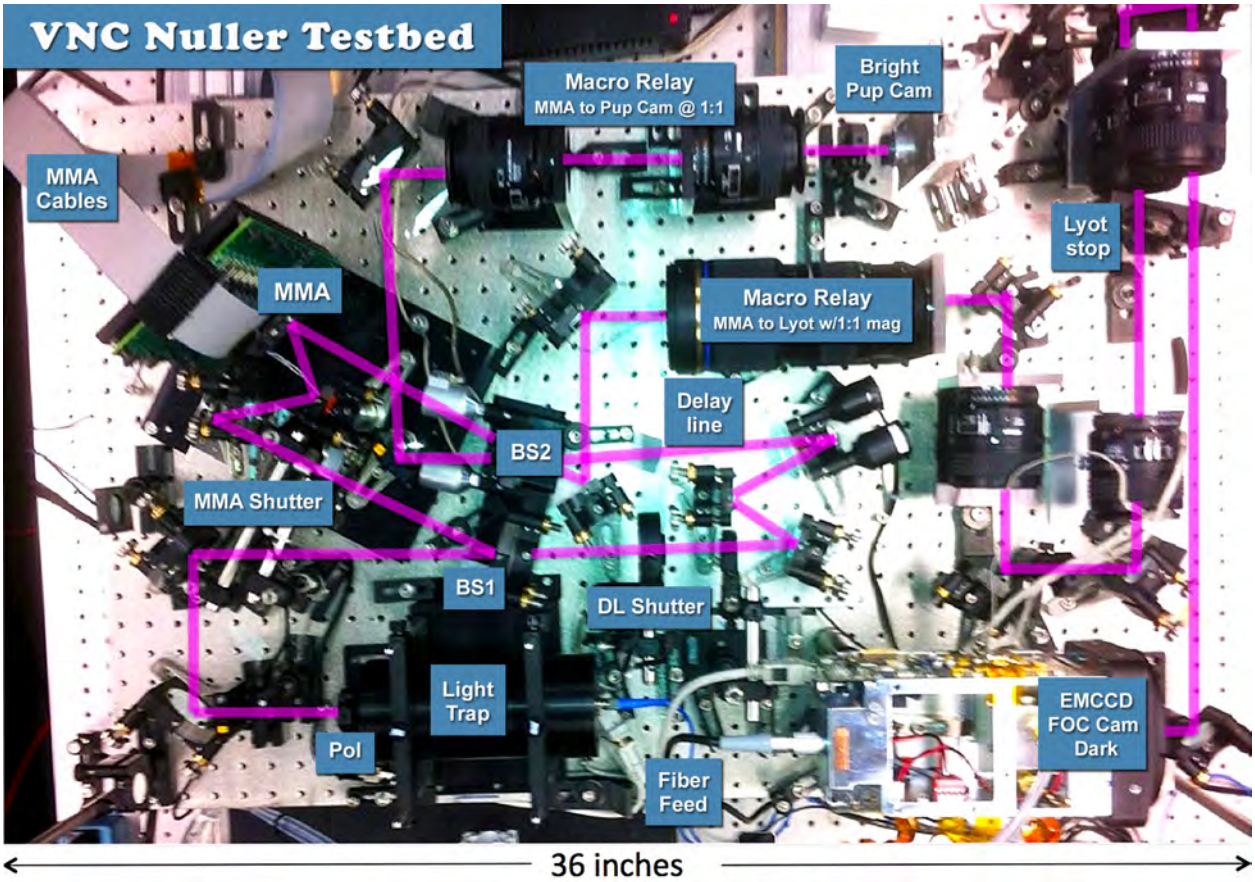
The WFIRST Project science team at Goddard includes Neil Gehrels (Project Scientist), Jeff Kruk (Instrument Scientist), Richard Barry, Ken Carpenter, Harvey Moseley, Bernie Rauscher and Ed Wollack. This team joined the engineers from the Project Office in working with the SDT to study the implementation of WFIRST. Rauscher and Gehrels are members of the SDT.

Balloon Exoplanet Nulling Interferometer (BENI)

One approach to moving forward with exoplanet missions is to use suborbital platforms such as sounding rockets and long-duration balloons. Sounding rockets have short flights and small payload volumes that preclude any significant exoplanet science, however, Ultra Long Duration Balloons (ULDB) can ascend to > 100,000 feet, stay aloft for as long as 100 days, have subarcsecond pointing control, and can carry instruments with enough aperture to enable significant exoplanet science and to lower technology risk for those technologies deemed critical for space flight. The VNC team studied the feasibility of the BENI mission using a ULDB with a gondola with < 1 arcsecond pointing and a 1.2-meter-aperture telescope feeding light into a VNC and determined that with existing technology we could assess the luminosity and morphology for > 20 target dust and debris disks and that some bright Jovian planets could be seen.

Visible Nulling Coronagraph for Exoplanets

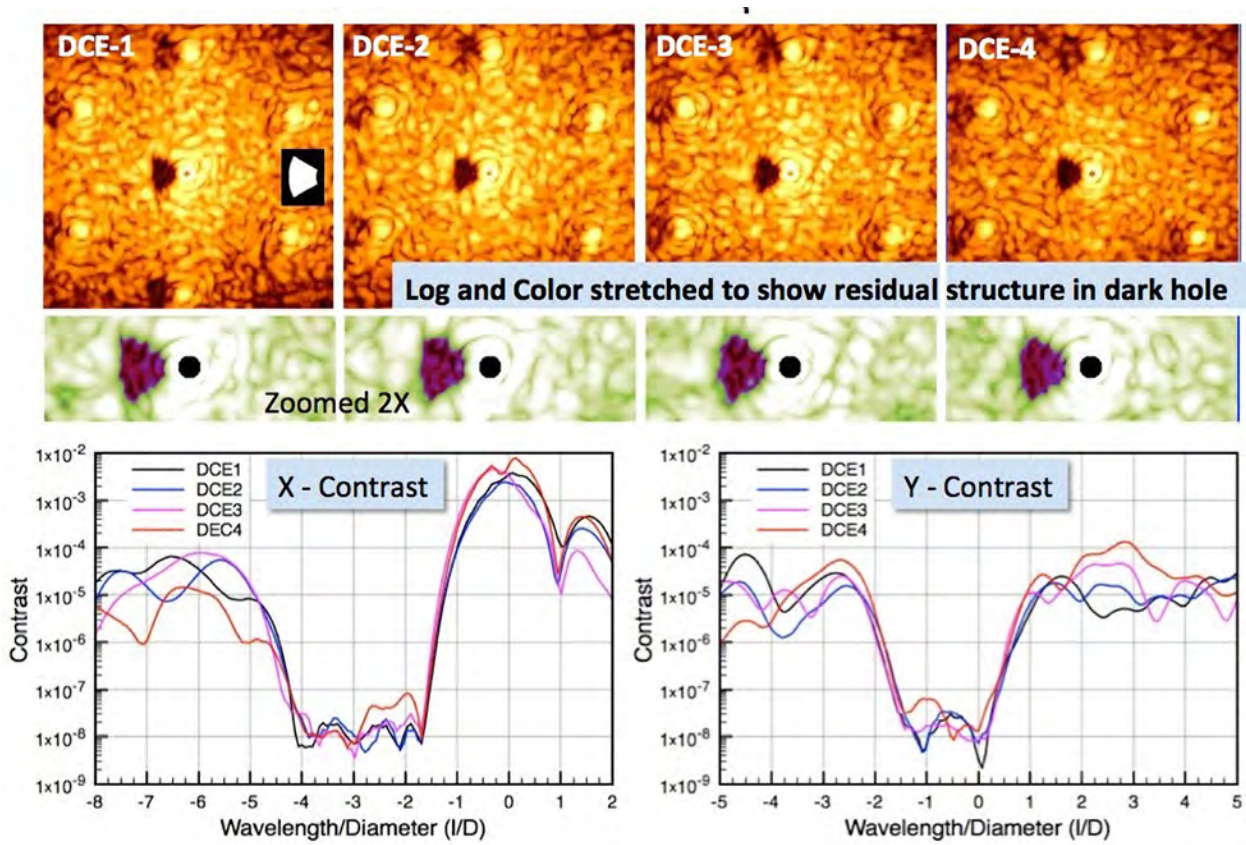
Exoplanet science is rapidly advancing due to its high scientific value, and broad interest in answering the question: Is there life elsewhere in the universe? Exo-



The GSFC Vacuum Nuller Testbed. Light enters from the fiber feed into a light trap that collimates and filters the light to emulate the beam from a collecting telescope and define the aperture stop. An optical relay re-images the aperture stop onto both the MMA and its conjugate optic in the delay-line arm after splitting light 50:50 at beamsplitter-1 (BS1). The light is combined at beamsplitter-2, yielding two output beams known as the bright and dark outputs. The dark output contains the planetary photons, while the bright output contains the stellar photons; both output channels are used for wavefront and amplitude control. The total number of photons is conserved across both channels, allowing realization of a null-control scheme that depends only on the brightness of the target star and is independent of the state of the VNC. This is a significant advantage over other approaches in that it allows rapid control. The angle of separation between the star and planet where the VNC operates is $2\lambda/D$, where λ is the wavelength and D the diameter of the aperture. In visible light this is ~50 milliarcseonds for a 4m aperture.

planet imaging requires instrument contrasts (ratio of star to planet luminosity) exceeding $>10^9$ at planet-to-star angular separations (inner working angle) of typically less 100 milliarcseconds. High-contrast imaging of this magnitude requires a telescope coupled to a coronagraph to suppress the star light relative to the planet's light at these small angular separations. Imaging over this range of contrast is extremely demanding and requires exquisite and stable control of wavefront, amplitude, and polarization errors over a range of wavelengths. Goddard developed the Visible Nulling Coronagraph (VNC) as a joint effort between the Sciences and Exploration Directorate, the Applied Engineering & Technology Directorate, and on-site contractors to better understand and meet these demanding science, instrument and technology requirements.

The VNC was designed, fabricated, assembled and tested within a vacuum tank at Goddard in Building 34 and is the only Goddard-led exoplanet coronagraph effort. Following completion, the VNC was used to achieve the highest contrast ever recorded, at unprecedented inner working angles, with a nulling coronagraph. This significant achievement provides Goddard with a viable instrument approach for upcoming flight opportunities that include the NRO telescope, an Exoplanet Probe, a future large-aperture successor to the Hubble Space Telescope, and subor-



The top row shows contrast maps from four different data collection events (DCE) on a log and color-stretched scale to show residual structure. The dark hole where a planet would be searched for is evident just left of the image center. The image at upper left contains an inset of the dark-hole control mask shifted to the right side. The middle row shows the dark-hole region from the top row magnified by a factor of 2. The central core is masked to compress the image dynamic range for display purposes. The plots at the bottom show X (left to right) and Y (top to bottom) plots through the center of the dark hole versus radial distance in units of λ/D.

bital balloon-borne exoplanet missions. Additionally the VNC advanced critical technologies suitable for other competing exoplanet mission approaches; these include the hexagonal-packed MEMS deformable mirror, the spatial filter array, Lyot masks, the achromatic phase shifter, and extreme wavefront control. The overall VNC effort enhances Goddard's science competitiveness and technology readiness for upcoming exoplanet mission opportunities.

Specifically the VNC effort consisted of:

- *Design the VNC instrument*: design, procurement, assembly, alignment; interfacing the control system, cameras and data collection/processing system; and insertion into tank and test. This effort was funded by GSFC IRAD (FY08/09/10) and is currently funded under two (FY10/11 PI: M. Clampin & FY12/13 PI: R. Lyon) NASA/Strategic Astrophysics Technology (SAT) awards.
- *Hex-packed MEMS deformable mirror (DM)*: The VNC worked with IRIS-AO (Berkeley, Calif.) to obtain phase-I/II NASA SBIRs for the development and delivery of a sequence of successively better DMs, and two additional NASA SAT awards were funded to environmentally test two competing DM technologies. Goddard will perform the environment testing in 2013 and will pre- and post-test the DMs in the existing VNC.
- *Spatial Filter Arrays (SFA)*: Four different vendors delivered different forms for the SFA that were, or are undergoing, testing with the VNC. Two of the vendors were funded under GSFC IRAD and two from NASA SBIRs.
- *Achromatic Phase Shifters (APS)*: As part of the FY12/13 SAT the VNC team designed and developed custom APS that are undergoing fabrication and coating using Applied Engineering & Technology Directorate facilities. The APS will be available for initial testing in April 2013.

- *Wavefront Sensing and Control*: Developed the mathematical models/algorithms, coded in C on a multiprocessor workstation, to work in near real-time. This allows wavefront sensing at 40 frames per second in the VNC laboratory environment and serves to mitigate the residual lab vibration and thermal drift.

The first funded SAT (FY10/11) has been completed and the milestone, of 10^8 contrast at 2 λ/D, has been achieved. Additionally localized regions achieved better than 10^9 contrast at less than 4 λ/D. This milestone was achieved narrowband and required the DM, precision WFC, and photon counting, and this milestone was designed to assess the performance of the DM, relative to contrast, in closed loop as driven by the WFC.

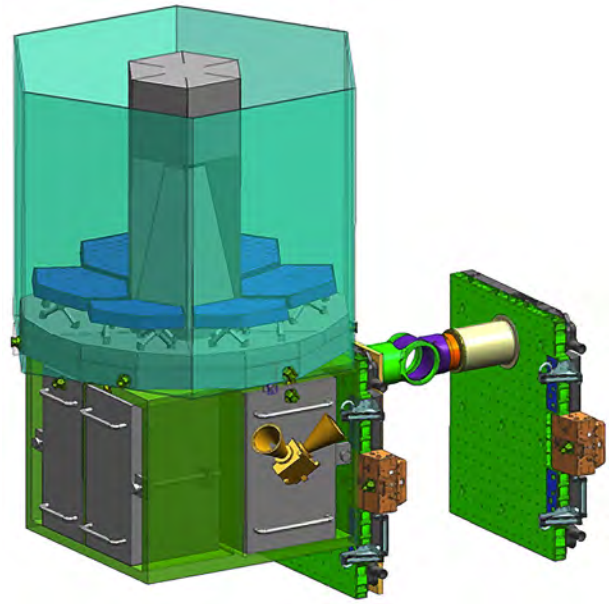
The ongoing FY12/13 SAT is to expand the spectral bandpass of the previous milestone from 1 nm to 60 nm and while achieving a contrast, across the band, of 10^9. This milestone requires the ongoing development of APS and it is expected that the broadband milestone will be achieved in late 2013.

ISS as a Testbed for Future Complex Optical Systems

Large and complex space optical systems that may be launched in the 2020s and 2030s will be necessarily much larger than this decade's James Webb Space Telescope. It is likely, therefore, that such missions will require assembly on orbit and may, in addition, be enhanced by subsequent upgrade and servicing. However, whether such challenging tasks are carried out via robots or astronauts—or a combination of both—the required capabilities do not now exist.

Dr. Harley Thronson continues to play a leading role in a small group of Goddard scientists and engineers that is working with colleagues at the Jet Propulsion Laboratory and NASA Johnson Space Center to assess the International Space Station (ISS) as a long-term testbed to develop the capabilities to use astronauts and robots to enable future very large optics. The Optical Testbed and Integration on ISS Experiment (OpTIIX) entered Phase B study in early 2012, although is stalled due to lack of funding. The primary goal of OpTIIX, is to retire technical risk in complex robotic assembly in space before the 2020 NRC Decadal Survey.

Although significant design work still needs to be carried out, the basic notion is to launch to ISS the components of a modular optical system, including a basic control system and instrument. Robots would then be used to assemble, test and upgrade the system over a few years. The team intends also to explore whether purely autonomous deployment/assembly would be more cost-effective than using external human or robotic agents. The resulting optical system on ISS would be capable of very limited observations, at least at the start. Even so, the knowledge and experience gained by attempting the construction and servicing of large, precise structures will be essential in enabling very ambitious optical systems in space in future decades.

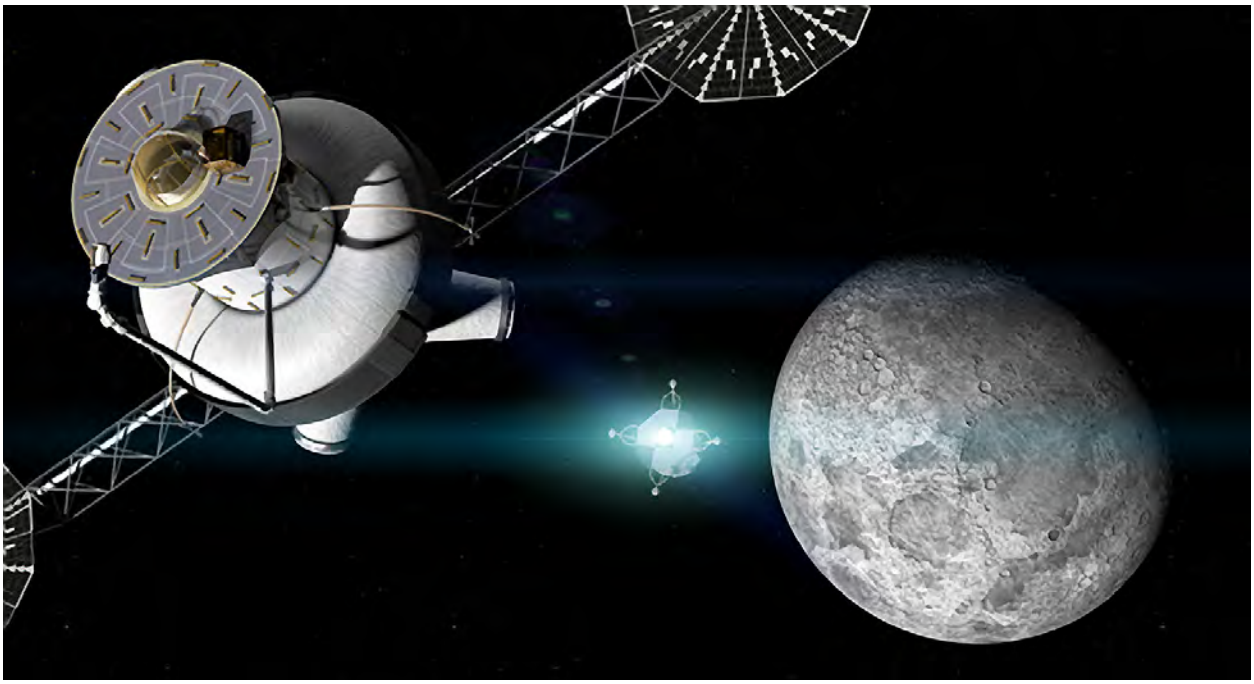


The Optical Testbed and Integration on ISS Experiment (OpTIIX) concept is intended to be a 1.4m optical system that will retire the risk of key elements of the robotic assembly and upgrade of future very large telescopes in space. NASA GSFC has overall responsibility for the imaging camera housed within one of the gray orbital replacement units at the base of the segmented telescope assembly.

An unsolicited proposal to restart the OpTIIX project is under consideration by NASA HQ.

Human Operations Beyond Low-Earth Orbit

NASA's human space flight program, although with continuing significant uncertainty in its goals and priorities, consistently identifies operations in free space beyond low-Earth orbit (LEO) as a priority. Whether as a staging site for long-duration voyages beyond the Earth-Moon system, supporting human and telerobotic exploration of the lunar surface, or advancing technologies developed on the International Space



One concept for a long-duration human habitation system operating at the Earth-Moon L1 or L2 venue is shown here, shortly after an advanced robotic surface rover has been dispatched to the lunar surface. John Frassanito & Associates

Station (ISS), continued human operations in free space have been recommended to NASA for decades as a major enabling capability.

Dr. Harley Thronson continues to lead a small working group of scientists and engineers at Goddard, other NASA centers, and in industry, which has for several years been developing concepts for how equipment and facilities developed for human space flight might be used to achieve other goals. Such work has a long history at Goddard: In the early 1970s, Frank Cepollina and colleagues persisted in advocating that the space shuttle be adapted to service and upgrade satellites in LEO. This was almost two decades before Cepollina's team used the shuttle to rescue NASA's premier astronomical observatory. Vision and perseverance eventually pays off!

Currently, Thronson's team has taken on the ambitious task of designing a long-duration human habitation system for either the L1 or L2 Earth-Moon location. Its primary purpose would be to develop capabilities necessary for safe and comfortable human operations beyond LEO in the early 2020s. A major goal for this habitat—dubbed a "Gateway" by its designers—is to support lunar surface operations, either with astronauts or with telerobots. However, in addition, the capability to repair, assemble and upgrade complex science facilities, including large optical systems, is also under consideration.

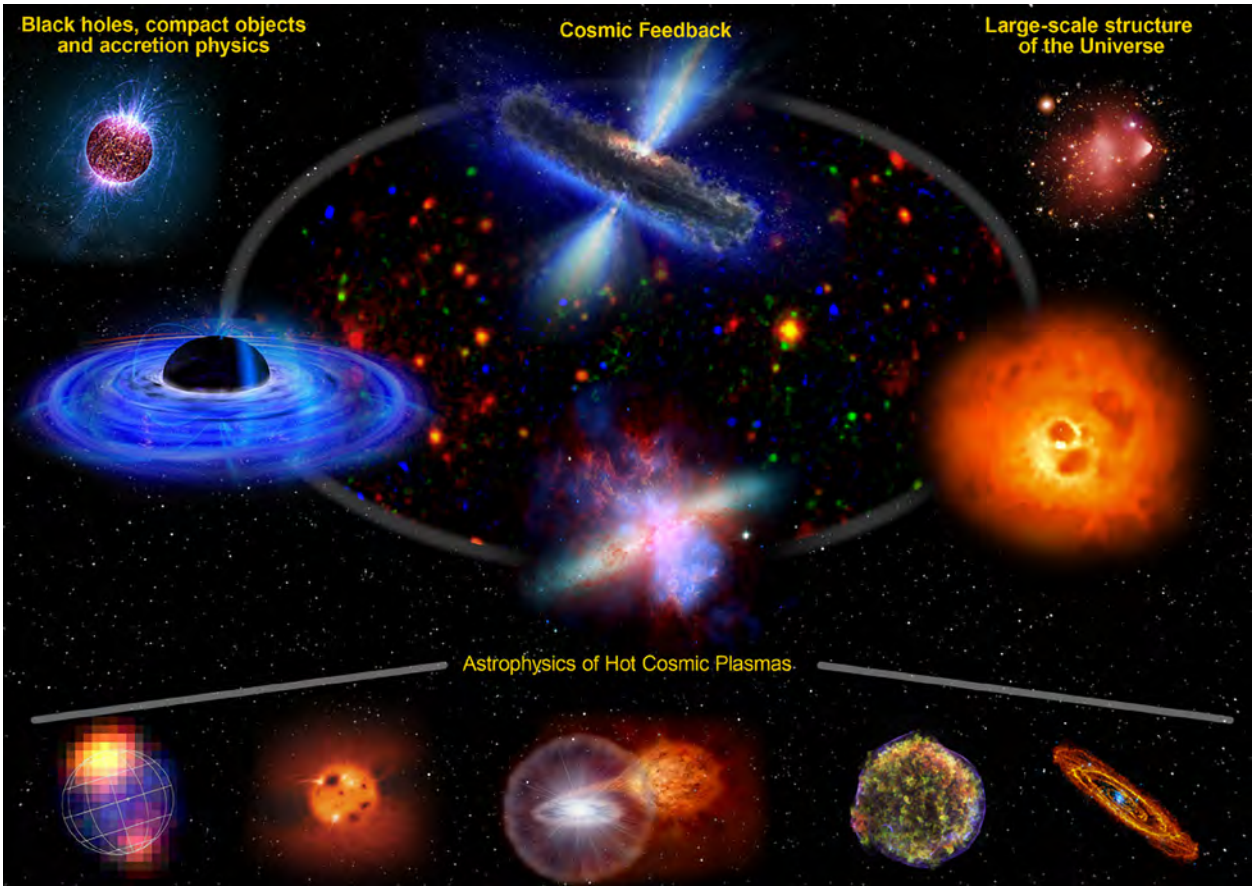
More recently, Thronson has been leading a GSFC team that is assessing how on-orbit staging of a human mission to Mars in the 2030s could be achieved using conventional or near-term technologies, as well as pre-emplacing at Mars the elements necessary for safe return, perhaps within a total round-trip duration less than a year.

X-ray Mission and Concept Studies

International X-ray Observatory (IXO) was to be an international flagship X-ray observatory with joint participation from NASA, the European Space Agency (ESA) and Japan's Aerospace Exploration Agency (JAXA). IXO is a facility-class mission for launch in the 2020s that would address major astrophysical questions in the "hot universe" by providing breakthrough capabilities in X-ray spectroscopy, imaging, timing and polarimetry.

IXO was ranked as the fourth priority for NASA in the 2010 decadal survey report New Worlds, New Horizons. The panel recommended that NASA support a substantial technology development program over the next decade, primarily to mature the X-ray mirror technology.

Nearly in parallel with the 2010 decadal survey, ESA was evaluating future missions through its Cosmic Visions study. IXO was one of three L-class missions, along with LISA and a Jupiter probe (JUICE), which were to be ranked by ESA in June 2011. As all three missions relied on substantial NASA contributions, and none were ranked highest in their respec-



IXO's science goals included the physics of black holes, the growth of large-scale structure, and other regions near and far whose physics could be revealed by a new flagship X-ray mission. This image is taken from ESA's Athena Assessment Study Report.

tive U.S. decadal surveys, ESA decided in March 2011 to reconstitute all three at a lower cost and without substantial U.S. participation. NASA's response was to terminate the IXO (and LISA) studies.

The replacement L-class candidate for IXO was called the Advanced Telescope for High ENergy Astrophysics (ATHENA). It had very different architecture: a pair of identical co-axial mirrors, one of which illuminates an X-ray calorimeter, the other a Wide Field Imager. ATHENA would have addressed most of the IXO science objectives, at a considerably lower cost. U.S. participation would have been limited. In May 2012, ESA selected JUICE as its L1 mission; a revised version of ATHENA will be proposed in 2013 as an L2/L3 candidate.

Subsequent to the termination of IXO, a concept for a mission that performs the high-priority IXO science at a total cost below $2 billion was developed and validated through the GSFC Mission Design Laboratory. This mission concept, the Advanced X-ray Spectroscopy and Imaging Observatory (AXSIO), features an X-ray calorimeter and a retractable grating spectrometer behind a single large mirror, preserving IXO's key components.

In September 2011, NASA Headquarters requested that the PCOS Program Office coordinate a study to determine the degree to which missions at various cost levels between $300 million and $2 billion could accomplish the IXO science objectives. Rob Petre served as Study Scientist, and Andy Ptak was a member of the Science Support Team. This study was initiated through an HQ Request for Information (RFI) for mission concepts and supporting technology. A total of 29 responses were received, 15 of which described mission concepts. In November, NASA HQ selected a Community Science Team (CST) to provide science input for the study. The Study Team hosted two-day workshop in December 2011 to involve the larger community; attendance exceeded 100. Using the workshop discussion and the RFI responses as input, the CST defined four notional missions for further study: AXSIO, plus single instrument missions

built around a calorimeter, gratings and wide-field imager. Through the first half of 2012, each of these notional missions was studied. The study included development of performance specifications by the CST, a design run through the GSFC Mission Design Laboratory, and subsequent costing using PRICE-H and other costing methods. Possible cost savings through descopes and foreign contributions were assessed. The study team also assessed the readiness of the enabling technology for each of the notional missions and the estimated cost to advance each technology to TRL-6 (the level assumed in the mission cost estimates). All of this information was compiled in the X-ray Missions Concepts Study Report (http://pcos.gsfc.nasa.gov/studies/x-ray-mission.php).

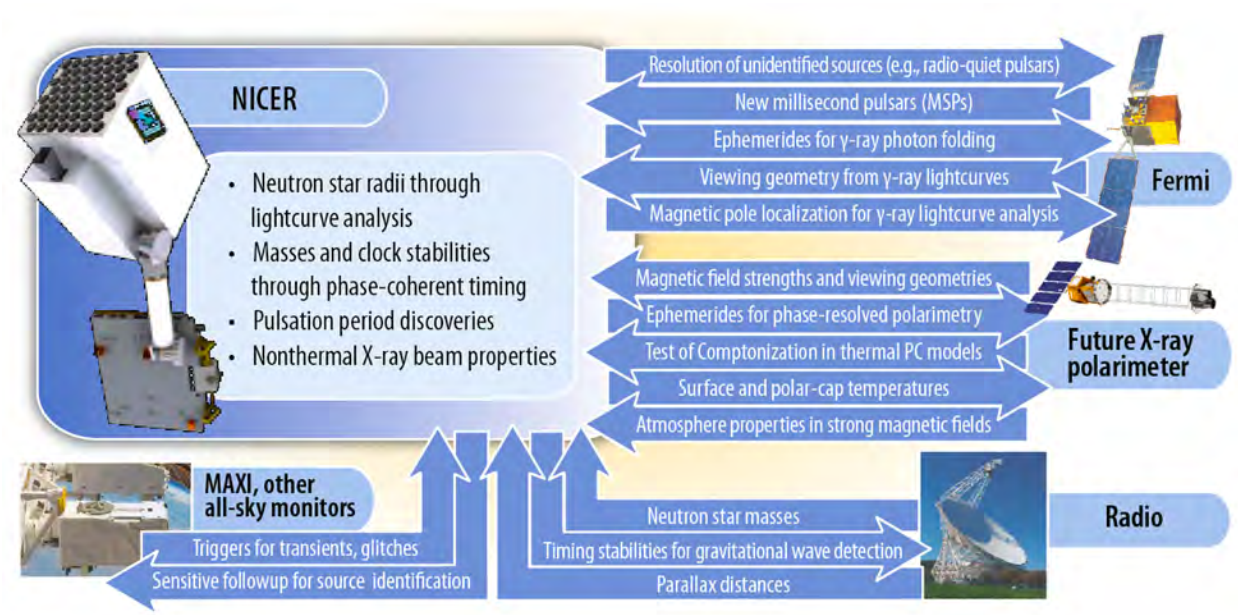
The final report was submitted to NASA Headquarters in July 2012, and received favorably. Its primary conclusion is that X-ray observatories in the $1 billion class that address the high-priority IXO science objectives are feasible for start within this decade, but only if technical risk is controlled by prior development of key technology to TRL-6. This report results were presented to the NASA Astrophysics Division (July 2012), the Physics of the Cosmos Program Analysis Group (PhysPAG) (August 2012), the newly reinstituted NRC Committee for Astronomy and Astrophysics (CAA, October 2012), and will be presented to the membership of the American Astronomical Society (January 2013).

The primary study outcome, that it is feasible to develop an X-ray observatory that addresses a substantial share of IXO science for ~$1 billion, factored into the NASA Astrophysics Division Implementation Plan. That plan calls for a 2015 decision about what strategic astrophysics mission NASA will start in 2017. One candidate is an "X-ray Probe" mission, to be based on one of the notional missions in the X-ray Mission Concepts Study.

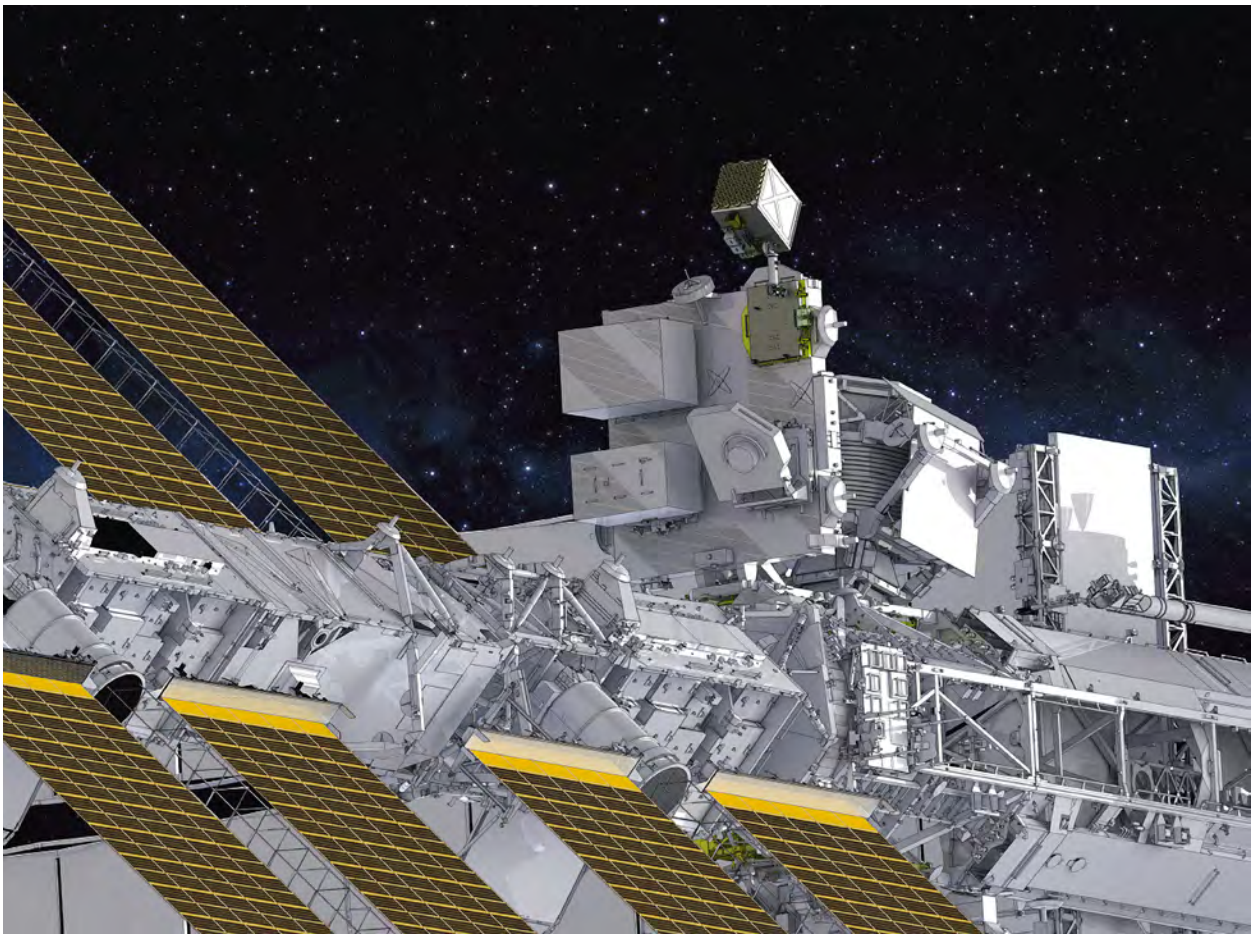
As input to that decision, the GSFC-led study team is undertaking two activities. First, it is developing a Technology Development Plan (TDP) describing the steps, timeline and funding required for raising the critical instrumentation of an X-ray probe class mission to the appropriate readiness level. The TDP will be completed by May 2013. Second, a mission study will be performed in which one of the notional missions from the Study will be further developed in order to make possible an accurate cost estimate. This study will start in late 2013 and will be completed by mid-2015.

Neutron Star Interior Composition Explorer (NICER)

NICER is a proposed Explorer Mission of Opportunity (PI: Keith Gendreau), an International Space Station (ISS) payload devoted to the study of neutron stars through soft-X-ray timing. Neutron stars are unique environments in which all four fundamental forces of nature are simultaneously important. They squeeze more than 1.4 solar masses into a city-size volume, giving rise to the highest stable densities known



The interplay among the capabilities of ground-based radio and operating space-based X-ray and gamma-ray observatories amplifies the scientific returns from all.



An artist's view of NICER observing neutron stars from its perch on the ISS.

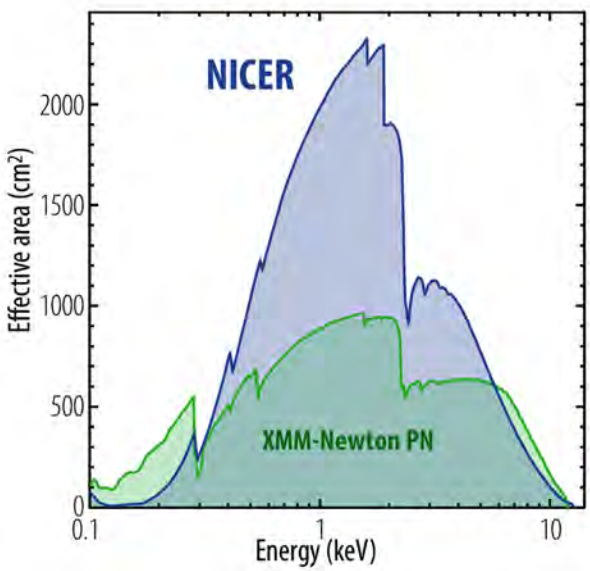
anywhere. The nature of matter under these conditions is a decades-old unsolved problem, one most directly addressed with measurements of the masses and, especially, radii of neutron stars to high precision (i.e., better than 10 percent uncertainty). With few such constraints forthcoming from observations, theory has advanced a host of models to describe the physics governing neutron star interiors.

By answering a long-standing astrophysics question—How big is a neutron star?—NICER will confront nuclear physics theory with unique measurements, exploring the exotic states of matter within neutron stars through rotation-resolved X-ray spectroscopy. The capabilities that NICER brings to this investigation are unique: simultaneous fast timing and spectroscopy, with low background and high throughput. These capabilities will also enable NICER to:

- Probe the dynamic processes associated with neutron stars
- Establish the sites and mechanisms of radiation in their extreme magnetospheres, and
- Definitively measure the stability of neutron stars as clocks, with implications for gravitational-wave detection, timekeeping, and spacecraft navigation.

Through synergies with radio and gamma-ray investigations, NICER will enable a vital multiwavelength approach to neutron star studies. NICER will also provide continuity in X-ray-timing astrophysics post-Rossi X-ray Timing Explorer (RXTE), a rapid response capability for study of the transient sky, and new discovery space in soft-X-ray timing science. NICER achieves these goals by deploying its X-ray Timing Instrument (XTI) as an attached payload on a zenith-side ExPRESS Logistics Carrier (ELC) aboard the International Space Station (ISS).

The XTI represents an innovative configuration of high-heritage components. The heart of the instrument is an aligned collection of 56 X-ray "concentrator" optics (XRC) and silicon drift detector (SDD) pairs. Each XRC collects X-rays over a large geometric area from a 25 arcmin2 region of the sky and focuses them onto a small SDD. The SDD detects in-



NICER has twice the effective area and four times the sensitivity of the European Space Agency's XMM-Newton, and 25 times the time-tagging resolution of RXTE.

dividual photons, recording their energies with good (approximately 3 percent) spectral resolution and their detection times to an unprecedented 100 nanoseconds RMS relative to Universal Time. Together, this assemblage provides a high signal-to-noise-ratio photon-counting capability within the 0.2–12 keV X-ray band, perfectly matched to the typical spectra of neutron stars as well as a broad collection of other astrophysical sources.

From NICER's ELC platform, a star-tracker–based pointing system allows the XTI to point to and track neutron stars and other celestial targets over virtually a full hemisphere. The pointing system design accommodates the ISS vibration and contamination environments, and enables (together with NICER's GPS-based absolute timing) high-precision pulsar light-curve measurements through ultra-deep exposures spanning the 18-month mission lifetime. Anticipated launch of NICER is in late 2016, and additional information is available via the HEASARC (http://heasarc.gsfc.nasa.gov/docs/nicer).

NICER was first proposed in February 2011 and selected into Phase A in September 2011. A detailed 11-month engineering study to demonstrate the mission's feasibility and technical readiness culminated with the submission, in September 2012, of a 1,000-plus page Concept Study Report to the NASA Explorers program. The NICER team—a close-knit collaboration between ASD and GSFC's Advanced Engineering and Technology Directorate—then began preparations for a site visit by the Explorer review panel, to be held Jan. 29, 2013, at Goddard. A selection decision is expected in the spring of 2013.

ASD members of the NICER science team are Zaven Arzoumanian (Deputy PI), Lorella Angelini, Alice Harding, Michael Loewenstein, Craig Markwardt, Takashi Okajima, Peter Serlemitsos, Yang Soong, Tod Strohmayer, and Stephen Drake. The mission team includes MIT (detectors) and commercial partners providing flight hardware; the Naval Research Laboratory and universities across the U.S., as well as in Canada and Mexico, are providing additional science expertise.

Space-based Gravitational-Wave Observatory (SGO) and New Gravitational-Wave Observatory (NGO)

For more than a decade, the Laser Interferometer Space Antenna (LISA) has been the preferred mission concept for carrying out gravitational wave observations from space. Although LISA was highly ranked for its compelling science in several reviews by the National Academy of Sciences, most recently in *New Worlds, New Horizons*, the Astro2010 Decadal Survey, funding constraints have forced the two agencies to end the partnership and identify new mission concepts compatible with their respective programmatic constraints. In the U.S., the class of missions under study is referred to as Space-based Gravitational-wave Observatory (SGO). In Europe, it is New Gravitational-wave Observatory (NGO) or enhanced LISA (eLISA)

During 2012, the SGO study team concluded a mission-concept study initiated in 2011 to explore lower-cost options and issued a final report. The study explored alternate architectures to establish how science performance varied with cost and began with a Request for Information and the formation of a Community Science Team. The final report (available for download from http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php) concluded that there is no mission concept with compelling science at, or below, $1B, although it may be possible for NASA to partner with ESA at the Probe Class mission level or below. Four representative mission concepts were analyzed in detail for cost, risk, and science. Table 1 summarizes the results.

ESA concluded their study of NGO, a LISA-like design for the first large (L1) mission opportunity under the Cosmic Vision Programme. NGO differs from LISA in that there are two, rather than three, interferometer arms, and the arms are 1 rather than 5 million kilometers long. NGO would launch on two Soyuz spacecraft. The final report, or Yellow Book, is avail-

A summary of U.S. study of four representative SGO mission concepts comparing science, risk, and cost.

Massive Black Hole Binaries					
Total detected	108–220	41–52	37–45	21–32	21–32
Detected at $z \geq 10$	3–57	1–4	1–5	1–6	1–6
Both mass errors ≤ 1%	67–171	18–42	8–25	11–26	11–26
One spin error ≤ 1%	49–130	11–27	3–11	7–18	7–18
Both spin errors ≤ 1%	1–17	<1	0	<1	<1
Distance error ≤ 3%	81–108	12–22	2–6	10–17	10–17
Sky location ≤ 1 deg^2	71–112	14–21	2–4	15–18	15–18
Sky location ≤ 0.1 deg^2	22–51	4–8	≤ 1	5–8	5–8
Total EMRIs detected†	800	~35	~20	~15	~15
WD binaries detected (resolved)	4×10^4	7×10^3	5×10^3	5×10^3	5×10^3
WD binaries with 3D location	8×10^3	8×10^2	3×10^2	1.5×10^2	1.5×10^2
Stochastic Background Sensititvity (rel. to LISA)	1.0	0.2	0.15*	0.25	0.25
Top Team X Risk	Moderate‡	Low	Moderate	Moderate	High
Top Team X + Core Team Risk	Moderate‡	Low	High	High	High
Team X Cost Estimate (FY 12$)	2.1B	1.9B	1.6B	1.4B	1.2B

† Based on median rate: estimates for EMRI rates vary by as much as an order of magnitude in each direction.

* Two-arm instruments such as LAGRANGE/McKenzie lack the "GW null" channel that can be used to distinguish between stochastic backgrounds & instrumental noise, making such measurements more challenging.

‡ The moderate risk for SGO High comes about from the thruster development necessary to demonstrate the required lifetime of 5 years for science operations.

able for download from http://sci2.esa.int/cosmic-vision/NGO_YB.pdf.

In April 2012 ESA selected the JUpiter ICy moons Explorer (JUICE) mission for the L1 opportunity. The European gravitational wave community has responded by organizing a consortium and adopting the name eLISA (enhanced LISA) to prepare for the next opportunity, which is an L2 mission. The L2 call for proposals is expected to be announced in February 2013 with a selection in late 2013. The call is expected to be a "cornerstone" call, that is, for science themes with example mission concepts.

To prepare for the possible selection of gravitational waves as the theme by ESA, NASA is writing a technology development plan to outline a strategy to have several candidate technologies available at the TRL 5 level by 2015. The candidate technologies are micro-newton thrusters, a laser system, and a telescope. The development of a telescope, led by J. Livas, has been funded for two years through the Strategic Astrophysics Technology (SAT) program.

J. I. Thorpe has continued to support the LISA Pathfinder (LPF) mission, currently expected to launch in 2015. LPF consists of an ESA payload called the LISA Test Package (LTP) and a NASA payload called the ST7 Disturbance Reduction System. Thorpe was awarded an IRAD along with P. Maghami (Attitude Control Systems Engineering Branch) and J. Baker to conduct four specific investigations to study the possibility of combining LTP interferometer data with ST-7 capacitive-sensing data to improve the baseline noise performance. The team is also planning an ST-7 drift-mode experiment to study the noise added by the electrostatic suspension, and to study potential applications of the LPF mission to fundamental physics experiments in an extended mission phase.

2012 Education and Public Outreach Highlights of NASA's Astrophysics Science Division

2012 has been a year of challenges for ASD's E/PO team, but also one of many successes. Like many other programs and projects, this year we were faced with budget reductions that required some staffing changes and reassessment of our programs, but we have a strong team doing great work, so we expect the new year to bring even more success for our team, and therefore for the Division. We have extensive E/PO projects that align with the Physics of the Cosmos (PCOS) and Cosmic Origins (COR) program offices, and our team also supports NASA astrophysics missions, including Astro-H, JWST, Suzaku, and HEASARC; as well as preliminary E/PO programs for missions in development.

This year Dr. Amber Straughn of the Observational Cosmology Laboratory has been the civil servant Lead for the team, Dr. Koji Mukai (CRESST/USRA) the Acting Lead and Missions and Grants Lead, and Dr. Barbara Mattson (CRESST/USRA) the PCOS/COR Lead. Dr. Jim Lochner, who was the E/PO Lead prior to his two-year detail to HQ, has accepted a position with USRA as Director of University Communications and Engagement. He will also be working with the USRA Vice President for Government Relations, interfacing with staffers on the Hill. Our team is very happy for Jim in this exciting new opportunity, but will miss the excitement and enthusiasm he brought to our team. We wish him the best in his new position.

Our team has accomplished much in the past year; here we present some of the highlights.

PCOS/COR EPO

This was an exciting year for the PCOS/COR E/PO program, under the leadership of Barbara Mattson. As the first fully-funded year of PCOS/COR E/PO, this year was one full of building foundations for our new initiatives and new growth for our established programs.

Space Forensics

The year marked the kickoff of the Space Forensics project as a cornerstone element of the PCOS/COR E/PO program, led by Sara Mitchell. This project presents astronomical mysteries in the style of crime-solving narratives and activities for each "case." Earlier this year, brainstorming sessions with ASD scientists and E/PO personnel created a list of dozens of prospective case concepts. Through focus groups conducted in conjunction with an external evaluator, the

Space Forensics team whittled this down to four case topics that will be developed during FY12 and FY13: supernovae, black holes, gamma-ray bursts, and gravitational waves. Work is currently under way on the development of the first topic ("The Case of the Exploding Star"), with a professional science writer preparing a mystery-style narrative to frame classroom activities about supernovae. A PCOS/COR undergraduate summer intern performed a literature review and created a database of NASA E/PO activities about these topics, to leverage existing, evaluated content as much as possible. The project's external evaluator is developing tools and methodologies for assessing the pilot implementation of this case in early 2013. Over the course of the year, the Space Forensics team presented the project to educators visiting Goddard as well as at nationwide conferences such as the National Science Teachers Association and the 21st Century Community Learning Centers Summer Institute. They also presented a poster to E/PO peers at the Astronomical Society of the Pacific conference.

Blueshift

(http://universe.nasa.gov/blueshift/)

NASA Blueshift (team members Sara Mitchell and Maggie Masetti) celebrated its fifth anniversary this year as the Division's social media and new media presence. The Blueshift team releases 8–10 blog posts per month on their website, providing a "backstage pass" to the missions, personnel, and discoveries

within the Division. They also highlight connections between ASD science and pop culture. In addition to blogs, this year saw the return of regular Blueshift podcasts, including episodes interviewing Dr. Dan Wik about NuSTAR, Dr. Amber Straughn about galaxies and JWST, "The Big Bang Theory" science advisor (and former Goddard intern) Dr. David Saltzberg about astrophysics in pop culture, and "Bad Astronomer" Dr. Phil Plait about skeptical thinking and public engagement in science. Blueshift also connects with the public through Twitter and Facebook, and these platforms have shown steady growth in followers and engagement. Over the course of 2012, audiences on both sites have nearly doubled.

Big Explosions & Strong Gravity

(http://bigexplosions.gsfc.nasa.gov/)

Big Explosions and Strong Gravity (BESG) is a highly successful outreach program begun in 2004 in cooperation with the Girl Scouts of Central Maryland and led by Sarah Eyermann. In a one-day event, girls explore the science behind supernovae and black holes with hands-on activities tailored to the middle school level. Whenever possible, professional scientists, engineers, postdocs, and graduate students assist with these activities, giving the girls a chance to interact with professionals in science and technology fields. Though BESG was initially created for Girl Scouts, the individual activities are appropriate for a much broader audience. The program resources are currently being expanded to be useful to a wider variety of out-of-school settings and groups under Physics of the Cosmos/Cosmic Origins umbrella. In 2012, an initial list was generated of possible target groups for this expansion, and research into the needs of those groups has been started. In addition, the BESG team presented posters and workshops about the program and its expansion at four different conferences around the country.

Astrophysics Missions E/PO

Suzaku & Astro-H

This year, Suzaku E/PO prepared to close out as Astro-H E/PO began, both programs led by Barbara Mattson. To provide continuity from one mission to another, Barbara created a new public website, titled "Collaboration Across Cultures," to combine the educational pages from NASA/JAXA collaborations in X-ray astronomy. The collaboration site consists of pages ported from the original Suzaku Learning Center website along with new pages written to highlight Astro-H, ASCA, and Ginga.

Mattson also finished the development of the Suzaku-funded Science in the Media curriculum module. The Science in the Media module leads high school students through an exploration of a new scientific discovery as it goes from the scientist to the media. This module was submitted, and passed, NASA's education product review this year, and will be unveiled with a press feature in early 2013.

JWST

JWST E/PO and Communications is a partnership between Goddard and the Space Telescope Science Institute, as well as other contractor collaborations. This has been a very active and successful year for JWST; here we present some of the highlights. STScI is leading the JWST "STEM Innovation Project," which is an interdisciplinary approach that focuses on the engineering aspects of JWST as well as future potential scientific discoveries through project-based learning. This project is currently being piloted in several states.

JWST social media (led by Maggie Masetti) grew a great deal in 2012. We started the year with just over 19,000 Twitter followers and more than doubled that number, with over 40,000 followers currently. On Facebook, we started 2012 with just over 24,000 followers and have more than doubled this number as well, with over 50,000. We have had over 132,000 views of our YouTube videos and more than 160,000 views of our images on Flickr in 2012. We've held two tweetchats during which John Mather answered questions about JWST science, and also held a Reddit "Ask Me Anything," also with Mather, where he took questions from people in the online Reddit community. This resulted in well over 600 comments on the AMA thread, and it reached the #1 spot on Reddit's "Top" page the day after the event. These online chats have been archived on www.jwst.nasa.gov.

In other JWST Outreach and Communications news, the team averaged ~4 Press Releases and Features per month, produced numerous Webb Snapshot and Behind the Webb videos, supported numerous outreach events such as the Shuttle Celebration at the Intrepid Museum in New York City and the USA Science and Engineering Festival as well as local events at the GSFC Visitor's Center, and hosted several film crews at GSFC for different local, national, and international television programs. JWST partnered again in 2012 with the RealWorld InWorld Engineering Design Challenge, in which student teams compete in both a classroom and virtual world setting, and have

online interactions with NASA scientists and engineers.

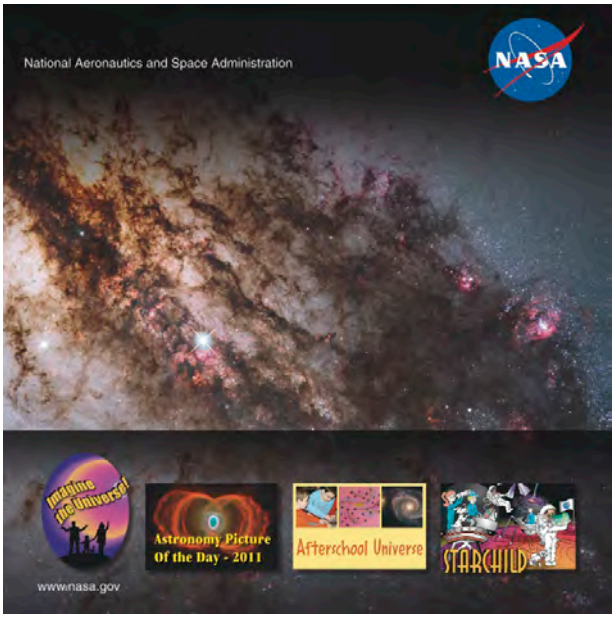
HEASARC

The HEASARC E/PO program continues to fulfill its mission of bringing high-energy astronomy and cosmology to teachers and their students. Dr. Barbara Mattson (CRESST/USRA) leads the E/PO program.

As part of an Education and Public Outreach for Earth and Space Sciences (EPOESS) grant, Mattson, with the assistance of Meredith Gibb (Syneren Technologies), produced in 2012 the 16th edition of the Imagine the Universe! DVD-ROM, featuring the websites for Imagine and StarChild as well as the 2011 collection of Astronomy Pictures of the Day. The guest website on the 16th edition DVD was Afterschool Universe, an ASD E/PO initiative aimed at providers of afterschool programs.

In addition, Mattson worked with our evaluator, Dr. Allyson Walker (Cornerstone Evaluation Associates), to develop two surveys to determine the utility of continuing the production of the annual Imagine! DVD. The first survey probed how requesters of the 15th edition use the DVD. The critical question in this first survey probed users to find if there was anything they currently did that they would not be able to do if the DVD was no longer produced—half of those who answered the survey said there was something they would not be able to do. Further analysis showed that those who would miss the annual DVD used the DVD in more ways and with more audiences than those who would not miss the DVD. This second survey sought to determine how users value the Imagine! DVD as compared to the Imagine! website. Responses were solicited from subscribers of the Imagine the Universe! News mailing list and Imagine! DVD requesters from the past five years. This second survey found that there is still a number of Imagine! users who value the DVD, despite the same information being available on the Internet; frequently these users are those without reliable Internet connections for their educational activities. The E/PO team is reviewing the results of both surveys to determine the future of the Imagine! DVD.

The HEASARC E/PO team, through George Gliba (Syneren Technologies) continued to fulfill requests for our educational materials from educators across the country. These orders for materials came through the Imagine the Universe! site order form and through a partnership with the Night Sky Network, a nationwide coalition of amateur astronomy clubs bringing the science, technology, and inspiration of NASA's missions to the general public. Gliba filled over 900 requests during 2012. By far, the most requested item



is the Imagine the Universe! DVDs, with over 7,000 sent out to educators, NASA educator ambassadors, workshop providers, and amateur astronomers. During this time, Gliba also distributed over 600 educational posters and associated booklets (when available).

Updates to the Imagine the Universe! web pages continued throughout 2012. Most notably, Mattson and freelance writer Kate Carroll (USRA) created a special exhibit on the Imagine! site celebrating the 50th anniversary of cosmic X-ray astronomy. For this series of articles, Carroll interviewed current and former ASD scientists (Drs. Peter Serlemitsos, Kimberly Weaver, Koji Mukai, Katja Pottschmidt (UMBC), Joe Hill, and Richard Mushotzky(UMCP)) to get their perspectives on the past, present and future of cosmic X-ray astronomy.

Grants and External Collaborations

Family Science Night

(http://sdo.gsfc.nasa.gov/epo/families/fsn.php)

The NASA Family Science Night (FSN) program is a joint endeavor between the Astrophysics and Heliophysics Science Divisions at Goddard, which began in 2006. The project taps into the immense influence that parents and families have on children's interest

FAMILY SCIENCE NIGHT

and engagement in science, encouraging families to explore science activities together in a comfortable learning environment. The FSN program currently offers a portfolio of nine evaluated sessions about a variety of topics in astronomy, with a network of dozens of implementation sites around the country. Through a supplemental E/PO grant from PI Dr. Aki Roberge, the FSN team has expanded the program's portfolio in 2012 to include new content about extrasolar planets and astrobiology. The sessions developed under this grant have been pilot tested at Goddard and are currently undergoing refinement before further release.

Afterschool Universe

(http://universe.nasa.gov/au/)

Afterschool Universe

Afterschool Universe (AU) is a curriculum developed for use with middle-school-aged children in afterschool programs, summer camps, and other out-of-school-time venues. It explores basic astronomy concepts through engaging activities, with a focus on the Universe outside the solar system, introducing topics of great interest not typically studied in school. Developed by the Astrophysics Science Division at NASA's Goddard Space Flight Center, AU was successfully pilot tested in 2006 and 2007, and has since been implemented around the country (and in a few others). For the past 3 years, and EPOESS grant has funded the continued expansion of the AU program through a train-the-trainer initiative. 2012 was the final year of this effort. The networks and ambassadors that had been trained by the AU team continued running their own trainings, and submitted their evaluation data to an external evaluator. The collected data was analyzed, and has been compiled into a final evaluation report.

Astro4Girls

In 2012, the ASD EPO team participated in a NASA-funded astrophysics forum collaboration called "Astro4Girls and Their Families." This pilot program offered a variety of informal science events at nine public libraries nationwide during Women's History Month (March) 2012. The goals were to engage girls and their families to discover the Universe for themselves, and celebrate the contribution of women to astronomy and science. The team partnered with the Varnum Memorial Library in Jeffersonville, VT, and provided them with resources about the electromagnetic spectrum and spectroscopy. They ran an event with 4th and 6th graders during the first week in May, using activities drawn from Afterschool Universe, Big Explosions & Strong Gravity, and Family Science Night.

ASD Press and Communications

One of the primary means by which ASD science news is communicated to the general public is through press releases and web features. Francis Reddy (Syneren Technologies) fills this crucial role for the Division, and was recognized this year by a Peer Award. In 2012 numerous press releases and features on Fermi, Swift, and other Division mission and science news were issued, many accompanied with videos, which dramatically furthered the reach and impact. This partnership with NASA TV has resulted in very successful visualizations which are accessed via the Goddard SVS server, YouTube, and the very popular NASAViz iPad app. Many of the most popular videos featured on NASA.gov have been astrophysics-themed. In addition to the ASD-specific releases, we also partner with Headquarters for releases as well.

2012 Publications

The characterization of Virgo data and its impact on gravitational-wave searches. Aasi, J., Abadie, J., Abbott, B. P., et al. 2012 *Class. Quantum Gravity* 29, 155002, doi:10.1088/0264-9381/29/15/155002

Search for gravitational waves associated with gamma-ray bursts during LIGO Science Run 6 and Virgo Science Runs 2 and 3. Abadie, J., Abbott, B. P., Abbott, R. et al. 2012 *Astrophys. J.* 760, 12, doi:10.1088/0004-637X/760/1/12

Search for gravitational waves from intermediate mass binary black holes. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 102004, doi:10.1103/PhysRevD.85.102004

First low-latency LIGO+Virgo search for binary in spirals and their electromagnetic counterparts. Abadie, J., Abbott, B. P., Abbott, R. et al. 2012 *Astron. Astrophys.* 2012 541, A155, doi:10.1051/0004-6361/201218860

All-sky search for gravitational-wave bursts in the second joint LIGO-Virgo run. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 122007, doi:10.1103/PhysRevD.85.122007

Upper limits on a stochastic gravitational-wave background using LIGO and Virgo interferometers at 600–1000 Hz. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 122001, doi:10.1103/PhysRevD.85.122001

Search for gravitational waves from low mass compact binary coalescence in LIGO's sixth science run and Virgo's science runs 2 and 3. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 82002, doi:10.1103/PhysRevD.85.082002

All-sky search for periodic gravitational waves in the full S5 LIGO data. Abadie, J., Abbott, B. P., Abbott, R. et al. 2012 *Phys. Rev. D* 85, 22001, doi:10.1103/PhysRevD.85.022001

Implementation and testing of the first prompt search for gravitational wave transients with electromagnetic counterparts . Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Astron. Astrophys.* 539, A124, doi:10.1051/0004-6361/201118219

Erratum: Search for gravitational waves from binary black hole inspiral, merger, and ringdown [*Phys. Rev. D* 83, 122005 (2011)]. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 89904, doi:10.1103/PhysRevD.86.069903

Publisher's note: Search for gravitational waves from compact binary coalescence in LIGO and Virgo data from S5 and VSR1 [*Phys. Rev. D* 82, 102001(2010)]. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 89903, doi:10.1103/PhysRevD.85.089903

Publisher's note: All-sky search for gravitational-wave bursts in the first joint LIGO-GEO-Virgo run [*Phys. Rev. D* 81, 102001 (2010)]. Abadie, J., Abbott, B. P., Abbott, R., et al. *Phys. Rev. D* 85, 89905, doi:10.1103/PhysRevD.85.089905

Publisher's note: Search for gravitational waves associated with the August 2006 timing glitch of the Vela pulsar [*Phys. Rev. D* 83, 042001 (2011)]. Abadie, J., Abbott, B. P., Abbott, R., et al. 2012 *Phys. Rev. D* 85, 89902, doi:10.1103/PhysRevD.85.089902

Implications for the origin of GRB 051103 from LIGO observations. Abadie, J., Abbott, B. P., Abbott, T. D., et al. 2012 *Astrophys. J.* 755, 2, doi:10.1088/0004-637X/755/1/2

Model independent search for new phenomena in pp^- collisions at $\sqrt{s}$=1.96TeV. Abazov, V. M., Abbott, B., Acharya, B. S., et al. 2012 *Phys. Rev. D* 85, 92015, doi:10.1103/PhysRevD.85.092015

Observation of anisotropy in the Galactic cosmic-ray arrival directions at 400 TeV with IceCube. Abbasi, R., Abdou, Y., Abu-Zayyad, T., et al. *Astrophys. J.* 746, 33, doi:10.1088/0004-637X/746/1/33

The design and performance of IceCube DeepCore. Abbasi, R., Abdou, Y., Abu-Zayyad, T., et al. 2012 *Astropart. Phys.* 35, 615, doi:10.1016/j.astropartphys.2012.01.004

Multiyear search for dark matter annihilations in the Sun with the AMANDA-II and IceCube detectors. Abbasi, R., Abdou, Y., Abu-Zayyad, T., et al. 2012 *Phys. Rev. D* 85, 42002, doi:10.1103/PhysRevD.85.042002

Neutrino analysis of the 2010 September Crab Nebula flare and time-integrated constraints on neutrino emission from the Crab using IceCube. Abbasi, R., Abdou, Y., Abu-Zayyad, T., et al. 2012 *Astrophys. J.* 745, 45, doi:10.1088/0004-637X/745/1/45

Time-dependent searches for point sources of neutrinos with the 40-string and 22-string configurations of IceCube. Abbasi, R., Abdou, Y., Abu-Zayyad, T., et al. 2012 *Astrophys. J.* 744, 1, doi:10.1088/0004-637X/744/1/1

Background studies for acoustic neutrino detection at the South Pole. Abbasi, R., Abdou, Y., Abu-Zayyad, T., et al. 2012 *Astropart. Phys.* 35, 312, doi:10.1016/j.astropartphys.2011.09.004

Constraints on the emission model of the "Naked-eye Burst" GRB 080319B. Abdo, A. A., Abeysekara, A. U., Allen, B. T., et al. *Astrophys. J.* Lett. 753, L31, doi:10.1088/2041-8205/753/2/L31

Spectrum and morphology of the two brightest Milagro sources in the Cygnus region: MGRO J2019+37 and MGRO J2031+41. Abdo, A. A., Abeysekara, U., Allen, B. T., et al. 2012 *Astrophys. J.* 753, 159, doi:10.1088/0004-637X/753/2/159

Fermi observations of γ-ray emission from the Moon. Abdo, A. A., Ackermann, M., Ajello, M., et al. 2012 *Astrophys. J.* 758, 140, doi:10.1088/0004-637X/758/2/140

Observation and spectral measurements of the Crab Nebula with Milagro. Abdo, A. A., Allen, B. T., Atkins, R., et al. 2012 *Astrophys. J.* 750, 63, doi:10.1088/0004-637X/750/1/63

PSR J0007+7303 in the CTA1 supernova remnant: New gamma-ray results from two years of Fermi Large Area Telescope observations. Abdo, A. A., Wood, K. S., DeCesar, M. E., et al. 2012 *Astrophys. J.* 744, 146, doi:10.1088/0004-637X/744/2/146

Search for antihelium with the BESS-Polar spectrometer. Abe, K., Fuke, H., Haino, S., et al. *Phys. Rev. Lett.* 108, 131301, doi:10.1103/PhysRevLett.108.131301

Measurement of the cosmic-ray antiproton spectrum at solar minimum with a long-duration balloon flight over Antarctica. Abe, K., Fuke, H., Haino, S. et al. 2012 *Phys. Rev. Lett.,* 108, 51102, doi:10.1103/PhysRev-Lett.108.051102

On the sensitivity of the HAWC observatory to gamma-ray bursts. Abeysekara, A. U., Aguilar, J. A., Aguilar, S., et al. 2012 *Astropart. Phys.* 35, 641, doi:10.1016/j.astropartphys.2012.02.001

The 2010 very high energy γ-ray flare and 10 years of multi-wavelength observations of M87. Abramowski, A., Acero, F., Aharonian, F., et al. 2012 *Astrophys. J.* 746, 151, doi:10.1088/0004-637X/746/2/151

Search for dark matter annihilation signals from the Fornax Galaxy Cluster with H.E.S.S. Abramowski, A., Acero, F., Aharonian, F., et al. 2012 *Astrophys. J.* 750, 123, doi:10.1088/0004-637X/750/2/123

Spectral analysis and interpretation of the γ-ray emission from the starburst galaxy NGC 253. Abramowski, A., Acero, F., Aharonian, F., et al. 2012 *Astrophys. J.* 757, 158, doi:10.1088/0004-637X/757/2/158

Discovery of gamma-ray emission from the extragalactic pulsar wind nebula N157B with H.E.S.S. Abramowski, A., Acero, F., Aharonian, F., et al. *Astron. Astrophys.* 545, L2, doi:10.1051/0004-6361/201219906

Discovery of hard-spectrum γ-ray emission from the BL Lacertae object 1ES0414+009. Abramowski, A., Acero, F., Aharonian, F., et al. *Astron. Astrophys.* 538, A103, doi:10.1051/0004-6361/201118406

Discovery of VHE and gamma-ray emission and multi-wavelength observations of the BL Lacertae object 1RXS J101015.9-311909. Abramowski, A., Acero, F., Aharonian, F., et al. *Astron. Astrophys.* 542, A94, doi:10.1051/0004-6361/201218910

Constraints on the gamma-ray emission from the cluster-scale AGN outburst in the Hydra A galaxy cluster. Abramowski, A., Acero, F., Aharonian, F., et al. *Astron. Astrophys.* 545, A103, doi:10.1051/0004-6361/201219655

HESS observations of the Carina Nebula and its enigmatic colliding wind binary Eta Carinae. Abramowski, A., Acero, F., Aharonian, F., et al. *Mon. Not. R. Astron. Soc.* 424, 128, doi:10.1111/j.1365-2966.2012.21180.x

Search for gamma-ray emission from X-ray-selected Seyfert galaxies with Fermi-LAT. Ackermann, M., Abel, M., Allafort, A., et al. 2012 *Astrophys. J.* 747, 104, doi:10.1088/0004-637X/747/2/104

The Fermi Large Area Telescope on orbit: Event classification, instrument response functions, and calibration. Ackermann, M., Ajello, M., Albert, A., et al. 2012 *Astrophys. J. Suppl.* 203, 4, doi:10.1088/0067-0049/203/1/4

Anisotropies in the diffuse gamma-ray background measured by the Fermi LAT. Ackermann, M., Ajello, M., Albert, A., et al. *Phys. Rev. D* 85, 83007, doi:10.1103/PhysRevD.85.083007

Publisher's note: Anisotropies in the diffuse gamma-ray background measured by the Fermi LAT [*Phys. Rev. D* 85, 083007 (2012)]. Ackermann, M., Ajello, M., Albert, A., et al. *Phys. Rev. D* 85, 109901, doi:10.1103/PhysRevD.85.109901

Fermi LAT search for dark matter in gamma-ray lines and the inclusive photon spectrum. Ackermann, M., Ajello, M., Albert, A., et al. *Phys. Rev. D* 86, 22002, doi:10.1103/PhysRevD.86.022002

Gamma-ray observations of the Orion molecular clouds with the Fermi Large Area Telescope. Ackermann, M., Ajello, M., Allafort, A., et al. *Astrophys. J.* 756 4, doi:10.1088/0004-637X/756/1/4

A statistical approach to recognizing source classes for unassociated sources in the first Fermi-LAT catalog. Ackermann, M., Ajello, M., Allafort, A., et al. *Astrophys. J.* 753, 83, doi:10.1088/0004-637X/753/1/83

In-flight measurement of the absolute energy scale of the Fermi Large Area Telescope. Ackermann, M., Ajello, M., Allafort, A., et al. *Astropart. Phys.* 35, 346, 10.1016/j.astropartphys.2011.10.007

Measurement of separate cosmic-ray electron and positron spectra with the Fermi Large Area Telescope. Ackermann, M., Ajello, M., Allafort, A., et al. *Phys. Rev. Lett.* 108, 11103, doi:10.1103/PhysRevLett.108.011103.

Fermi detection of γ-ray emission from the M2 soft X-ray flare on 2010 June 12. Ackermann, M., Ajello, M., Allafort, A., et al. *Astrophys. J.* 745, 144, doi:10.1088/0004-637X/745/2/144

Fermi Large Area Telescope study of cosmic rays and the interstellar medium in nearby molecular clouds. Ackermann, M., Ajello, M., Allafort, A., et al. *Astrophys. J.* 755, 22, doi:10.1088/0004-637X/755/1/22

The cosmic-ray and gas content of the Cygnus region as measured in γ-rays by the Fermi Large Area Telescope. Ackermann, M., Ajello, M., Allafort, A., et al. *Astron. Astrophys.* 538, A71, doi:10.1051/0004-6361/201117539

GeV observations of star-forming galaxies with the Fermi Large Area Telescope. Ackermann, M., Ajello, M., Allafort, A., et al. *Astrophys. J.* 755, 164, doi:10.1088/0004-637X/755/2/164

Fermi-LAT observations of the diffuse γ-ray emission: Implications for cosmic rays and the interstellar medium. Ackermann, M., Ajello, M., Atwood, W. B., et al. *Astrophys. J.* 750, 3, doi:10.1088/0004-637X/750/1/3

Constraints on the Galactic halo dark matter from Fermi-LAT diffuse measurements. Ackermann, M., Ajello, M., Atwood, W. B., et al. *Astrophys. J.* 761, 91, doi:10.1088/0004-637X/761/2/91

Multi-wavelength observations of blazar AO 0235+164 in the 2008–2009 flaring state. Ackermann, M., Ajello, M., Ballet, J., et al. *Astrophys. J.* 751, 159, doi:10.1088/0004-637X/751/2/159

Search for dark matter satellites using Fermi-LAT. Ackermann, M., Albert, A., Baldini, L., et al. *Astrophys. J.* 747, 121 doi:10.1088/0004-637X/747/2/121

Periodic emission from the gamma-ray binary 1FGL J1018.6-5856. Ackermann, M., Ajello, M., Ballet, J., et al. *Science* 335, 189, doi:10.1126/science.1213974

Wavefront sensing and controls for the James Webb Space Telescope. Acton, D. Scott, Knight, J. Scott, Contos, A., et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84422H, doi:10.1117/12.925015

Chandra grating spectroscopy of three hot white dwarfs. Adamczak, J., Werner, K., Rauch, T., et al. *Astron. Astrophys.* 546, A1, doi:10.1051/0004-6361/201219718

Power-law template for infrared point-source clustering. Addison, Graeme E., Dunkley, Joanna, Hajian, Amir, et al. *Astrophys. J.* 752, 120, doi:10.1088/0004-637X/752/2/120

Fermi Large Area Telescope observations of the supernova remnant G8.7-0.1. Ajello, M., Allafort, A., Baldini, L., et al. *Astrophys. J.* 744, 80, doi:10.1088/0004-637X/744/1/80

Limits on large extra dimensions based on observations of neutron stars with the Fermi-LAT. Ajello, M., Baldini, L., Barbiellini, G., et al. *J. Cosmo. Astropart. Phys.* 2,12, doi:10.1088/1475-7516/2012/02/012

A search for active galactic nuclei in the most extreme UV-selected starbursts using the European VLBI Network. Alexandroff, R., Overzier, R. A., Paragi, Z., et al. *Mon. Not. R. Astron. Soc.* 423, 1325, doi:10.1111/j.1365-2966.2012.20959.x

Discovery of high-energy and very high energy γ-ray emission from the blazar RBS 0413. Aliu, E., Archambault, S., Arlen, T., et al. *Astrophys. J.* 750, 94, doi:10.1088/0004-637X/750/2/94

VERITAS observations of six bright, hard-spectrum Fermi-LAT blazars. Aliu, E., Archambault, S., Arlen, T., et al. *Astrophys. J.* 759, 102, doi:10.1088/0004-637X/759/2/102

Multiwavelength Observations of the AGN 1ES 0414+009 with VERITAS, Fermi-LAT, Swift-XRT, and MDM. Aliu, E., Archambault, S., Arlen, T., et al. *Astrophys. J.* 755, 118, doi:10.1088/0004-637X/755/2/118

VERITAS deep observations of the dwarf spheroidal galaxy Segue 1. Aliu, E., Archambault, S., Arlen, T., et al. *Phys. Rev. D* 85, 62001, doi:10.1103/PhysRevD.85.062001

VERITAS observations of the nova in V407 Cygni. Aliu, E., Archambault, S., Arlen, T., et al. *Astrophys. J.* 754, 77, doi:10.1088/0004-637X/754/1/77

Search for a correlation between very-high-energy gamma rays and giant radio pulses in the Crab pulsar. Aliu, E., Archambault, S., Arlen, T., et al. *Astrophys. J.* 760, 136, doi:10.1088/0004-637X/760/2/136

VERITAS Observations of Day-scale Flaring of M 87 in 2010 April. Aliu, E., Arlen, T., Aune, T., et al. *Astrophys. J.* 746, 141, doi:10.1088/0004-637X/746/2/141

Low-frequency (11 mHz) oscillations in H1743-322: A new class of black hole quasi-periodic oscillations? Altamirano, D. and Strohmayer, T. *Astrophys. J.* 754, L23, doi:10.1088/2041-8205/754/2/L23 Aug 2012

Low-frequency gravitational-wave science with eLISA/NGO. Amaro-Seoane, Pau, Aoudia, Sofiane, Babak, Stanislav, et al. *Class. Quantum Gravity* 29, 124016, doi:10.1088/0264-9381/29/12/124016

Constraints on cosmic rays, magnetic fields, and dark matter from gamma-ray observations of the Coma cluster of galaxies with VERITAS and Fermi. Arlen, T., Aune, T., Beilicke, M., et al. *Astrophys. J.* 757, 123, doi:10.1088/0004-637X/757/2/123

Current status of ASTRO-H Hard X-ray Telescopes (HXTs). Awaki, Hisamitsu, Kunieda, Hideyo, Furuzawa, Akihiro, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray,* 844324, doi:10.1117/12.926753

GRB110721A: An extreme peak energy and signatures of the photosphere. Axelsson, M., Baldini, L., Barbiellini, G., et al. *Astrophys. J.* 757, L31, doi:10.1088/2041-8205/757/2/L31

Implications of weak link effects on thermal characteristics of transition-edge sensors. Bailey, C. N., Adams, J. S., Bandler, S. R., et al. *J. Low Temp. Phys.* 167, 121, doi:10.1007/s10909-012-0562-2

Development of a TES-Based anti-coincidence detector for future X-ray observatories. Bailey, C. N., Adams, J. S., Bandler, S. R., et al. *J. Low Temp. Phys.* 167, 236, doi:10.1007/s10909-012-0567-x

An analysis of the rapidly rotating Bp star HD 133880. Bailey, J. D., Grunhut, J., Shultz, M., et al. *Mon. Not. R. Astron. Soc.* 423, 328, doi:10.1111/j.1365-2966.2012.20881.x

Comparison of atom interferometers and light interferometers as space-based gravitational wave detectors. Baker, John G. and Thorpe, J. I. *Phys. Rev. Lett.* 108, 211101, doi:10.1103/PhysRevLett.108.211101

Development of full shell foil X-ray mirrors. Balsamo, Erin, Gendreau, Keith C., Arzoumanian, Zaven, et al. *Proc. SPIE 8450, Modern Technologies in Space- and Ground-based Telescopes and Instrumentation II*, 845052, doi:10.1117/12.926152

Suzaku observations of the non-thermal supernova remnant HESS J1731-347. Bamba, Aya, Pühlhofer, Gerd, Acero, Fabio, *Astrophys. J.* 756, 149, doi:10.1088/0004-637X/756/2/149

Magnetically coupled microcalorimeters. Bandler, S. R., Irwin, K. D., Kelly, D., et al. *J. Low Temp. Phys. 167*, 254, doi:10.1007/s10909-012-0544-4

Can the lateral proximity effect be used to create the superconducting transition of a micron-sized TES? Barrentine, E. M., Brandl, D. E., Brown, A. D., et al. *J. Low Temp. Phys.*167, 195, doi:10.1007/s10909-012-0578-7

A precise physical orbit for the M-dwarf binary Gliese 268. Barry, R. K., Demory, B.-O., Ségransan, D., *Astrophys. J.* 760, 55, doi:10.1088/0004-637X/760/1/55

The search for high-mass X-ray binaries in the Phoenix dwarf galaxy. Bartlett, E. S., Coe, M. J., Haberl, F., et al. *Mon. Not. R. Astron. Soc.* 422, 2302, doi:10.1111/j.1365-2966.2012.20791.x

IGR J12319-0749: Evidence for another extreme blazar found with INTEGRAL. Bassani, L., Landi, R., Marshall, F. E., *Astron. Astrophys.* 543, A1, doi:10.1051/0004-6361/201219243

GEMS X-ray polarimeter performance simulations. Baumgartner, Wayne H., Strohmayer, Tod, Kallman, Tim, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84434K, doi:10.1117/12.927270

Concepts for high-performance soft X-ray grating spectroscopy in a moderate-scale mission. Bautz, Marshall W., Cash, Webster C., Davis, John E., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844315, doi:10.1117/12.926810

The proper motion of the central compact object RX J0822-4300 in the supernova remnant Puppis A. Becker, Werner, Prinz, Tobias, Winkler, P. Frank, and Petre, Robert. *Astrophys. J.* 755, 141, doi:10.1088/0004-637X/755/2/141

What turns galaxies off? The different morphologies of star-forming and quiescent galaxies since z ~ 2 from CANDELS. Bell, Eric F., van der Wel, Arjen, Papovich, Casey, et al. *Astrophys. J.* 753, 167, doi:10.1088/0004-637X/753/2/167

Precision attitude control for the BETTII balloon-borne interferometer. Benford, Dominic J., Fixsen, Dale J., Rinehart, Stephen A., et al. *Proc. SPIE 8444, Ground-based and Airborne Telescopes IV*, 84442P, doi:10.1117/12.927224

Characterization of new hard X-ray cataclysmic variables. Bernardini, F., de Martino, D., Falanga, M., et al. *Astron. Astrophys.* 542, A22, doi:10.1051/0004-6361/201219233

An unexpectedly low oscillator strength as the origin of the Fe XVII emission problem. Bernitt, S., Brown, G. V., Rudolph, J. K., et al. *Nature* 492, 225, doi:10.1038/nature11627

The Milky Way tomography with Sloan Digital Sky Survey. IV. Dissecting dust. Berry, Michael, Ivezić, Željko, Sesar, Branimir, et al. *Astrophys. J.* 757, 166, doi:10.1088/0004-637X/757/2/166

Temporal deconvolution study of long and short gamma-ray burst light curves. Bhat, P. N., Briggs, Michael S., Connaughton, Valerie, et al. *Astrophys. J.* 744, 141, doi:10.1088/0004-637X/744/2/141

Precise alignment and permanent mounting of thin and lightweight X-ray segments. Biskach, Michael P., Chan, Kai-Wing, Hong, Melinda N., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84433Z, doi:10.1117/12.927279

High resolution rapid response observations of compact radio sources with the Ceduna Hobart Interferometer (CHI). Blanchard, J. M., Lovell, J. E. J., Ojha, R., et al. *Astron. Astrophys.* 538, A150, doi:10.1051/0004-6361/201117593

The Keck aperture masking experiment: Dust-enshrouded red giants. Blasius, T. D., Monnier, J. D., Tuthill, P. G., et al. *Mon. Not. R. Astron. Soc.* 426, 2652, doi:10.1111/j.1365-2966.2012.21543.x

SPICES: Spectro-polarimetric Imaging and Characterization of Exoplanetary Systems. From planetary disks to nearby super Earths. Boccaletti, Anthony, Schneider, Jean, Traub, Wes et al. *Exp. Astron.* 34, 355, doi:10.1007/s10686-012-9290-5

Demonstration of the wide-field imaging interferometer testbed using a calibrated hyperspectral image projector. Bolcar, Matthew R., Leisawitz, David, Maher, Stephen, and Rinehart, Stephen. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 84452D, doi:10.1117/12.926221

Approaches for achieving broadband achromatic phase shifts for visible nulling coronagraphy. Bolcar, Matthew R. and Lyon, Richard G. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 84452C, doi:10.1117/12.926237

The infrared properties of sources matched in the WISE all-sky and Herschel ATLAS surveys. Bond, Nicholas A., Benford, Dominic J., Gardner, Jonathan P., et al. *Astrophys. J. Lett.* 750, L18, doi:10.1088/2041-8205/750/1/L18

Evolution in the continuum morphological properties of Lyα-emitting galaxies from z = 3.1 to z = 2.1. Bond, Nicholas A., Gawiser, Eric, Guaita, Lucia, et al. *Astrophys. J.* 753, 95, doi:10.1088/0004-637X/753/2/95

The Advanced X-ray Spectroscopic Imaging Observatory (AXSIO). Bookbinder, Jay A., Smith, Randall K., Bandler, Simon, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844317, doi:10.1117/12.927309

Properties of Galactic early-type O-supergiants. A combined FUV-UV and optical analysis. Bouret, J.-C., Hillier, D. J., Lanz, T., and Fullerton, A. W. *Astron. Astrophys.* 544, A67, doi:10.1051/0004-6361/201118594

AXIOM: advanced X-ray imaging of the magnetosphere. Branduardi-Raymont, Graziella, Sembay, Steve F., Eastwood, Jonathan P., et al. *Exp. Astron.* 33, 403, doi:10.1007/s10686-011-9239-0

A Swift look at SN 2011fe: The earliest ultraviolet observations of a Type Ia supernova. Brown, Peter J., Dawson, Kyle S., de Pasquale, Massimiliano, et al. *Astrophys. J.* 753, 22, doi:10.1088/0004-637X/753/1/22

Flash mixing on the white dwarf cooling curve: Spectroscopic confirmation in NGC 2808. Brown, Thomas M., Lanz, Thierry, Sweigart, Allen V., et al. *Astrophys. J.* 748, 85, doi:10.1088/0004-637X/748/2/85

Gamma-ray activity in the Crab Nebula: The exceptional flare of 2011 April. Buehler, R., Scargle, J. D., Blandford, R. D., et al. *Astrophys. J.* 749, 26, doi:10.1088/0004-637X/748/2/85

A new method to constrain supernova fractions using X-ray observations of clusters of galaxies. Bulbul, Esra, Smith, Randall K., and Loewenstein, Michael. *Astrophys. J.* 753, 54, doi:10.1088/0004-637X/753/1/54

High-resolution XMM-Newton spectroscopy of the cooling flow cluster A3112. Bulbul, G. Esra, Smith, Randall K., Foster, Adam, et al. *Astrophys. J.* 747, 32, doi:10.1088/0004-637X/747/1/32

First Light with RATIR: An Automated 6-band Optical/NIR Imaging Camera. Butler, Nat, Klein, Chris, Fox, Ori, et al. *Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV*, 844610, doi:10.1117/12.926471

X-ray and optical observations of A 0535+26. Camero-Arranz, A., Finger, M. H., Wilson-Hodge, C. A., et al. *Astrophys. J.* 754, 20, doi:10.1088/0004-637X/754/1/20

4U 1626-67 as seen by Suzaku before and after the 2008 torque reversal. Camero-Arranz, A., Pottschmidt, K., Finger, M. H., et al. *Astron. Astrophys.* 546, A40, doi:10.1051/0004-6361/201219656

PSR J2030+3641: Radio discovery and gamma-ray study of a middle-aged pulsar in the now identified Fermi-LAT source 1FGL J2030.0+3641. Camilo, F., Kerr, M., Ray, P. S., et al. *Astrophys. J.* 746, 39, doi:10.1088/0004-637X/746/1/39

XMM-Newton and Swift observations of the Type IIb supernova 2011dh in Messier 51. Campana, Sergio and Immler, Stefan. *Mon. Not. R. Astron. Soc.,* 427, L70, doi:10.1111/j.1745-3933.2012.01347.x

The shape of long outbursts in U Gem type dwarf novae from AAVSO data. Cannizzo, John K. *Astrophys. J.* 757, 174, doi:10.1088/0004-637X/757/2/174

The Kepler light curves of V1504 Cygni and V344 Lyrae: A study of the outburst properties. Cannizzo, John K., Smale, Alan P., Wood, Matt A., et al. *Astrophys. J.* 747, 117, doi:10.1088/0004-637X/747/2/117

The nature of the unresolved extragalactic cosmic soft X-ray background. Cappelluti, N., Ranalli, P., Roncarelli, M., et al. *Mon. Not. R. Astron. Soc.* 427, 651, doi:10.1111/j.1365-2966.2012.21867.x

Simultaneous Swift X-ray and UV views of comet C/2007 N3 (Lulin). Carter, J. A., Bodewits, D., Read, A. M., and Immler, S. *Astron. Astrophys.* 541, A70, doi:10.1051/0004-6361/201117950

Swift J2058.4+0516: Discovery of a possible second relativistic tidal disruption flare? Cenko, S. Bradley, Krimm, Hans A., Horesh, Assaf, et al. *Astrophys. J.* 753, 77, doi:10.1088/0004-637X/753/1/77

Cryogenic photogrammetry and radiometry for the James Webb Space Telescope Microshutters. Chambers, Victor J., Morey, Peter A., Zukowski, Barbara J., et al. *Proc. SPIE 8450, Modern Technologies in Space- and Ground-based Telescopes and Instrumentation II*, 84501F, doi:10.1117/12.924171

Reflective coating for lightweight X-ray optics. Chan, Kai-Wing, Zhang, William W., Windt, David, Hong, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84433S, doi:10.1117/12.926890

Radio and X-ray observations of SN 2006jd: Another strongly interacting Type IIn supernova. Chandra, Poonam, Chevalier, Roger A., Chugai, Nikolai, et al. *Astrophys. J.* 755, 110, doi:10.1088/0004-637X/755/2/110

Fabrication of microstripline wiring for large format transition edge sensor arrays. Chervenak, J. A., Adams, J. M., Bailey, C. N., et al. *J. Low Temp. Phys.*167, 547, doi:10.1007/s10909-012-0552-4

Chandra X-ray observations of the two brightest unidentified high Galactic latitude Fermi-LAT γ-ray sources. Cheung, C. C., Donato, D., Gehrels, N., et al. *Astrophys. J.* 756, 33, doi:10.1088/0004-637X/756/1/33

The dependence of quenching upon the inner structure of galaxies at $0.5 \leq z < 0.8$ in the DEEP2/AEGIS survey. Cheung, Edmond, Faber, S. M., Koo, David C., et al. *Astrophys. J.* 760, 131, doi:10.1088/0004-637X/760/2/131

The radio light curve of the gamma-ray nova in V407 Cyg: Thermal emission from the ionized symbiotic envelope, devoured from within by the nova blast. Chomiuk, Laura, Krauss, Miriam I., Rupen, Michael P., et al. *Astrophys. J.* 761, 173, doi:10.1088/0004-637X/761/2/173

Electromagnetic design of feedhorn-coupled transition-edge sensors for cosmic microwave background polarimetry. Chuss, D. T., Bennett, C. L., Costen, N., et al. *J. Low Temp. Phys.* 167, 923, doi:10.1007/s10909-011-0433-2

Phase-controlled polarization modulators. Chuss, David T., Wollack, Edward J., Novak, G., et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 84521Y, doi:10.1117/12.925214

The evolution of Lyα-emitting galaxies between z = 2.1 and z = 3.1. Ciardullo, Robin, Gronwall, Caryl, Wolf, Christopher, et al. *Astrophys. J.* 744, 110, doi:10.1088/0004-637X/744/2/110

Status of the James Webb Space Telescope Observatory. Clampin, Mark C. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84422A, doi:10.1117/12.926429

Space telescopes. Clampin, Mark and Flanagan, Kathryn A. *Opt. Eng.* 51, 11001, doi:10.1117/1.OE.51.1.011001

On dark peaks and missing mass: A weak-lensing mass reconstruction of the merging cluster system A520. Clowe, Douglas, Markevitch, Maxim, Bradač, Maruša, et al. *Astrophys. J.* 758, 128, doi:10.1088/0004-637X/758/2/128

A giant radio flare from Cygnus X-3 with associated γ-ray emission. Corbel, S., Dubus, G., Tomsick, J. A., et al. *Mon. Not. R. Astron. Soc.* 421, 2947, doi:10.1111/j.1365-2966.2012.20517.x

Observed limits on charge exchange contributions to the diffuse X-ray background. Crowder, S. G., Barger, K. A., Brandl, D. E., et al. *Astrophys. J.* 758, 143, doi:10.1088/0004-637X/758/2/143

Lithium abundances of the super-metal-rich open cluster NGC 6253. Cummings, Jeffrey D., Deliyannis, Constantine P., Anthony-Twarog, et al. *Astron. J.* 144, 137, doi:10.1088/0004-6256/144/5/137

Direct imaging confirmation and characterization of a dust-enshrouded candidate exoplanet orbiting Fomalhaut. Currie, Thayne, Debes, John, Rodigas, Timothy J., et al. *Astrophys. J. Lett.* 760, L32, doi:10.1088/2041-8205/760/2/L32

Direct detection and orbital analysis of the exoplanets HR 8799 bcd from archival 2005 Keck/NIRC2 data. Currie, Thayne, Fukagawa, Misato, Thalmann, Christian, et al. *Astrophys. J. Lett.* 755, L34, doi:10.1088/2041-8205/755/2/L34

Keck/NIRC2 imaging of the warped, asymmetric debris disk around HD 32297. Currie, Thayne, Rodigas, Timothy J., Debes, John, et al. *Astrophys. J.* 757, 28, doi:10.1088/0004-637X/757/1/28

SBS 0846+513: A new γ-ray-emitting narrow-line Seyfert 1 galaxy. D'Ammando, F., Orienti, M., Finke, J., et al. *Mon. Not. R. Astron. Soc.* 426, 317, doi:10.1111/j.1365-2966.2012.21707.x

PKS 2123-463: A confirmed γ-ray blazar at high redshift. D'Ammando, F., Rau, A., Schady, P., et al. *Mon. Not. R. Astron. Soc.* 427, 893, doi:10.1111/j.1365-2966.2012.22041.x

The cosmic history of hot gas cooling and radio active galactic nucleus activity in massive early-type galaxies. Danielson, A. L. R., Lehmer, B. D., Alexander, D. M., et al. *Mon. Not. R. Astron. Soc.* 422, 494, doi:10.1111/j.1365-2966.2012.20626.x

New brown dwarf discs in Upper Scorpius observed with WISE. Dawson, P., Scholz, A., Ray, T. P., et al. *Mon. Not. R. Astron. Soc.* 429, 903, doi:10.1093/mnras/sts386

Measuring the redshift dependence of the cosmic microwave background monopole temperature with Planck data. de Martino, I., Atrio-Barandela, F., da Silva, A., et al. *Astrophys. J.* 757, 144, doi:10.1088/0004-637X/757/2/144

Star formation in H I tails: HCG 92, HCG 100 and six interacting systems. de Mello, D. F., Urrutia-Viscarra, F., Mendes de Oliveira, C., et al. *Mon. Not. R. Astron. Soc.* 426, 2441, doi:10.1111/j.1365-2966.2012.21429.x

Calibration sources for the soft X-ray spectrometer instrument on ASTRO-H. de Vries, C. P., Lowes, P., den Herder, J. W., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844353, doi:10.1117/12.924146

ORIGIN: Metal creation and evolution from the cosmic dawn. den Herder, Jan-Willem, Piro, Luigi, Ohashi, Takaya, et al. *Exp. Astron.* 34, 519, doi:10.1007/s10686-011-9224-7

The X-ray microcalorimeter spectrometer onboard Athena. den Herder, J. W., Bagnali, D., Bandler, S., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84432B, doi:10.1117/12.924269

Very high-resolution solar X-ray imaging using diffractive optics. Dennis, B. R., Skinner, G. K., Li, M. J., and Shih, A. Y. *Solar Phys.* 279, 573, doi:10.1007/s11207-012-0016-7

A multi-epoch timing and spectral study of the ultraluminous X-ray NGC 5408 X-1 with XMM-Newton. Dheeraj, Pasham R. and Strohmayer, Tod E. *Astrophys. J.* 753, 139, doi:10.1088/0004-637X/753/2/139

RXTE observations of anomalous X-ray pulsar 1E 1547.0-5408 during and after its 2008 and 2009 outbursts. Dib, Rim, Kaspi, Victoria M., Scholz, Paul, and Gavriil, Fotis P. *Astrophys. J.* 748, 3, doi:10.1088/0004-637X/748/1/3

Herschel PACS observations and modeling of debris disks in the Tucana-Horologium Association. Donaldson, J. K., Roberge, A., Chen, C. H., et al. *Astrophys. J.* 753, 147, doi:10.1088/0004-637X/753/2/147

The HEASARC Swift gamma-ray burst archive: The pipeline and the catalog. Donato, D., Angelini, L., Padgett, C. A., et al. *Astrophys. J. Suppl.* 203, 2

The missing cavities in the SEEDS polarized scattered light images of transitional protoplanetary disks: A generic disk model. Dong, R., Rafikov, R., Zhu, Z., et al. *Astrophys. J.* 750, 161, doi:10.1088/0004-637X/750/2/161

The structure of pre-transitional protoplanetary disks. I. Radiative transfer modeling of the disk+cavity in the PDS 70 system. Dong, Ruobing, Hashimoto, Jun, Rafikov, Roman, et al. *Astrophys. J.* 760, 111, doi:10.1088/0004-637X/760/2/111

Active galactic nucleus obscuration from winds: From dusty infrared-driven to warm and X-ray photoionized. Dorodnitsyn, A. and Kallman, T. *Astrophys. J.* 761, 70, doi:10.1088/0004-637X/761/1/70

AGN obscuration through dusty, infrared-dominated flows. II. Multidimensional, radiation-hydrodynamics modeling. Dorodnitsyn, A., Kallman, T., and Bisnovatyi-Kogan, G. S. *Astrophys. J.* 747, 8, doi:10.1088/0004-637X/761/1/70

A method for localizing energy dissipation in blazars using Fermi variability. Dotson, Amanda, Georganopoulos, Markos, Kazanas, Demosthenes, and Perlman, Eric S. *Astrophys. J. Lett.* 758, L15, doi:10.1088/2041-8205/758/1/L15

Imposing a Lagrangian particle framework on an Eulerian hydrodynamics infrastructure in FLASH. Dubey, A., Daley, C., ZuHone, J., Ricker, P. M., Weide, K., and Graziani, C. *Astrophys. J. Suppl.* 201, 27, doi:10.1088/0067-0049/201/2/27

Kilopixel X-ray microcalorimeter arrays for astrophysics: Device performance and uniformity. Eckart, M. E., Adams, J. S., Bailey, C. N., et al. *J. Low Temp. Phys.* 167, 732, doi:10.1007/s10909-012-0514-x

The gas distribution in the outer regions of galaxy clusters. Eckert, D., Vazza, F., Ettori, S., et al. *Astron. Astrophys.* 541, A57, doi:10.1051/0004-6361/201118281

The Cosmology Large Angular Scale Surveyor (CLASS): 40 GHz optical design. Eimer, Joseph R., Bennett, Charles L., Chuss, David T., et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI,* 845220, doi:10.1117/12.925464

The first hyper-luminous infrared galaxy discovered by WISE. Eisenhardt, Peter R. M., Wu, Jingwen, Tsai, Chao-Wei, et al. *Astrophys. J.* 755, 173, doi:10.1088/0004-637X/755/2/173

Spectral comparison of weak short bursts to the persistent X-rays from the magnetar 1E 1547.0-5408 in its 2009 outburst. Enoto, T., Nakagawa, Y. E., Sakamoto, T., and Makishima. K. *Mon. Not. R. Astron. Soc.* 427, 2824, 10.1111/j.1365-2966.2012.22086.x

A peculiar class of debris disks from Herschel/DUNES. A steep fall off in the far infrared. Ertel, S., Wolf, S., Marshall, J. P. et al. *Astron. Astrophys.* 541, A148, doi:10.1051/0004-6361/201118077

Swift follow-up observations of candidate gravitational-wave transient events. Evans, P. A., Fridriksson, J. K., Gehrels, N., et al. *Astrophys. J. Suppl.* 203, 28, doi:10.1088/0067-0049/203/2/28

Staring at 4U 1909+07 with Suzaku. Fürst, F., Pottschmidt, K., Kreykenbohm, I., et al. *Astron. Astrophys.* 547, A2, doi:10.1051/0004-6361/201219845Nov 2012

On the determination of the spin of the black hole in Cyg X-1 from X-ray reflection spectra. Fabian, A. C., Wilkins, D. R., Miller, J. M., et al. *Mon. Not. R. Astron. Soc.* 424, 217, doi:10.1111/j.1365-2966.2012.21185.x

Mechanical design and integration of the support structure for the Reionization And Transients InfRared Instrument RATIR. Farah, Alejandro, González, J. Jesús, Kutyrev, Alexander S., et al. *Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV*, 84469O, doi:10.1117/12.927040

Numerical solution of the radiative transfer equation: X-ray spectral formation from cylindrical accretion onto a magnetized neutron star. Farinelli, R., Ceccobello, C., Romano, P., and Titarchuk, L. *Astron. Astrophys.* 538, A67, doi:10.1051/0004-6361/201118008

James Webb Space Telescope optical telescope element mirror development history and results. Feinberg, Lee D., Clampin, Mark, Keski-Kuha, Ritva, et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84422B, doi:10.1117/12.924271

LOFT: the Large Observatory For X-ray Timing. Feroci, M., den Herder, J. W., Bozzo, E., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84432D, doi:10.1117/12.926310

MARE-1 in Milan: Status and perspectives. Ferri, E., Arnaboldi, C., Ceruti, et al. *J. Low Temp. Phys.* 167, 1035, doi:10.1007/s10909-011-0421-6

Update on the Micro-X Sounding Rocket payload. Figueroa-Feliciano, E., Adams, J. S., Baker, R., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84431B, doi:10.1117/12.927167

Herschel-ATLAS: VISTA VIKING near-infrared counterparts in the Phase 1 GAMA 9-h data. Fleuren, S., Sutherland, W., Dunne, L., et al. *Mon. Not. R. Astron. Soc.* 423, 2407, doi:10.1111/j.1365-2966.2012.21048.x

Very early ultraviolet and optical observations of the Type Ia supernova 2009ig. Foley, Ryan J., Challis, P. J., Filippenko, A. V., et al. *Astrophys. J.* 744, 38, doi:10.1088/0004-637X/744/1/38

A jet break in the X-ray light curve of short GRB 111020A: Implications for energetics and rates. Fong, W., Berger, E., Margutti, R., et al. *Astrophys. J.* 756, 189, doi:10.1088/0004-637X/756/2/189

Performance and calibration of H2RG detectors and SIDECAR ASICs for the RATIR camera. Fox, Ori D., Kutyrev, Alexander S., Rapchun, David A., et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 84531O, doi:10.1117/12.926620

Time-resolved ultraviolet spectroscopy of the M-dwarf GJ 876 exoplanetary system. France, Kevin, Linsky, Jeffrey L., Tian, Feng, et al. *Astrophys. J. Lett.* 750, L32, doi:10.1088/2041-8205/750/2/L32

Physical structure and nature of supernova remnants in M101. Franchetti, Nicholas A., Gruendl, Robert A., Chu, You-Hua, et al. *Astron. J.* 143, 85, doi:10.1088/0004-6256/143/4/85

Carnegie Hubble program: A mid-infrared calibration of the Hubble constant. Freedman, Wendy L., Madore, Barry F., Scowcroft, Victoria, et al. *Astrophys. J.* 758, 24, doi:10.1088/0004-637X/758/1/24

Spatially Resolved HST Grism Spectroscopy of a Lensed Emission Line Galaxy at z ~ 1. Frye, Brenda L., Hurley, Mairead, Bowen, David V., et al. *Astrophys. J.* 754, 17, doi:10.1088/0004-637X/758/1/24

Evidence for helical magnetic fields in kiloparsec-scale AGN jets and the action of a cosmic battery. Gabuzda, D. C., Christodoulou, D. M., Contopoulos, I., and Kazanas, D. *J. Phys. Conf. Ser.* 355, 12019, doi:10.1088/1742-6596/355/1/012019

Mirror illumination and spillover measurements of the Atacama Cosmology Telescope. Gallardo, Patricio, Dünner, Rolando, Wollack, Edward, et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 845224, doi:10.1117/12.926585

The James Webb Space Telescope: extending the science. Gardner, Jonathan P. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 844228, doi:10.1117/12.926551

An Fe XXIV absorption line in the persistent spectrum of the dipping low-mass X-ray binary 1A 1744-361. Gavriil, Fotis P., Strohmayer, Tod E., and Bhattacharyya, Sudip *Astrophys. J.* 753, 2, doi:10.1088/0004-637X/753/1/2

A Substellar Common Proper-motion Companion to the Pleiad H II 1348. Geißler, Kerstin, Metchev, Stanimir A., Pham, Alfonse, et al. *Astrophys. J.* 746, 44, doi:10.1088/0004-637X/746/1/44

The X-ray Advanced Concepts Testbed (XACT) sounding rocket payload. Gendreau, Keith, Arzoumanian, Zaven, Asami, Fumi, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84434V, doi:10.1117/12.926418

The Neutron star Interior Composition ExploreR (NICER): an Explorer mission of opportunity for soft X-ray timing spectroscopy. Gendreau, Keith C., Arzoumanian, Zaven, and Okajima, Takashi. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844313, doi:10.1117/12.926396

General relativistic simulations of magnetized plasmas around merging supermassive black holes. Giacomazzo, Bruno, Baker, John G., Miller, M. Coleman, et al. *Astrophys. J. Lett.* 752, L15, doi:10.1088/2041-8205/752/1/L15

NIRSpec detectors: noise properties and the effect of signal dependent inter-pixel crosstalk. Giardino, Giovanna, Sirianni, Marco, Birkmann, Stephan M., Rauscher, Bernard J., Lindler, Don, Boeker, Torsten, Ferruit, Pierre, et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 84531T, doi:10.1117/12.925357

Simultaneous Planck, Swift, and Fermi observations of X-ray and γ-ray selected blazars. Giommi, P., Polenta, G., Lähteenmäki, A., et al. *Astron. Astrophys.* 541, A160, doi:10.1051/0004-6361/201117825

The Fermi GBM gamma-ray burst spectral catalog: The first two years. Goldstein, Adam, Burgess, J. Michael, Preece, Robert D., et al. *Astrophys. J. Suppl.* 199, 19, doi:10.1088/0067-0049/199/1/19.

Optimizing the observing efficiency of the James Webb Space Telescope. Gordon, Karl D., Balzano, Victoria, Blair, William, et al. *Proc. SPIE 8448, Observatory Operations: Strategies, Processes, and Systems IV*, 84481U, doi:10.1117/12.926130

Study of the dependency on magnetic field and bias voltage of an AC-biased TES microcalorimeter. Gottardi, L., Adams, J., Bailey, C., et al. *J. Low Temp. Phys.*, 167, 214, doi:10.1007/s10909-012-0494-x

Breakthrough capability for the NASA astrophysics explorer program: reaching the darkest sky. Greenhouse, Matthew A., Benson, Scott W., Falck, Robert D., et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 844214, doi:10.1117/12.923658

Spitzer photometry of WISE-selected brown dwarf and hyper-luminous infrared galaxy candidates. Griffith, Roger L., Kirkpatrick, J. Davy, Eisenhardt, Peter R. M., et al. Astron. J. 144, 148, doi:10.1088/0004-6256/144/5/148

Laboratory measurements of the dielectronic recombination satellite transitions of He-like Fe XXV and H-like Fe XXVI. Gu, M. F., Beiersdorfer, P., Brown, G. V., et al. *Can. J. Phys.* 90, 351, doi:10.1139/P2012-025

Discovery of the millisecond pulsar PSR J2043+1711 in a Fermi source with the Nançay radio telescope. Guillemot, L., Freire, P. C. C., Cognard, I., et al. *Mon. Not. R. Astron. Soc.* 422, 1294, doi:10.1111/j.1365-2966.2012.20694.x

Pulsed gamma rays from the original millisecond and black widow pulsars: A case for caustic radio emission? Guillemot, L., Johnson, T. J., Venter, C., et al. *Astrophys. J.* 744, 33, doi:10.1088/0004-637X/744/1/33

The XMM-Newton survey of the Small Magellanic Cloud. Haberl, F., Sturm, R., Ballet, J., et al. *Astron. Astrophys.* 545, A128, doi:10.1051/0004-6361/201219758

Long-term monitoring of the high-energy γ-ray emission from LS I +61°303 and LS 5039. Hadasch, D., Torres, D. F., Tanaka, T., et al. *Astrophys. J.* 749, 54, doi:doi:10.1088/0004-637X/749/1/54

X-raying the beating heart of a newborn star: Rotational modulation of high-energy radiation from V1647 Ori. Hamaguchi, Kenji, Grosso, Nicolas, Kastner, Joel H., et al. *Astrophys. J.* 754, 32, doi:10.1088/0004-637X/754/1/32

Evidence of galaxy cluster motions with the kinematic Sunyaev-Zel'dovich effect. Hand, Nick, Addison, Graeme E., Aubourg, Eric, et al. *Phys. Rev. Lett.* 109, 41101, doi:10.1103/PhysRevLett.109.041101

Erratum: A decade of timing an accretion-powered millisecond pulsar: The continuing spin-down and orbital evolution of SAX J1808.4–3658 [(2009, *Astrophys. J.*, 702, 1673)]. Hartman, Jacob M., Patruno, Alessandro, Chakrabarty, Deepto, et al. *Astrophys. J.* 757, 193, doi:10.1088/0004-637X/757/2/193

Polarimetric imaging of large cavity structures in the pre-transitional protoplanetary disk around PDS 70: Observations of the disk. Hashimoto, J., Dong, R., Kudo, T., et al. *Astrophys. J. Lett.* 758, L19, doi:10.1088/2041-8205/758/1/L19

Joint analysis of X-ray and Sunyaev-Zel'dovich observations of galaxy clusters using an analytic model of the intracluster medium. Hasler, Nicole, Bulbul, Esra, Bonamente, Massimiliano, et al. *Astrophys. J.* 748, 113, doi:10.1088/0004-637X/748/2/113

The structure and emission model of the relativistic jet in the quasar 3C 279 inferred from radio to high-energy γ-ray observations in 2008-2010. Hayashida, M., Madejski, G. M., Nalewajko, K., et al. *Astrophys. J.* 754, 114, doi:10.1088/0004-637X/754/2/114

Reconstructing the γ-ray photon optical depth of the universe to z ~ 4 from multiwavelength galaxy survey data. Helgason, Kari and Kashlinsky, Alexander. *Astrophys. J. Lett.* 758, L13, doi:10.1088/2041-8205/758/1/L13

Reconstructing the near-infrared background fluctuations from known galaxy populations using multiband measurements of luminosity functions. Helgason, Kari, Ricotti, Massimo, and Kashlinsky, Alexander. *Astrophys. J.* 752, 113, doi:10.1088/0004-637X/752/2/113

CfA4: Light curves for 94 Type Ia supernovae. Hicken, Malcolm, Challis, Peter, Kirshner, Robert P., et al. *Astrophys. J. Suppl.* 200, 12, doi:10.1088/0067-0049/200/2/12

The design and qualification of the GEMS X-ray polarimeters. Hill, J. E., Baker, R. G., Black, J. K., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84431Q, doi:10.1117/12.928435

Optical TiO and VO band emission in two embedded protostars: IRAS 04369+2539 and IRAS 05451+0037. Hillenbrand, Lynne A., Knapp, Gillian R., Padgett, Deborah L., et al. *Astron. J.* 143, 37, doi:10.1088/0004-6256/143/2/37

GRB 081029: A gamma-ray burst with a multi-component afterglow. Holland, Stephen T., De Pasquale, Massimiliano, Mao, Jirong, et al. *Astrophys. J.* 745, 41, doi:10.1088/0004-637X/745/1/41

PDS 144: The first confirmed Herbig Ae-Herbig Ae wide binary. Hornbeck, J. B., Grady, C. A., Perrin, M. D., et al. *Astrophys. J.* 744, 54, doi:10.1088/0004-637X/744/1/54

Gas, stars, and star formation in ALFALFA dwarf galaxies. Huang, Shan, Haynes, Martha P., Giovanelli, Riccardo, et al. *Astron. J.* 143, 133, doi:10.1088/0004-6256/143/6/133

An all silicon feedhorn-coupled focal plane for cosmic microwave background polarimetry. Hubmayr, J., Appel, J. W., Austermann, J. E., et al. *J. Low Temp. Phys.* 167, 904, doi:10.1007/s10909-011-0420-7

On the weak-wind problem in massive stars: X-ray spectra reveal a massive hot wind in μ Columbae. Huenemoerder, David P., Oskinova, Lidia M., Ignace, Richard, et al. *Astrophys. J. Lett.* 756, L34, doi:10.1088/2041-8205/756/2/L34

Development of a telescope for medium-energy gamma-ray astronomy. Hunter, Stanley D., Bloser, Peter F., Dion, Michael P., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84430F, doi:10.1117/12.925216

A Chandra X-ray survey of ejecta in the Cassiopeia A supernova remnant. Hwang, Una and Laming, J. Martin. *Astrophys. J.* 746, 130, doi:10.1088/0004-637X/746/2/130

A ground calibration of the engineering model of the SXT onboard ASTRO-H using the ISAS 30m pencil beam facility. Ichihara, K., Hayashi, T., Ishida, M., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844357, doi:10.1117/12.925860

Possible detection of an emission cyclotron resonance scattering feature from the accretion-powered pulsar 4U 1626-67. Iwakiri, W. B., Terada, Y., Mihara, T., et al. *Astrophys. J.* 751, 35, doi:10.1088/0004-637X/751/1/35

Constructing a WISE high resolution galaxy atlas. Jarrett, T. H., Masci, F., Tsai, C. W., et al. *Astron. J.* 144, 68, doi:10.1088/0004-6256/144/2/68

A Chandra observation of the ultraluminous infrared galaxy IRAS 19254–7245 (the Superantennae): X-ray emission from the compton-thick active galactic nucleus and the diffuse starburst. Jia, Jianjun, Ptak, Andrew, Heckman, Timothy M., et al. *Astrophys. J.* 759, 41, doi:10.1088/0004-637X/759/1/41

Sloshing gas in the core of the most luminous galaxy cluster RXJ1347.5–1145. Johnson, Ryan E., Zuhone, John, Jones, Christine, et al. *Astrophys. J.* 751, 95, doi:10.1088/0004-637X/751/2/95

Ultra-low noise large-area InGaAs quad photoreceiver with low crosstalk for laser interferometry space antenna. Joshi, Abhay, Datta, Shubhashish, Rue, Jim, et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 84532G, doi:10.1117/12.918285

ACCESS: design and sub-system performance. Kaiser, Mary Elizabeth, Morris, Matthew J., McCandliss, Stephan R.,et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 844246, doi:10.1117/12.927204

The extended pulsar magnetosphere. Kalapotharakos, Constantinos, Contopoulos, Ioannis, and Kazanas, Demos. *Mon. Not. R. Astron. Soc.* 420, 2793, doi:10.1111/j.1365-2966.2011.19884.x

Gamma-ray light curves from pulsar magnetospheres with finite conductivity. Kalapotharakos, Constantinos, Harding, Alice K., Kazanas, Demosthenes, and Contopoulos, Ioannis. *Astrophys. J. Lett.* 754, L1, doi:10.1088/2041-8205/754/1/L1

Toward a realistic pulsar magnetosphere. Kalapotharakos, Constantinos, Kazanas, Demosthenes, Harding, Alice, and Contopoulos, Ioannis. *Astrophys. J.* 749, 2, doi:10.1088/0004-637X/749/1/2

Seeking counterparts to Advanced LIGO/Virgo transients with Swift. Kanner, Jonah, Camp, Jordan, Racusin, Judith, et al. *Astrophys. J.* 759, 22,

New measurements of the cosmic infrared background fluctuations in deep Spitzer/IRAC survey data and their cosmological implications. Kashlinsky, A., Arendt, R. G., Ashby, M. L. N., et al. *Astrophys. J.* 753, 63, doi:10.1088/0004-637X/759/1/22

The radius of baryonic collapse in disc galaxy formation. Kassin, Susan A., Devriendt, Julien, Fall, S. Michael, et al. *Mon. Not. R. Astron. Soc.* 424, 502, doi:10.1111/j.1365-2966.2012.21219.x

The epoch of disk settling: z ~ 1 to now. Kassin, Susan A., Weiner, Benjamin J., Faber, S. M., et al. *Astrophys. J.* 758, 106, doi:10.1088/0004-637X/758/2/106

Discovery of a pulsar wind nebula candidate in the Cygnus Loop. Katsuda, Satoru, Tsunemi, Hiroshi, Mori, Koji, et al. *Astrophys. J. Lett.* 754, L7, doi:10.1088/2041-8205/754/1/L7

High-resolution X-ray spectroscopy of the Galactic supernova remnant Puppis A with XMM-Newton/RGS. Katsuda, Satoru, Tsunemi, Hiroshi, Mori, Koji, et al. *Astrophys. J.* 756, 49, doi:10.1088/0004-637X/756/1/49

XMM-Newton view of the N 206 superbubble in the Large Magellanic Cloud. Kavanagh, P. J., Sasaki, M., and Points, S. D. *Astron. Astrophys.* 547, A19, doi:10.1051/0004-6361/201219532

The insignificance of major mergers in driving star formation at z ~ 2. Kaviraj, S., Cohen, S., Windhorst, R. A., et al. *Mon. Not. R. Astron. Soc. Lett. 429, L40,* doi:10.1093/mnrasl/sls019

Five new millisecond pulsars from a radio survey of 14 unidentified Fermi-LAT gamma-ray sources. Kerr, M., Camilo, F., Johnson, T. J., et al. *Astrophys. J. Lett.* 748, L2, doi:10.1088/2041-8205/748/1/L2

James Webb Space Telescope optical telescope element mirror coatings. Keski-Kuha, Ritva A., Bowers, Charles W., Quijada, Manuel A., et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84422J, doi:10.1117/12.925470

The resolved stellar population in 50 regions of M83 from HST/WFC3 early release science observations. Kim, Hwihyun, Whitmore, Bradley C., Chandar, Rupali, et al. *Astrophys. J.* 753, 26, doi:10.1088/0004-637X/753/1/26

The integration and test program of the James Webb Space Telescope. Kimble, Randy A., Davila, Pamela S., Diaz, Charles E., et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84422K, doi:10.1117/12.926793

An extreme X-ray disk wind in the black hole candidate IGR J17091-3624. King, A. L., Miller, J. M., Raymond, J., et al. *Astrophys. J. Lett.* 746, L20, doi:10.1088/2041-8205/746/2/L20

Software solution for autonomous observations with H2RG detectors and SIDECAR ASICs for the RATIR camera. Klein, Christopher R., Kubánek, Petr, Butler, Nathaniel R., et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 84532S, doi:10.1117/12.925817

Outburst of GX 304-1 monitored with INTEGRAL: Positive correlation between the cyclotron line energy and flux. Klochkov, D., Doroshenko, V., Santangelo, A., et al. *Astron. Astrophys.* 542, L28, doi:10.1051/0004-6361/201219385

Swift J045106.8–694803: A highly magnetized neutron star in the Large Magellanic Cloud. Klus, H., Bartlett, E. S., Bird, A. J., et al. *Mon. Not. R. Astron. Soc.* 428, 3607, doi:10.1093/mnras/sts304 0

Why do compact active galactic nuclei at high redshift scintillate less? Koay, J. Y., Macquart, J.-P., Rickett, B. J., et al. *Astrophys. J.* 756, 29, doi:10.1088/0004-637X/756/1/29

CANDELS: Constraining the AGN-Merger Connection with Host Morphologies at z ~ 2. Kocevski, Dale D., Faber, S. M., Mozena, Mark, et al. *Astrophys. J.* 744, 148, doi:10.1088/0004-637X/744/2/148

Wide-field Infrared Survey Explorer observations of the evolution of massive star-forming regions. Koenig, X. P., Leisawitz, D. T., Benford, D. J., et al. *Astrophys. J.* 744, 130, doi:10.1088/0004-637X/744/2/130

Synchrotron spectral curvature from 22 MHz to 23 GHz. Kogut, A. *Astrophys. J.* 753, 110, doi:10.1088/0004-637X/753/2/110

The Primordial Inflation Polarization Explorer (PIPER). Kogut, Alan, Ade, Peter A. R., Benford, Dominic, et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 84521J, doi:10.1117/12.925204

The Hard X-ray Imager (HXI) for the ASTRO-H mission. Kokubun, Motohide, Nakazawa, Kazuhiro, Enoto, Teruaki, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844325, doi:10.1117/12.925648

Discovery of an unidentified Fermi object as a black widow-like millisecond pulsar. Kong, A. K. H., Huang, R. H. H., Cheng, K. S., et al. *Astrophys. J. Lett.* 747, L3, doi:10.1088/2041-8205/747/1/L3

The merger history, active galactic nucleus, and dwarf galaxies of Hickson Compact Group 59. Konstantopoulos, I. S., Gallagher, S. C., Fedotov, K., et al. *Astrophys. J.* 745, 30, doi:10.1088/0004-637X/745/1/30

Observations of outflowing ultraviolet absorbers in NGC 4051 with the Cosmic Origins Spectrograph. Kraemer, S. B., Crenshaw, D. M., Dunn, J. P., et al. *Astrophys. J.* 751, 84, doi:10.1088/0004-637X/751/2/84

Calorimetric low-temperature detectors for X-ray spectroscopy on trapped highly-charged heavy ions. Kraft-Bermuth, S., Andrianov, V., Bleile, A., et al. *J. Low Temp. Phys.* 167, 765, doi:10.1007/s10909-012-0520-z

Hubble Space Telescope observations of the HD 202628 debris disk. Krist, John E., Stapelfeldt, Karl R., Bryden, Geoffrey, and Plavchan, Peter. *Astron. J.* 144, 45, doi:10.1088/0004-6256/144/2/45

The Galactic centre mini-spiral with CARMA. Kunneriath, D., Eckart, A., Vogel, S. N., et al. *J. Phys. Conf. Ser.* 372, 12063, doi:10.1088/1742-6596/372/1/012063

The Galactic centre mini-spiral in the mm-regime. Kunneriath, D., Eckart, A., Vogel, S. N., et al. *Astron. Astrophys.* 538, doi:10.1051/0004-6361/201117676

MuSE: a novel experiment for CMB polarization measurement using highly multimoded bolometers. Kusaka, Akito, Fixsen, Dale J., Kogut, Alan J., et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 84521L, doi:10.1117/12.926271

High-contrast near-infrared polarization imaging of MWC 480. Kusakabe, N., Grady, C. A., Sitko, M. L., et al. *Astrophys. J.* 753, 153, doi:10.1088/0004-637X/753/2/153

Formation and destruction of jets in X-ray binaries. Kylafis, N. D., Contopoulos, I., Kazanas, D., and Christodoulou, D. M. *Astron. Astrophys.* 538, A5, doi:10.1051/0004-6361/201117052

Modelling the huge, Herschel-resolved debris ring around HD 207129. Löhne, T., Augereau, J.-C., Ertel, S., et al. *Astron. Astrophys.* 537, A110, 10.1051/0004-6361/201117731

Disentangling AGN and star formation in soft X-rays. LaMassa, Stephanie M., Heckman, T. M., and Ptak, A. *Astrophys. J.* 758, 82, doi:10.1088/0004-637X/758/2/82

Exploring the connection between star formation and active galactic nucleus activity in the local universe. LaMassa, Stephanie M., Heckman, T. M., Ptak, A., et al. *Astrophys. J.* 758, 1, doi:10.1088/0004-637X/758/1/1

An icy Kuiper belt around the young solar-type star HD 181327. Lebreton, J., Augereau, J.-C., Thi, W.-F., et al. *Astron. Astrophys.* 539, A17, doi:10.1051/0004-6361/201117714

The 4 Ms Chandra Deep Field-South number counts apportioned by source class: Pervasive active galactic nuclei and the ascent of normal galaxies. Lehmer, B. D., Xue, Y. Q., Brandt, W. N., et al. *Astrophys. J.* 752, 46, doi:10.1088/0004-637X/752/1/46

Developing wide-field spatio-spectral interferometry for far-infrared space applications. Leisawitz, David, Bolcar, Matthew R., Lyon, Richard G., et al. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 84450A, doi:10.1117/12.926812

The path to far-IR interferometry in space: recent developments, plans, and prospects. Leisawitz, David and Rinehart, Stephen A. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 844223, doi:10.1117/12.926806

Large proton anisotropies in the 18 August 2010 solar particle event. Leske, R. A., Cohen, C. M. S., Mewaldt, R. A., et al. *Solar Phys.* 281, 301, doi:10.1007/s11207-012-0018-5

Evolution of chorus waves and their source electrons during storms driven by corotating interaction regions. Li, Wen, Thorne, Richard, Bortnik, Jacob, et al. *J. Geophy. Res. Space Phys.* 117, 8209, doi:10.1029/2012JA017797

The diffuse gamma-ray background from Type Ia supernovae. Lien, Amy and Fields, Brian D. *Astrophys. J.* 747, 120, doi:10.1088/0004-637X/747/2/120

James Webb Space Telescope: Large deployable cryogenic telescope in space. Lightsey, Paul A., Atkinson, Charles, Clampin, Mark, and Feinberg, Lee D. *Opt. Eng.* 51, 11003, doi:10.1117/1.OE.51.1.011003

Spitzer evidence for a late-heavy bombardment and the formation of ureilites in η Corvi at ~1 Gyr. Lisse, C. M., Wyatt, M. C., Chen, C. H., et al. *Astrophys. J.* 747, 93, doi:10.1088/0004-637X/747/2/93

Hubble Space Telescope Hα imaging of star-forming galaxies at z ~ 1–1.5: Evolution in the size and luminosity of giant H II regions. Livermore, R. C., Jones, T., Richard, J., Bower, et al. *Mon. Not. R. Astron. Soc.* 427, 688, doi:10.1111/j.1365-2966.2012.21900.x

An in-depth study of the abundance pattern in the hot interstellar medium in NGC 4649. Loewenstein, Michael and Davis, David S. *Astrophys. J.* 757, 121, doi:10.1088/0004-637X/757/2/121

Dark matter search using XMM-Newton observations of Willman 1. Loewenstein, Michael and Kusenko, Alexander. *Astrophys. J.* 751, 82, doi:10.1088/0004-637X/751/2/82

Status of the James Webb Space Telescope integrated science instrument module. Lundquist, Ray A., Balzano, Vicki, Davila, Pam, et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84422M, doi:10.1117/12.925515

Probing the X-ray binary populations of the ring galaxy NGC 1291. Luo, B., Fabbiano, G., Fragos, T., et al. *Astrophys. J.* 749, 130, doi:10.1088/0004-637X/749/2/130

Dust attenuation and Hα star formation rates of z ~ 0.5 galaxies. Ly, Chun, Malkan, Matthew A., Kashikawa, Nobunari, et al. *Astrophys. J. Lett.* 747, L16, doi:10.1088/2041-8205/747/1/L16

Space telescope sensitivity and controls for exoplanet imaging. Lyon, Richard G. and Clampin, Mark. *Opt. Eng.* 51, 11002, doi:10.1117/1.OE.51.1.011002

Wide-field imaging interferometry spatial-spectral image synthesis algorithms. Lyon, R. G., Leisawitz, D. T., Rinehart, S. A., et al. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 84450B, doi:10.1117/12.926920

High contrast vacuum nuller testbed (VNT) contrast, performance, and null control. Lyon, Richard G., Clampin, Mark, Petrone, Peter, et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 844208, doi:10.1117/12.926889

Constraining the absolute orientation of η Carinae's binary orbit: A 3D dynamical model for the broad [Fe III] emission. Madura, T. I., Gull, T. R., Owocki, S. P., et al. *Mon. Not. R. Astron. Soc.* 420, 2064, doi:10.1111/j.1365-2966.2011.20165.x

HST/STIS spectroscopy of the magnetic Of?p star HD 108: The low state at ultraviolet wavelengths. Marcolino, W. L. F., Bouret, J.-C., Walborn, N. R., et al. *Mon. Not. R. Astron. Soc.* 422, 2314, doi:10.1111/j.1365-2966.2012.20820.x

Inverse Compton X-ray emission from supernovae with compact progenitors: Application to SN2011fe. Margutti, R., Soderberg, A. M., Chomiuk, L., et al. *Astrophys. J.* 751, 134, doi:10.1088/0004-637X/751/2/134

Observational effects of magnetism in O stars: Surface nitrogen abundances. Martins, F., Escolano, C., Wade, G. A., et al. *Astron. Astrophys.* 538, A29, doi:10.1051/0004-6361/201118039

Astronomy: A conversation about observation. Mather, John and Mao, Minnie. *Nature* 490, S5, doi:10.1038/490S5a

Parasitic interference in classical and nulling stellar interferometry. Matter, A., Defrère, D., Danchi, W. C., et al. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 84453J, doi:10.1117/12.926456

Direct imaging of extra-solar planets in star forming regions. Lessons learned from a false positive around IM Lupi. Mawet, D., Absil, O., Montagnier, G., et al. *Astron. Astrophys.* 544, A131, doi:10.1051/0004-6361/201219662

Subaru imaging of asymmetric features in a transitional disk in upper Scorpius. Mayama, S., Hashimoto, J., Muto, T., et al. *Astrophys. J. Lett.* 760, L26, doi:10.1088/2041-8205/760/2/L26

Design and analysis of modules for segmented X-ray optics. McClelland, Ryan S., Biskach, Michael P., Chan, Kai-Wing, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84433Y, doi:10.1117/12.927200

A massive, cooling-flow-induced starburst in the core of a luminous cluster of galaxies. McDonald, M., Bayliss, M., Benson, B. A., et al. *Nature* 488, 349, doi:10.1038/nature11379

Scientific design of a high contrast integral field spectrograph for the Subaru Telescope. McElwain, Michael W., Brandt, Timothy D., Janson, Markus, et al. *Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV*, 84469C, doi:10.1117/12.927108

NIMBUS: the Near-infrared Multi-Band Ultraprecise Spectroimager for SOFIA. McElwain, Michael W., Mandell, Avi, Woodgate, Bruce, et al. *Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV*, 84467B, doi:10.1117/12.927094

Fermi Gamma-Ray Space Telescope. McEnery, Julie E., Michelson, Peter F., Paciesas, William S., Ritz, Steven. *Opt. Eng.* 51, 11012, doi:10.1117/1.OE.51.1.011012

Running a distributed virtual observatory: U.S. Virtual Astronomical Observatory operations. McGlynn, Thomas A., Hanisch, Robert J., Berriman, G. Bruce, and Thakar, Aniruddha R. *Proc. SPIE 8448, Observatory Operations: Strategies, Processes, and Systems IV*, 84480E, doi:10.1117/12.926083

Observations of Herbig Ae/Be stars with Herschel/PACS. The atomic and molecular contents of their protoplanetary discs. Meeus, G., Montesinos, B., Mendigutía, I., et al. *Astron. Astrophys.* 544, A78, doi:10.1051/0004-6361/201219225

The Atacama Cosmology Telescope: ACT-CL J0102-4915 "El Gordo," a massive merging cluster at redshift 0.87. Menanteau, Felipe, Hughes, John P., Sifón, Cristóbal, et al. *Astrophys. J.* 748, 7, doi:10.1088/0004-637X/748/1/7

Keck Interferometer Nuller science highlights. Mennesson, Bertrand, Millan-Gabet, Rafael, Colavita, M. M., et al. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 844507, doi:10.1117/12.926548

Energy spectra, composition, and other properties of ground-level events during Solar Cycle 23. Mewaldt, R. A., Looper, M. D., Cohen, C. M. S., et al. *Space Sci. Rev.* 171, 97, doi:10.1007/s11214-012-9884-2

On the role of the accretion disk in black hole disk-jet connections. Miller, J. M., Pooley, G. G., Fabian, A. C., et al. *Astrophys. J.* 757, 11, doi:10.1088/0004-637X/757/1/11

The disk-wind-jet connection in the black hole H 1743–322. Miller, J. M., Raymond, J., Fabian, A. C., et al. *Astrophys. J. Lett.* 759, L6, doi:10.1088/2041-8205/759/1/L6

Using the XMM-Newton optical monitor to study cluster galaxy evolution. Miller, Neal A., O'steen, Richard, Yen, Steffi, et al. *Pub. Astron. Soc. Pacific* 124, 95, doi:10.1086/664187

Disc-jet coupling in the 2009 outburst of the black hole candidate H1743–322. Miller-Jones, J. C. A., Sivakoff, G. R., Altamirano, D., et al. *Mon. Not. R. Astron. Soc.* 421 468, doi:10.1111/j.1365-2966.2011.20326.x

The high-resolution X-ray microcalorimeter spectrometer, SXS, on Astro-H. Mitsuda, Kazuhisa, Kelley, Richard L., Boyce, Kevin R., et al. *J. Low Temp. Phys.*167, 795, doi:10.1007/s10909-012-0482-1

Search for X-ray emission associated with the Shapley Supercluster with Suzaku. Mitsuishi, Ikuyuki, Gupta, Anjali, Yamasaki, Noriko Y., et al. Pub. Astron. Soc. Japan 64, 18.

The Carnegie Hubble Program: The Leavitt Law at 3.6 and 4.5 μm in the Milky Way. Monson, Andrew J., Freedman, Wendy L., Madore, Barry F., et al. *Astrophys. J.* 759, 146, doi:10.1088/0004-637X/759/2/146

WISE detections of dust in the habitable zones of planet-bearing stars. Morales, Farisa Y., Padgett, D. L., Bryden, G., et al. *Astrophys. J.* 757, 7, doi:10.1088/0004-637X/757/1/7

Enabling large focal plane arrays through mosaic hybridization. Miller, Timothy M., Jhabvala, Christine A., Leong, Edward, et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 84532H, doi:10.1117/12.926491

The pre-collimator for the ASTRO-H X-ray telescopes: shielding from stray lights. Mori, Hideyuki, Maeda, Yoshitomo, Ishida, Manabu, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84435B, doi:10.1117/12.925902

The reawakening of the sleeping X-ray pulsar XTE J1946+274. Müller, S., Kühnel, M., Caballero, I., et al. *Astron. Astrophys.* 546, A125, doi:10.1051/0004-6361/201219580

Chandra observations of dying radio sources in galaxy clusters. Murgia, M., Markevitch, M., Govoni, F., et al. *Astron. Astrophys.* 548, A75, doi:10.1051/0004-6361/201219702

Discovery of small-scale spiral structures in the disk of SAO 206462 (HD 135344B): Implications for the physical state of the disk from spiral density wave theory. Muto, T., Grady, C. A., Hashimoto, J., et al. *Astrophys. J. Lett.* 748, L22, doi:10.1088/2041-8205/748/2/L22

Performance of magnetic penetration thermometers for X-ray astronomy. Nagler, P. C., Adams, J. S., Balvin, M. A., et al. *J. Low Temp. Phys.* 167, 455, doi:10.1007/s10909-012-0516-8

Long-duration X-ray flash and X-ray-rich gamma-ray bursts from low-mass Population III stars. Nakauchi, Daisuke, Suwa, Yudai, Sakamoto, Takanori, et al. *Astrophys. J.* 759, 128, doi:10.1088/0004-637X/759/2/128

X-ray emission from an asymmetric blast wave and a massive white dwarf in the gamma-ray emitting Nova V407 Cyg. Nelson, Thomas, Donato, Davide, Mukai, Koji, et al. *Astrophys. J.* 748, 43, doi:10.1088/0004-637X/748/1/43

A universal scaling for the energetics of relativistic jets from black hole systems. Nemmen, R. S., Georganopoulos, M., Guiriec, S., et al. *Science* 338, 1445, doi:10.1126/science.1227416

The Gemini NICI planet-finding campaign: Discovery of a multiple system orbiting the young A star HD 1160. Nielsen, Eric L., Liu, Michael C., Wahhaj, Zahed, et al. *Astrophys. J.* 750, 53, doi:10.1088/0004-637X/750/1/53

Fermi Large Area Telescope second source catalog. Nolan, P. L., Abdo, A. A., Ackermann, M., et al. *Astrophys. J. Suppl.* 199, 31, doi:10.1088/0067-0049/199/2/31

Suzaku observations of 4U 1957+11: Potentially the most rapidly spinning black hole in (the halo of) the galaxy. Nowak, Michael A., Wilms, Jörn, Pottschmidt, Katja, et al. *Astrophys. J.* 744, 107, doi:10.1088/0004-637X/744/2/107

Development of a quasi-monoenergetic 6 MeV Gamma Facility at NASA Goddard Space Flight Center. Nowicki, S. F., Hunter, S. D., Parsons, A. M. *Nucl. Instrum. Methods Phys. Res. Section A* 705, 111, doi:10.1016/j.nima.2012.12.066

Development of a quasi-monoenergetic 6 MeV gamma facility. Nowicki, Suzanne F., Hunter, Stanley D., Bodnarik, Julia G., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844337, doi:10.1117/12.925473

Precision laser development for interferometric space missions NGO, SGO, and GRACE follow-on. Numata, K. and Camp, J. *J. Phys. Conf. Ser*. 363, 12054, doi:10.1088/1742-6596/363/1/012054

Estimation of frequency noise in semiconductor lasers due to mechanical thermal noise. Numata, Kenji and Camp, Jordan. *Phys. Lett. A* 376, 798, doi:10.1016/j.physleta.2012.01.013

Precision and fast wavelength tuning of a dynamically phase-locked widely-tunable laser. Numata, Kenji, Chen, Jeffrey R., and Wu, Stewart T. *Opt. Express* 20, 14234, doi:10.1364/OE.20.014234

Multiwavelength observations of the Type IIb supernova 2009mg. Oates, S. R., Bayless, A. J., Stritzinger, M. D., et al. *Mon. Not. R. Astron. Soc.* 424, 1297, doi:10.1111/j.1365-2966.2012.21311.x

A correlation between the intrinsic brightness and average decay rate of Swift/UVOT gamma-ray burst optical/ultraviolet light curves. Oates, S. R., Page, M. J., De Pasquale, M., et al. *Mon. Not. R. Astron. Soc. Lett.* 426, L86, doi:10.1111/j.1745-3933.2012.01331.x

From radio with love: An overview of the role of radio observations in understanding high-energy emission from active galaxies. Ojha, Roopesh. *J. Phys. Conf. Ser.* 355, 12006, doi:10.1088/1742-6596/355/1/012006

First measurement of the ASTRO-H soft X-ray telescope performance. Okajima, Takashi, Serlemitsos, Peter J., Soong, Yang, and Hahne, Devin J. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844320, doi:10.1117/12.926443

The Herschel Multi-tiered Extragalactic Survey: HerMES. Oliver, S. J., Bock, J., Altieri, B., et al. *Mon. Not. R. Astron. Soc.* 424, 1614, doi:10.1111/j.1365-2966.2012.20912.x

The Fermi GBM gamma-ray burst catalog: The first two years. Paciesas, William S., Meegan, Charles A., von Kienlin, Andreas, et al. *Astrophys. J. Suppl.* 199, 18, doi:10.1088/0067-0049/199/1/18

The suppression of star formation by powerful active galactic nuclei. Page, M. J., Symeonidis, M., Vieira, J. D., et al. *Nature* 485, 213, doi:10.1038/nature11096

Atomic decay data for modeling K lines of iron peak and light odd-Z elements. Palmeri, P., Quinet, P., Mendoza, C., et al. *Astron. Astrophys.* 543, A44, doi:10.1051/0004-6361/201219438

Monte-Carlo simulations of the Suzaku-XRS residual background spectrum. Perinati, E., Kilbourne, C. A., Colasanti, L., et al. *J. Low Temp. Phys.* 167, 721, doi:10.1007/s10909-012-0608-5

Accelerator experiments with soft protons and hyper-velocity dust particles: application to ongoing projects of future X-ray missions. Perinati, E., Diebold, S., Kendziorra, E., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84430O, doi:10.1117/12.926118

Conceptual design of the Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) for the Subaru Telescope. Peters, Mary A., Groff, Tyler, Kasdin, N. et al. *Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV*, 84467U, doi:10.1117/12.926381

The NASA X-ray Mission concepts study. Petre, R., Bregman, J., Bautz, M., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84431I, doi:10.1117/12.926212

Constraining γ-ray pulsar gap models with a simulated pulsar population. Pierbattista, M., Grenier, I. A., Harding, A. K., and Gonthier, P. L. *Astron. Astrophys.* 545, A42, doi:10.1051/0004-6361/201219135

maXs: Microcalorimeter Arrays for High-Resolution X-ray Spectroscopy at GSI/FAIR. Pies, C., Schäfer, S., Heuser, S., et al. *J. Low Temp. Phys.* 167, 269, doi:10.1007/s10909-012-0557-z

Discovery of nine gamma-ray pulsars in Fermi Large Area Telescope data using a new blind search method. Pletsch, H. J., Guillemot, L., Allen, B., et al. *Astrophys. J.* 744, 105, doi:10.1088/0004-637X/744/2/105

Binary millisecond pulsar discovery via gamma-ray pulsations. Pletsch, H. J., Guillemot, L., Fehrmann, H., et al. *Science* 338, 1314, doi:10.1126/science.1229054

Advanced Technology Large-Aperture Space Telescope: Science drivers and technology developments. Postman, Marc, Brown, Tom, Sembach, Kenneth, et al. *Opt. Eng.* 51, 11007, doi:10.1117/1.OE.51.1.011007

Using the ISS as a testbed to prepare for the next generation of space-based telescopes. Postman, Marc, Sparks, William B., Liu, Fengchuan, et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84421T, doi:10.1117/12.926492

Characterization of the silicon drift detector for NICER instrument. Prigozhin, G., Gendreau, K., Foster, R., et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 845318, doi:10.1117/12.926667

Early ultraviolet observations of a Type IIn supernova (2007pk). Pritchard, T. A., Roming, P. W. A., Brown, P. J., et al. *Astrophys. J.* 750, 128, doi:10.1088/0004-637X/750/2/128

The kinematics of HH 34 from HST images with a nine-year time baseline. Raga, A. C., Noriega-Crespo, A., Rodríguez-González, A., et al. *Astrophys. J.* 748, 103, doi:10.1088/0004-637X/748/2/103

First Keck nulling observations of a young stellar object: Probing the circumstellar environment of the Herbig Ae Star MWC 325. Ragland, S., Ohnaka, K., Hillenbrand, L., et al. *Astrophys. J.* 746, 126, doi:10.1088/0004-637X/746/2/126

Weak-lensing Results for the Merging Cluster A1758. Ragozzine, B., Clowe, D., Markevitch, M., et al. *Astrophys. J.* 744, 94, doi:10.1088/0004-637X/744/2/94

Variability of the blazar 4C 38.41 (B3 1633+382) from GHz frequencies to GeV energies. Raiteri, C. M., Villata, M., Smith, P. S., et al. *Astron. Astrophys.* 545, A48, doi:10.1051/0004-6361/201219492

On the X-ray low- and high-velocity outflows in active galactic nuclei. Ramírez, J. M. and Tombesi, F. *Mon. Not. R. Astron. Soc. Lett.* 419, L64, doi:10.1111/j.1745-3933.2011.01180.x

Kepler observations of V447 Lyr: An eclipsing U Gem cataclysmic variable. Ramsay, Gavin, Cannizzo, John K., Howell, Steve B., et al. *Mon. Not. R. Astron. Soc.* 425, 1479, doi:10.1111/j.1365-2966.2012.21657.x

Development of metallic magnetic calorimeters for high precision measurements of calorimetric ^{187}Re and ^{163}Ho Spectra. Ranitzsch, P. C.-O., Porst, J.-P., Kempf, S., et al. *J. Low Temp. Phys.* 167, 1004, doi:10.1007/s10909-012-0556-0

Stellar laboratories: New Ge V and Ge VI oscillator strengths and their validation in the hot white dwarf RE 0503-289. Rauch, T., Werner, K., Biémont, É., et al. *Astron. Astrophys.* 546, A55, doi:10.1051/0004-6361/201220014

Reducing the read noise of HAWAII-2RG detector systems with improved reference sampling and subtraction (IRS^2). Rauscher, Bernard J., Arendt, Richard G., Fixsen, D. J., et al. *Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V*, 84531F, doi:10.1117/12.926089

Spatial distribution of solar energetic particles in the inner heliosphere. Reames, Donald V., Ng, Chee K., and Tylka, Allan J. *Solar Phys.* 126, doi:10.1007/s11207-012-0038-1

The Atacama Cosmology Telescope: High-resolution Sunyaev-Zel'dovich array observations of ACT SZE-selected clusters from the equatorial strip. Reese, Erik D., Mroczkowski, Tony, Menanteau, Felipe, et al. *Astrophys. J.* 751, 12, doi:10.1088/0004-637X/751/1/12

A 200-second quasi-periodicity after the tidal disruption of a star by a dormant black hole. Reis, R. C., Miller, J. M., Reynolds, M. T., et al. *Science* 337, 949, doi:10.1126/science.1223940

Near-Earth solar wind flows and related geomagnetic activity during more than four solar cycles (1963-2011). Richardson, Ian G. and Cane, Hilary V. *J. Space Weather Space Clim.* 2, A01, doi:10.1051/swsc/2012001

Solar wind drivers of geomagnetic storms during more than four solar cycles. Richardson, Ian G. and Cane, Hilary V. *J. Space Weather Space Clim.* 2, A01, doi:10.1051/swsc/2012001

Near-infrared band strengths of molecules diluted in n_2 and h_2o ice mixtures relevant to interstellar and planetary ices. Richey, C. R. and Gerakines, P. A. *Astrophys. J.* 759, 74, doi:10.1088/0004-637X/759/1/74

Science operations with the James Webb Space Telescope. Rigby, Jane, Sonneborn, George, Pollizzi, Joe, et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 844229, doi:10.1117/12.926504

Using statistical multivariable models to understand the relationship between interplanetary coronal mass ejecta and magnetic flux ropes. Riley, P. and Richardson, I. G. *Solar Phys.* 102, doi:10.1007/s11207-012-0006-9

Design and status of the Balloon Experimental Twin Telescope for infrared interferometry (BETTII): an interferometer at the edge of space. Rinehart, S. A., Barclay, R. B., Barry, R. K., et al. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 844508, doi:10.1117/12.926376

HD 172555: Detection of 63 μm [OI] emission in a debris disc. Riviere-Marichalar, P., Barrado, D., Augereau, J.-C., et al. *Astron. Astrophys.* 546, L8, doi:10.1051/0004-6361/201219745

Tracking near-infrared fringes on BETTII: a balloon-borne, 8m-baseline interferometer. Rizzo, Maxime J., Rinehart, Stephen A., Barry, Richard K., et al. *Proc. SPIE 8445, Optical and Infrared Interferometry III*, 84451T, doi:10.1117/12.925593

The exozodiacal dust problem for direct observations of exo-Earths. Roberge, Aki, Chen, Christine H., Millan-Gabet, Rafael, et al. *Pub. Astron. Soc. Pacific* 124, 799, doi:10.1086/667218

The Gray Needle: Large grains in the HD 15115 debris disk from LBT/PISCES/Ks and LBTI/LMIRcam/L' adaptive optics imaging. Rodigas, Timothy J., Hinz, Philip M., Leisenring, Jarron, et al. *Astrophys. J.* 752, 57, doi:10.1088/0004-637X/752/1/57

Fast simulations of gas sloshing and cold front formation. Roediger, E. and Zuhone, J. A. *Mon. Not. R. Astron. Soc.* 419, 1338, doi:10.1111/j.1365-2966.2011.19794.x

The unusual temporal and spectral evolution of the Type IIn supernova 2011ht. Roming, P. W. A., Pritchard, T. A., Prieto, J. L., et al. *Astrophys. J.* 751, 92, doi:10.1088/0004-637X/751/2/92

The Herschel Multi-tiered Extragalactic Survey: SPIRE-mm photometric redshifts. Roseboom, I. G., Ivison, R. J., Greve, T. R., et al. *Mon. Not. R. Astron. Soc.* 419, 2758, doi:10.1111/j.1365-2966.2011.19827.x

Detector architecture of the Cosmology Large Angular Scale Surveyor. Rostem, K., Bennett, C. L., Chuss, D. T., et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 84521N, doi:10.1117/12.927056

The longitudinal properties of a solar energetic particle event investigated using modern solar imaging. Rouillard, A. P., Sheeley, N. R., Tylka, A., et al. *Astrophys. J.* 752, 44, doi:10.1088/0004-637X/752/1/44

Fermi-LAT constraints on the pulsar wind nebula nature of HESS J1857+026. Rousseau, R., Grondin, M.-H., Van Etten, A., et al. *Astron. Astrophys.* 544, A3, doi:10.1051/0004-6361/201118685Aug 2012

Large Binocular Telescope and Spitzer spectroscopy of star-forming galaxies at $1 < z < 3$: Extinction and star formation rate indicators. Rujopakarn, W., Rieke, G. H., Papovich, C. J., et al. *Astrophys. J.* 755, 168, doi:10.1088/0004-637X/755/2/168

Swift X-ray upper limits on Type Ia supernova environments. Russell, B. R. and Immler, S. *Astrophys. J. Lett.* 748, L29, doi:10.1088/2041-8205/748/2/L29

A panchromatic catalog of early-type galaxies at intermediate redshift in the Hubble Space Telescope Wide Field Camera 3 early release science field. Rutkowski, M. J., Cohen, S. H., Kaviraj, S., et al. *Astrophys. J. Suppl.* 199, 4, doi:10.1088/0067-0049/199/1/4

The size evolution of passive galaxies: Observations from the Wide-Field Camera 3 early release science program. Ryan, R. E., Jr., McCarthy, P. J., Cohen, S. H., et al. *Astrophys. J.* 749, 53, doi:doi:10.1088/0004-637X/749/1/53

SN 2010ay is a luminous and broad-lined Type Ic supernova within a low-metallicity host galaxy. Sanders, N. E., Soderberg, A. M., Valenti, S., et al. *Astrophys. J.* 756, 184, doi:10.1088/0004-637X/756/2/184

Observations of the post-shock break-out emission of SN 2011dh with XMM-Newton. Sasaki, M. and Ducci, L. *Astron. Astrophys.* 546, A80, doi:10.1051/0004-6361/201220200

Short timescale variations of the Hα double-peaked profile of the nucleus of NGC 1097. Schimoia, Jaderson S., Storchi-Bergmann, Thaisa, Nemmen, Rodrigo S., et al. *Astrophys. J.* 748, 145, doi:10.1051/0004-6361/201220200

GX 3+1: The stability of spectral index as a function of mass accretion rate. Seifina, Elena and Titarchuk, Lev. *Astrophys. J.* 747, 99, doi:10.1088/0004-637X/747/2/99

Development of dielectric X-ray microcalorimeter. Sekiya, N., Yamasaki, N. Y., Mitsuda, Ket al. *J. Low Temp. Phys.* 167, 435, doi:10.1007/s10909-012-0563-1

The Keck Interferometer Nuller. Serabyn, E., Mennesson, B., Colavita, M. M., et al. *Astrophys. J.* 748, 55, doi:10.1088/0004-637X/748/1/55

Development of the onboard digital processing system for the soft X-ray spectrometer of ASTRO-H: performance in the engineering model tests. Seta, H., Tashiro, M. S., Ishisaki, Y., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84435D, doi:10.1117/12.924638

Advances in the RXTE proportional counter array calibration: Nearing the statistical limit. Shaposhnikov, Nikolai, Jahoda, Keith, Markwardt, Craig, et al. *Astrophys. J.* 757, 159, doi:10.1088/0004-637X/757/2/159

Source-plane reconstruction of the bright lensed galaxy RCSGA 032727–132609. Sharon, Keren, Gladders, Michael D., Rigby, Jane R., et al. *Astrophys. J.* 746, 161, doi:10.1088/0004-637X/746/2/161

Stray light suppression in the Goddard IRAM 2-Millimeter Observer (GISMO). Sharp, E. H., Benford, D. J., Fixsen, D. J., et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 84523I, doi:10.1117/12.926828

SOFIA observations of S106: Dynamics of the warm gas. Simon, R., Schneider, N., Stutzki, J., et al. *Astron. Astrophys.* 542, L12, doi:10.1051/0004-6361/201218931

Hubble Space Telescope FUV spectra of the post-common-envelope Hyades binary V471 Tauri. Sion, Edward M., Bond, Howard E., Lindler, Don, et al. *Astrophys. J.* 751, 66, doi:10.1088/0004-637X/751/1/66

Variability of disk emission in pre-main sequence and related stars. II.

Variability in the gas and dust emission of the Herbig Fe Star SAO 206462. Sitko, Michael L., Day, Amanda N., Kimes, Robin Let al. *Astrophys. J.* 745, 29, doi:10.1088/0004-637X/745/1/29

Inverse Compton X-ray halos around high-z radio galaxies: A feedback mechanism powered by far-infrared starbursts or the cosmic microwave background? Smail, Ian, Blundell, Katherine M., Lehmer, B. D., and Alexander, D. M. *Astrophys. J.* 760, 132, doi:10.1088/0004-637X/760/2/132

Anomalous low states and long-term variability in the black hole binary LMC X-3. Smale, Alan P. and Boyd, Patricia T. *Astrophys. J.* 756, 146, doi:10.1088/0004-637X/756/2/146

Fast X-ray transients towards the Galactic bulge with the Rossi X-ray Timing Explorer. Smith, D. M., Markwardt, C. B., Swank, J. H., and Negueruela, I. *Mon. Not. R. Astron. Soc.* 422, 2661, doi:10.1111/j.1365-2966.2012.20836.x

Science metrics for a NASA large optic X-ray microcalorimeter mission. Smith, Randall K., Bookbinder, Jay, Garcia, Michael, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84431J, doi:10.1117/12.926534

Small pitch transition-edge sensors with broadband high spectral resolution for solar physics. Smith, S. J., Adams, J. S., Bailey, C. N., et al. *J. Low Temp. Phys.* 167, 168, doi:10.1007/s10909-012-0574-y

Panchromatic observations of SN 2011dh point to a compact progenitor star. Soderberg, A. M., Margutti, R., Zauderer, B. A., et al. *Astrophys. J.* 752, 78, doi:10.1088/0004-637X/752/2/78

The first stars: mass growth under protostellar feedback. Stacy, Athena, Greif, Thomas H., and Bromm, Volker. *Mon. Not. R. Astron. Soc.* 422, 290, doi:10.1111/j.1365-2966.2012.20605.x.

Effect of Population III multiplicity on dark star formation. Stacy, Athena, Pawlik, Andreas H., Bromm, Volker, and Loeb, Abraham. *Mon. Not. R. Astron. Soc.* 421, 894, doi:10.1111/j.1365-2966.2011.20373.x

The GISMO-2 bolometer camera. Staguhn, Johannes G., Benford, Dominic J., Fixsen, Dale J., et al. *Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*, 84520T, doi:10.1117/12.927037

A determination of the intergalactic redshift-dependent ultraviolet-optical-NIR photon density using deep galaxy survey data and the gamma-ray opacity of the universe. Stecker, Floyd W., Malkan, Matthew A., and Scully, Sean T. *Astrophys. J.* 761, 128, doi:10.1088/0004-637X/761/2/128

Mid-infrared selection of active galactic nuclei with the Wide-Field Infrared Survey Explorer. I. Characterizing WISE-selected active galactic nuclei in COSMOS. Stern, Daniel, Assef, Roberto J., Benford, Dominic J., et al. *Astrophys. J.* 753, 30, doi:10.1088/0004-637X/753/1/30

Multi-wavelength observations of the enduring type IIn supernovae 2005ip and 2006jd. Stritzinger, Maximilian, Taddia, Francesco, Fransson, Claes, et al. *Astrophys. J.* 756, 173, doi:10.1088/0004-637X/756/2/173

Broadband spectroscopy using two Suzaku observations of the HMXB GX 301-2. Suchy, Slawomir, Fürst, Felix, Pottschmidt, Katja, et al. *Astrophys. J.* 745, 124, doi:10.1088/0004-637X/745/2/124

Measurement of reflectivity of X-ray mirror for soft X-ray telescope onboard ASTRO-H. Sugita, Satoshi, Furuzawa, Akihiro, Ishibashi, Kazunori, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844358, doi:10.1117/12.926711

Luminosity correlations for gamma-ray bursts and implications for their prompt and afterglow emission mechanisms. Sultana, J., Kazanas, D., and Fukumura, K. *Astrophys. J.* 758, 32, doi:10.1088/0004-637X/758/1/32

Bending of light in modified gravity at large distances. Sultana, Joseph and Kazanas, Demosthenes. *Phys. Rev. D* 85, 81502, doi:10.1103/PhysRevD.85.081502

Conformal Weyl gravity and perihelion precession. Sultana, Joseph, Kazanas, Demosthenes, and Said, Jackson Levi. *Phys. Rev. D* 86, 84008, doi:10.1103/PhysRevD.86.084008

A generalized porosity formalism for isotropic and anisotropic effective opacity and its effects on X-ray line attenuation in clumped O star winds. Sundqvist, Jon O., Owocki, Stanley P., Cohen, David H., et al. *Mon. Not. R. Astron. Soc.* 420, 1553, doi: 10.1111/j.1365-2966.2011.20141.x

The ASTRO-H X-ray Observatory. Takahashi, Tadayuki, Mitsuda, Kazuhisa, Kelley, Richard, et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84431Z, doi:10.1117/12.926190

Use of incident and reflected solar particle beams to trace the topology of magnetic clouds. Tan, Lun C., Malandraki, Olga E., Reames, Donald V., et al. *Astrophys. J.* 750, 146, doi:10.1088/0004-637X/750/2/146

Detection of a cool, accretion-shock-generated X-ray plasma in EX Lupi during the 2008 optical eruption. Teets, William K., Weintraub, David A., Kastner, Joel H., et al. *Astrophys. J.* 760, 89, doi:10.1088/0004-637X/760/1/89

Infrared and x-ray spectroscopy of the Kes 75 supernova remnant shell: Characterizing the dust and gas properties. Temim, Tea, Slane, Patrick, Arendt, Richard G., and Dwek, Eli. *Astrophys. J.* 745, 46, doi:10.1088/0004-637X/745/1/46

Properties and spatial distribution of dust emission in the Crab Nebula. Temim, Tea, Sonneborn, George, Dwek, Eli, Arendt, Richard G., et al. *Astrophys. J.* 753, 72, doi:10.1088/0004-637X/753/1/72

Chandra observations of Galaxy Zoo mergers: Frequency of binary active nuclei in massive mergers. Teng, Stacy H., Schawinski, Kevin, Urry, C. Megan, et al. *Astrophys. J.* 753, 165, doi:10.1088/0004-637X/753/2/165

He II λ4686 in η Carinae: Collapse of the wind-wind collision region during periastron passage. Teodoro, M., Damineli, A., Arias, J. I., et al. *Astrophys. J.* 746, 73, doi:10.1088/0004-637X/746/1/7

Constraining the high-energy emission from gamma-ray bursts with Fermi. Ackermann, M., Ajello, M., Baldini, L., et al. *Astrophys. J.* 754, 121, doi:10.1088/0004-637X/754/2/121

Cosmic ray studies with the Fermi Gamma-ray Space Telescope Large Area Telescope. Thompson, D. J., Baldini, L., & Uchiyama, Y. *Astropart. Phys.* 39, 22, doi:10.1016/j.astropartphys.2011.10.009

Gas modelling in the disc of HD 163296. Tilling, I., Woitke, P., Meeus, G., *Astron. Astrophys.* 538, A20, doi:10.1051/0004-6361/201116919

Current flow and pair creation at low altitude in rotation-powered pulsars' force-free magnetospheres: space charge limited flow. Timokhin, A. N. and Arons, J. *Mon. Not. R. Astron. Soc.* 356, 20, doi:10.1093/mnras/sts298

An upscattering spectral formation model for the prompt emission of gamma-ray bursts. Titarchuk, Lev, Farinelli, Ruben, Frontera, Filippo, and Amati, Lorenzo. *Astrophys. J.* 752, 116, doi:10.1088/0004-637X/752/2/116

X-ray Emission from the Wolf-Rayet bubble S 308. Toalá, J. A., Guerrero, M. A., Chu, Y.-H., et al. *Astrophys. J.* 755, 77, doi:10.1088/0004-637X/755/1/77

Evidence for ultrafast outflows in radio-quiet AGNs - III. Location and energetics. Tombesi, F., Cappi, M., Reeves, J. N., and Braito, V. *Mon. Not. R. Astron. Soc. Lett.* 422, L1, doi:10.1111/j.1745-3933.2012.01221.x

Comparison of ejection events in the jet and accretion disc outflows in 3C 111. Tombesi, F., Sambruna, R. M., Marscher, A. P., et al. *Mon. Not. R. Astron. Soc.* 424, 754, doi:10.1111/j.1365-2966.2012.21266.x

NGC 2782: a merger remnant with young stars in its gaseous tidal tail. Torres-Flores, S., de Oliveira, C. Mendes, de Mello, D. F., et al. *Mon. Not. R. Astron. Soc.* 421, 3612, doi:10.1111/j.1365-2966.2012.20589.x

The Chandra Multi-wavelength Project: Optical spectroscopy and the broadband spectral energy distributions of X-ray-selected AGNs.Trichas, Markos, Green, Paul J., Silverman, John D., et al. *Astrophys. J. Suppl.* 200, 17, doi:10.1088/0067-0049/200/2/17

Broadband study of GRB 091127: A sub-energetic burst at higher redshift? Troja, E., Sakamoto, T., Guidorzi, C., et al. *Astrophys. J.* 761, 50, doi:10.1088/0004-637X/761/1/50

Sonification of of Kepler Field SU UMa cataclysmic variable stars V344 Lyr and V1504 Cyg. Tutchton, R. M., Wood, M. A., Still, M. D., et al. *J. Southeast. Assoc. Res. Astron.* 6, 21.

A Suzaku study of ejecta structure and origin of hard X-ray emission in the supernova remnant G156.2+5.7. Uchida, Hiroyuki, Tsunemi, Hiroshi, Katsuda, Satoru, et al. *Publ. Astron. Soc. Japan* 64, 61.

The lag-luminosity relation in the GRB source frame: an investigation with Swift BAT bursts. Ukwatta, T. N., Dhuga, K. S., Stamatikos, M., et al. *Mon. Not. R. Astron. Soc.* 419, 614, doi:10.1111/j.1365-2966.2011.19723.x

Coronagraphic imaging of debris disks from a high altitude balloon platform. Unwin, Stephen, Traub, Wesley, Bryden, Geoffrey, et al. *Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and Millimeter Wave*, 84420G, doi:10.1117/12.924175

Effects of helium enrichment in globular clusters. I. Theoretical plane with PGPUC stellar evolution code. Valcarce, A. A. R., Catelan, M., and Sweigart, A. V. *Astron. Astrophys.* 547, A5, doi:10.1051/0004-6361/201219510

SGR J1550-5418 bursts detected with the Fermi Gamma-Ray Burst Monitor during its most prolific activity. van der Horst, A. J., Kouveliotou, C., Gorgone, N. M., et al. *Astrophys. J.* 749, 122, doi:10.1088/0004-637X/749/2/122

Modeling phase-aligned gamma-ray and radio millisecond pulsar light curves. Venter, C., Johnson, T. J., and Harding, A. K. *Astrophys. J.* 744, 34, doi:10.1088/0004-637X/744/1/34

SMART-X: Square Meter Arcsecond Resolution X-ray Telescope. Vikhlinin, A., Reid, P., Tananbaum, H., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 844316, doi:10.1117/12.926851

Detection of spectral evolution in the bursts emitted during the 2008-2009 active episode of SGR J1550–5418. von Kienlin, Andreas, Gruber, David, Kouveliotou, Chryssa, et al. *Astrophys. J.* 755, 150, doi:10.1088/0004-637X/755/2/150

Present-day descendants of z = 3 Lyα-emitting galaxies in the Millennium-II halo merger trees. Walker-Soler, Jean P., Gawiser, Eric, Bond, Nicholas A., et al. *Astrophys. J.* 752, 160, doi:10.1088/0004-637X/752/2/160

Probing pre-galactic metal enrichment with high-redshift gamma-ray bursts. Wang, F. Y., Bromm, Volker, Greif, Thomas H., et al. *Astrophys. J.* 760, 27, doi:10.1088/0004-637X/760/1/27

Evidence for type Ia supernova diversity from ultraviolet observations with the Hubble Space Telescope. Wang, Xiaofeng, Wang, Lifan, Filippenko, Alexei V., et al. *Astrophys. J.* 749, 126, doi:10.1088/0004-637X/749/2/126

Automation of the OAN/SPM 1.5-meter Johnson telescope for operations with RATIR. Watson, Alan M., Richer, Michael G., Bloom, Joshua S., et al. Proc. SPIE 8444, Ground-based and Airborne Telescopes IV, 84445L, doi:10.1117/12.926927

First detection of krypton and xenon in a white dwarf. Werner, Klaus, Rauch, Thomas, Ringat, Ellen, and Kruk, Jeffrey W. *Astrophys. J. Lett.* 753, L7, doi:10.1088/2041-8205/753/1/L7

The Swift Burst Alert Telescope perspective on non-thermal emission in HIFLUGCS galaxy clusters. Wik, Daniel R., Sarazin, Craig L., Zhang, Yu-Ying, et al. *Astrophys. J.* 748, 67, doi:10.1088/0004-637X/748/1/67

Responding to the event deluge. Williams, Roy D., Barthelmy, Scott D., Denny, Robert B., et al. *Proc. SPIE 8448, Observatory Operations: Strategies, Processes, and Systems IV*, 84480R, doi:10.1117/12.925252

The Swift Burst Alert Telescope detected Seyfert 1 galaxies: X-ray broadband properties and warm absorbers. Winter, Lisa M., Veilleux, Sylvain, McKernan, Barry, and Kallman, T. R. *Astrophys. J.* 745, 107, doi:10.1088/0004-637X/745/2/107

Submillimeter follow-up of WISE-selected hyperluminous galaxies. Wu, Jingwen, Tsai, Chao-Wei, Sayers, Jack, et al. *Astrophys. J.* 756, 96, doi:10.1088/0004-637X/756/1/96

Stellar populations of highly magnified lensed galaxies: Young starbursts at z ~ 2. Wuyts, Eva, Rigby, Jane R., Gladders, Michael D., et al. *Astrophys. J.* 745, 86, doi:10.1088/0004-637X/745/1/86

Constraints on the low-mass end of the mass-metallicity relation at z = 1-2 from lensed galaxies. Wuyts, Eva, Rigby, Jane R., Sharon, Keren, and Gladders, Michael D. *Astrophys. J.* 755, 73, doi:10.1088/0004-637X/755/1/73

Metallicities of emission-line galaxies from HST ACS PEARS and HST WFC3 ERS grism spectroscopy at 0.6 < z < 2.4. Xia, Lifang, Malhotra, Sangeeta, Rhoads, James, et al. *Astron. J.* 144, 28, doi:10.1088/0004-6256/144/1/28

Location prediction of electron TGFs. Xiong, S., Briggs, M. S., Connaughton, V., et al. *J. Geophys Res. Space Phys.* 117, 2309, doi:10.1029/2011JA017085

Tracking down the source population responsible for the unresolved cosmic 6–8 keV background. Xue, Y. Q., Wang, S. X., Brandt, W. N., et al. *Astrophys. J.* 758, 129, doi:10.1088/0004-637X/758/2/129

Data-oriented diagnostics of pileup effects on the Suzaku XIS. Yamada, Shin'ya, Uchiyama, Hideki, Dotani, Tadayasu, et al. *Publ. Astron. Soc. Japan* 64, 53.

Elemental abundances in the possible type Ia supernova remnant G344.7-0. Yamaguchi, H., Tanaka, M., Maeda, K., et al. *Astrophys. J.* 749, 137.

Development of resistive electrode gas electron multiplier (RE-GEM). Yoshikawa, A., Tamagawa, T., Iwahashi, T., et al. *J. Instrum.* 7, 6006, doi:10.1088/1748-0221/7/06/C06006

Variability-selected low-luminosity active galactic nuclei in the 4 Ms Chandra Deep Field-South. Young, M., Brandt, W. N., Xue, Y. Q., et al. *Astrophys. J.* 748, 124, doi:10.1088/0004-637X/748/2/124

A 3 pc scale Jet-driven outflow from Sgr A*. Yusef-Zadeh, F., Arendt, R., Bushouse, H., et al. *Astrophys. J. Lett.* 758, L11, doi:10.1088/2041-8205/758/1/L11

Energy-dependent orbital modulation of X-rays and constraints on emission of the jet in Cyg X-3. Zdziarski, Andrzej A., Maitra, Chandreyee, Frankowski, Adam, et al. *Mon. Not. R. Astron. Soc*. 426, 1031, doi:10.1111/j.1365-2966.2012.21635.x

η Carinae: Linelist for the emission spectrum of the Weigelt blobs in the 1700 to 10400 Å wavelength region. Zethson, T., Johansson, S., Hartman, H., and Gull, T. R. *Astron. Astrophys.* 540, A133, doi:10.1051/0004-6361/201116696

Unusual central engine activity in the double burst GRB 110709B. Zhang, Bin-Bin, Burrows, David N., Zhang, Bing, et al. *Astrophys. J.* 748, 132, doi:10.1088/0004-637X/748/2/132

Next generation astronomical x-ray optics: high angular resolution, light weight, and low production cost. Zhang, W. W., Biskach, M. P., Blake, P. N., et al. *Proc. SPIE 8443, Space Telescopes and Instrumentation 2012: Ultraviolet to Gamma Ray*, 84430S, doi:10.1117/12.926034

Panchromatic observations of the textbook GRB 110205A: Constraining physical mechanisms of prompt emission and afterglow. Zheng, W., Shen, R. F., Sakamoto, T., et al. *Astrophys. J.* 751, 90, doi:10.1088/0004-637X/751/2/90

GRB 110709A, 111117A, and 120107A: Faint high-energy gamma-ray photon emission from Fermi-LAT observations and demographic implications. Zheng, WeiKang, Akerlof, Carl W., Pandey, Shashi B., et al. 2012 *Astrophys. J.* 756, 64, doi:10.1088/0004-637X/756/1/64

BD–22°3467, a DAO-type star exciting the nebula Abell 35. Ziegler, M., Rauch, T., Werner, K., et al. *Astron. Astrophys.* 548, A109, doi:10.1051/0004-6361/201219536

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01-03-2013

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Goddard's Astrophysics Science Division Annual Report 2012

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Padi Boyd and Francis Reddy, Editors

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Astrophysics Science Division
NASA Goddard Space Flight Center

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITOR'S ACRONYM(S)
NASA/GSFC

11. SPONSORING/MONITORING REPORT NUMBER
TM-2013-XXXXXX

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited, Subject Category: 90
Report available from the NASA Center for Aerospace Information, 7115 Standard Drive, Hanover, MD 21076. (443)757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Astrophysics Science Division (ASD) at Goddard Space Flight Center (GSFC) is one of the largest and most diverse astrophysical organizations in the world, with activities spanning a broad range of topics in theory, observation, and mission and technology development. Scientific research is carried out over the entire electromagnetic spectrum—from gamma rays to radio wavelengths—as well as particle physics and gravitational radiation. Members of ASD also provide the scientific operations for three orbiting astrophysics missions—WMAP, RXTE, and Swift, as well as the Science Support Center for the Fermi Gamma-ray Space Telescope. A number of key technologies for future missions are also under development in the Division, including X-ray mirrors, space-based interferometry, high contrast imaging techniques to search for exoplanets, and new detectors operating at gamma-ray, X-ray, ultraviolet, infrared, and radio wavelengths. The overriding goals of ASD are to carry out cutting-edge scientific research, provide Project Scientist support for spaceflight missions, implement the goals of the NASA Strategic Plan, serve and support the astronomical community, and enable future missions by conceiving new concepts and inventing new technologies.

15. SUBJECT TERMS
Astronomical instruments and techniques; radio, gamma-ray, X-ray, ultraviolet, infrared astronomy; cosmology; particle physics; gravitational radiation; celestial mechanics; space plasmas; and interstellar and interplanetary gases and dust.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			William Oegerle
Unclassified	Unclassified	Unclassified	Unclassified	120	19b. TELEPHONE NUMBER *(Include area code)* (301) 286-8801