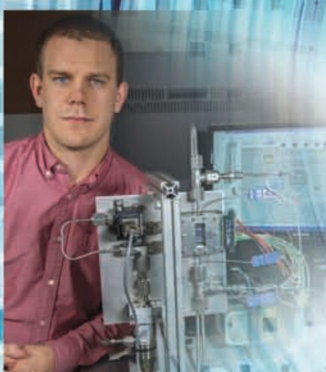
National Aeronautics and Space Administration

2015 R&D Achievements

The Full Spectrum: Smallsats to Flagships

A Report from the Goddard Office of the Chief Technologist



Goddard Space Flight Center
Greenbelt, Maryland

www.nasa.gov

inside

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Pictured are just a few of the technologists who are either pursuing or implementing new technologies. From top left, moving clockwise: roboticist Stephen Roderick (page 23), Goddard engineer Nithin Abraham (page 10), Goddard scientist Xiaoli Sun (page 19), and technologist Franklin Robinson (page 22).

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Message from the Chief Technologist:

From Smallsats to Flagships: Providing the Full Spectrum of Space Technologies

At the end of each year, we evaluate the effectiveness of the center's Internal Research and Development (IRAD) program. We ask: what did the program accomplish? Did the financial return on investment — that is, the return on technology development relative to its costs — exceed the initial investment? Is the program truly advancing the technologies that NASA will need in the future? Where can it improve?

The take-away in 2015 was heartening.

Our analysis indicated that the program continues to exceed our own ambitious goals, both technologically and financially, assuring the center's competiveness in the future. The financial return on investment due to follow-on NASA R&D funding and new mission and instrument starts — the classic measure for gauging effectiveness — was two times IRAD investments in FY15.

All Goddard science disciplines — astrophysics, heliophysics, planetary, and Earth science — prevailed under highly competitive conditions. They all won awards that assure that the science areas in which Goddard has traditionally excelled will continue to be well positioned for success in the future.

Digging deeper into the numbers, we found that of the IRAD-funded technologies that received additional NASA funding, seven resulted in either new missions or had been chosen for Phase-A studies. Perhaps more significant is the fact that these seven wins covered the gamut in mission types, from highly visible aircraft investigations to diminutive CubeSat and larger Explorer- or Discovery-class missions — literally the gamut in scientific research. Just as important, is that these competitive awards involved strategic partnerships with others who bring their own strengths to these missions.

Full Spectrum of Capabilities Assures Relevance

In other words, these achievements represented the full spectrum of space technology and platforms — a level of diversity important to maintain the center's relevance and viability.

Even the accomplishments of this year's IRAD Innovator of the Year — scientist Nikolaos Paschalidis — enabled a full spectrum of capabilities. Widely used microchips he created flew not only on NASA's New Horizons mission to Pluto — the agency's first-ever visit to this distant world — but also on the four-satellite, formation-flying Magnetospheric Multiscale mission, among others.

The technology also factored into NASA's selection of a new CubeSat mission awarded this year and the return of valuable science data from a National Science Foundation CubeSat mission called ExoCube.

IRAD Program Enables Science Across the Spectrum

These examples just scrape the surface. In this report, we highlight other notable achievements that underscore how Goddard, through its IRAD program, is enabling science across the full spectrum, positioning the center to win CubeSat and flagship-type missions in the future.

In closing, we are delighted that our program has supported the Goddard technology-development community in the areas that the center has deemed strategically important. We are delighted that our investments are reducing mission risk and, in many cases, involving partnerships with other institutions, enabling a far greater cross-fertilization of ideas and capabilities. In short, we are delighted that we are fulfilling our mission as a spaceflight center — developing the technologies NASA will need to carry out mission science across the full spectrum.

Peter Hughes
Chief Technologist
Goddard Space Flight Center

CHAPTER TWO

Where Success Begins: Aligning Investments to Goddard's Lines of Business

Four mission starts and two Phase-A studies were awarded in 2015, nothing like ending the year on a high note. These successes are just part of the story, however. Our technologists continued to secure impressive levels of follow-on funding to further advance their technologies, levels that more than compensated for our initial investment in their concepts (see page 5 for details).

We believe the secret to our success for both Goddard's Internal Research and Development (IRAD) and Center Innovation Fund (CIF) programs is our methodology — the focus and discipline we employ to identify investment priorities, unmet needs, and target opportunities.

Selection Criteria for IRAD and CIF

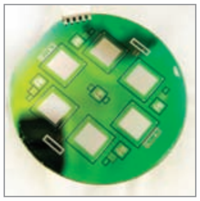
Under the IRAD program, for example, we fund only those efforts that map to one or more of Goddard's strategic lines of business. In addition, we adhere to strict selection standards and require principal investigators to compete for their awards.

For NASA's CIF, we award research dollars only to proposals that demonstrate technical merit, feasibility, relevance, and value to NASA. All are highly innovative, crosscutting, and considered early stage in their development. Many also leverage partner resources and have the potential to contribute significantly to national needs.

Lines of Business: At A Glance

Astrophysics
Focuses on missions and technologies enabling the study of galaxies, stars, and planetary systems beyond our own solar system.

Communications and Navigation
Supports systems and technologies needed for responsive communications and navigation.



Crosscutting Technology and Capabilities
Addresses capabilities applicable to more than one strategic line of business, everything from nanomaterials and electronics to detectors and system architectures.

Earth Science
Supports technologies and advanced science instruments needed to observe and understand changes in Earth's natural systems and processes, including climate, severe weather, the atmosphere, the oceans, sea ice and glaciers, and the land surface.

Heliophysics

Conducts research on the sun, its extended solar-system environment (the heliosphere), and interactions of Earth, other planets, small bodies, and interstellar gas with the heliosphere.

Human Exploration and Operations

Supports infusion of science and enabling capabilities and technologies into human exploration.

Planetary Science

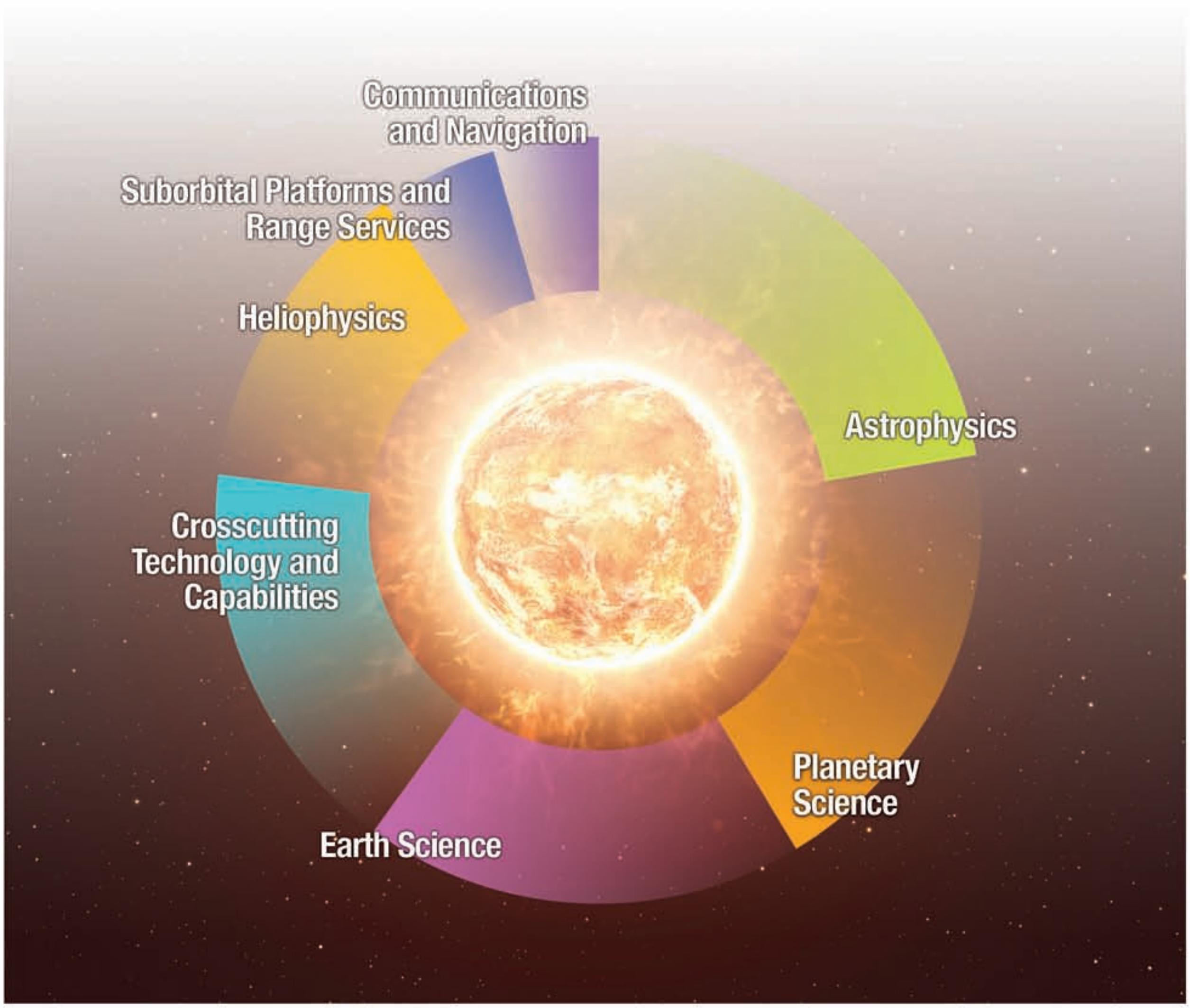
Supports technologies to explore the solar system, particularly instruments for landers and orbiting spacecraft.

Suborbital Platforms and Range Services

Supports systems typically used to place payloads into suborbital attitude, including sounding rockets, balloons, and manned and unmanned aircraft. In recent years, the LOB has expanded to include CubeSat capabilities. Range services include assets for conducting, launching, and operating missions.

Breakdown of FY15 Awards

Goddard is a successful organization. It has proven adept at creating, fine-tuning, and adapting emerging technologies largely because the center focuses on strategic technological areas that match the skills of the workforce. Here is the breakdown of our FY15 investments.



"Technically, I think Nick is as close to a genius as anyone can come. He is incredibly creative, finding solutions where others can't."

— Dr. Michael Hesse, Chief, Heliophysics Division

CHAPTER THREE

Personifying the Full Spectrum: Nikolaos Paschalidis Recognized as the FY15 IRAD Innovator of the Year

Heliophysicist Nikolaos Paschalidis — known simply as Nick among his friends and colleagues — won the FY15 IRAD Innovator of the Year award that Goddard bestows each year on the principal investigator who exemplifies the best in research and development.

Goddard space scientist Nikolaos Paschalidis created five instrument-enabling microchips. Here, he is pictured with the technology.

This year, the decision as to whom to honor ended up being straightforward. One of the center's most productive innovators, conceiving ideas, creating instruments, and mentoring the next generation of research scientists, Paschalidis enjoyed an extraordinary year.

Here's a snapshot:

- Five multi-purpose microchips, which he created 15 years ago to provide time-of-flight, energy, position, and other measurements, were put to the test this summer when the New Horizons spacecraft reached Pluto. This accomplishment, however, was just the latest in a long list of achievements for his continually evolving technology.

His application-specific integrated circuits also flew on the Magnetospheric Multiscale mission, launched in 2015, the Interstellar Boundary Explorer, Juno, MESSENGER, and the Van Allen Probes, among others. Upcoming missions, including BepiColombo, Solar Orbiter, and Solar Probe+, also will benefit from his work.

- His Mini Ion-Neutral Mass Spectrometer — the smallest instrument ever built of its type — returned valuable, much-sought-after data during the National Science Foundation-funded ExoCube mission. Paschalidis, however, cast his sights higher, finding an opportunity to fly an improved version of his instrument on a new Goddard-developed 6U CubeSat called Dellingr.

- His insights contributed to the award of two CubeSat missions: the Compact Radiation belt Explorer (CERES) and, in 2015, the CubeSat Mission to Study Solar Particles over the Earth's Poles Enhancement (CuSPP+) (see page 17). These wins underscored his incalculable value to the center's efforts to position itself as a world-class developer of small-satellite missions, instrumentation, and components.

Paschalidis's successes spanned the spectrum in mission types, from CubeSat to high-profile flagship-type missions. He personified the trends that will assure the center's leadership in the years to come.

Masthead Above:
This artist's rendering of NASA's New Horizons mission shows the spacecraft as it approaches Pluto. The mission passed by the planet in July 2015.

CHAPTER FOUR

The Year's Notable Accomplishments: Achieving the Full Spectrum of Capabilities

Since its conception in 1959, Goddard has remained true to its charter. Goddard is a space flight center. The center applies emerging technologies to enable forward-reaching science missions using a range of platforms — from flagship-type spacecraft and smallsats to high-altitude aircraft, balloons, and the International Space Station.

"All Goddard science disciplines — astrophysics, heliophysics, planetary, and Earth science — scored wins, meaning that the science areas in which Goddard has traditionally excelled continue to be well positioned for success in the future."
— Peter Hughes, Goddard Chief Technologist

In FY15, Goddard technologists certainly demonstrated their commitment to this charter. They enjoyed a number of notable accomplishments. They won new missions. They launched new missions. They passed critical mission milestones. They infused their technology into instrument concepts. And they received NASA follow-on funding to further advance their concepts.

This chapter details some of those accomplishments as well as others that underscore the center's success at developing technologies across the full spectrum.

Phase-A Studies and Missions Awarded; New Missions Launched; and Critical Mission Milestones Passed

The crowning achievement of any technology program is an investment that leads to the award of a new spaceflight mission. In FY15, principal investigators not only won new missions, but also met critical milestones in the development of previously awarded missions won due to previous R&D funding.

Polarimeter for Relativistic Astrophysical X-ray Sources (PRAXyS)

NASA's Explorer Program selected PRAXyS for a Phase-A study. Over the next several months, the team will flesh out the details of a mission that would explore the shape of space that has been distorted by a spinning black hole's gravity.
(Investment Area: Astrophysics)

Pre-Aerosol, Clouds, and ocean Ecosystem (PACE)

NASA formally assigned the PACE mission to Goddard in FY15 and is now considering the Goddard-developed Ocean Radiometer for Carbon Assessment (ORCA) as one of its payloads. If selected, ORCA will study microscopic phytoplankton, tiny green plants that float in the upper layer of the ocean and make up the base of the marine food chain.
(Investment Area: Earth Science)

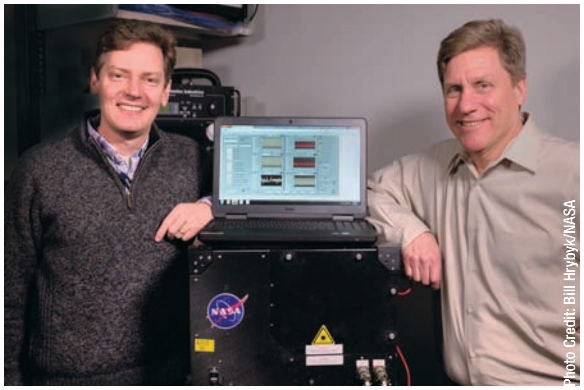
Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI)

NASA's Discovery Program announced the selection of five planetary mission concepts for Phase-A studies, including the Goddard-led DAVINCI, which would study the chemical composition of the Venusian atmosphere during a 63-minute descent. According to Principal Investigator Lori Glaze, the mission would answer scientific questions that have been considered high priorities for many years, such as whether volcanoes remain active today and how the surface interacts with the planet's atmosphere.
(Investment Area: Planetary Science)

A Soviet-era lander snapped this photo of the Venusian surface. A NASA team wants to return to Venus to discover whether volcanoes remain active today and how the surface interacts with the planet's atmosphere.

Atmospheric Tomography Mission (AToM)

NASA's Earth Venture Suborbital program selected the In-Situ Airborne Formaldehyde (ISAF) instrument as one of 15 instruments that will fly on AToM, an ambitious suborbital mission to obtain a general snapshot of the average atmosphere. ISAF, advanced in large part by IRAD funding, will calculate the levels of formaldehyde, a difficult-to-measure chemical useful as a surrogate or tracer for a whole host of volatile organic compounds that fuel the oxidation processes creating smog. Since ISAF's debut, Principal Investigator Tom Hanisco has further improved the instrument by applying an IRAD-supported carbon-nanotube coating on the instrument's baffle, which absorbs scattered light.
(Investment Area: Earth Science)



Goddard scientists Tom Hanisco (left) and Paul Newman (right) are serving as science team co-investigators on NASA's newest Earth Venture mission, AToM, short for the Atmospheric Tomography Mission.

Neutron Star Interior Composition/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT)

The Goddard team building NASA's NICER/SEXTANT mission — selected in large part due to past Goddard R&D support — sailed past all major development milestones in FY15 and is scheduled to be delivered to Cape Canaveral on time for its October 2016 launch. The revolutionary payload, which will carry out its studies aboard the International Space Station, will gather important scientific data about neutron stars and demonstrate groundbreaking navigation technologies all from the same platform.
(Investment Area: Astrophysics)

Technicians Alex Schaeffer (left) and Eric Norris (right) are seen reflected in a 3.3-foot-diameter parabolic mirror suspended 24 feet above the ground. The mirror provides a parallel beam that allowed the team to co-align NICER/SEXTANT's 56 X-ray optics.

Magnetospheric Multiscale (MMS) Mission

The highlight for Goddard's Heliophysics Division was the successful launch of MMS, a scientifically challenging mission made up of four identically equipped spacecraft that fly in a tight formation and take measurements 100 times faster than any previous space mission — a feat made possible by multiple new Goddard-developed technologies. (Investment Area: Heliophysics)

- Without Navigator GPS, it is conceivable that MMS could not have flown. This receiver and associated algorithms quickly acquire and track GPS radiowaves even in weak-signal areas, allowing the four spacecraft to fly in an exacting pyramid-shape formation. To the satisfaction of the technology's architect, Luke Winternitz, the system had tracked up to 12 GPS satellites and an average of nine shortly after the mission's March 2015 launch.

- Application-specific integrated circuits developed by Goddard heliophysicist Nikolaos Paschalidis — the recipient of this year's IRAD Innovator of the year award (see page 6) — also flew on two MMS instruments.

The four MMS spacecraft observatories are processed for launch in a cleanroom at the Astrotech Space Operations facility in Florida. The ambitious mission may not have happened without a handful of Goddard-developed technologies.

Technology Infusion

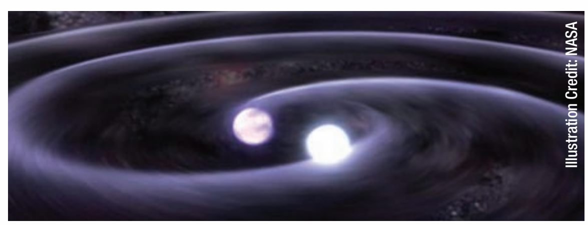
In addition to winning new missions, another significant metric for gauging success is whether a technology is used in a mission, instrument, or a NASA facility. As in past years, Goddard technologists were successful in infusing their technologies into the full spectrum of spaceflight applications.

Simulation and Modeling for Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On

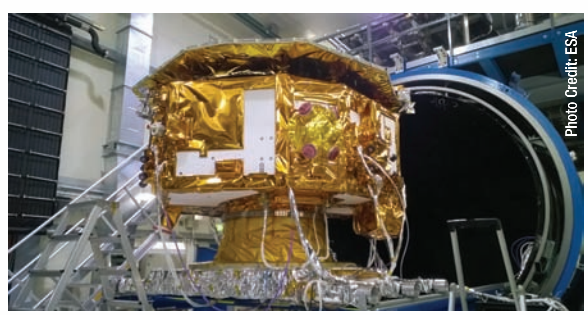
Principal Investigator Jeanne Sauber and former Goddard scientist Shin-Chan Han, who now works for Newcastle University in Australia, were selected to provide new simulation and modeling capabilities supporting NASA's GRACE mission as well as potential follow-on efforts. The team, which includes a number of university partners, attributes its win to its FY15 IRAD, where Sauber and Han created an innovative simulation to measure the gravity change associated with transient seismic and tsunami waves from space. (Investment Area: Earth Science)

LISA Pathfinder

A mission aimed at demonstrating technologies essential for detecting gravitational waves in space launched in December 2015. The LISA Pathfinder, which carries two payloads, including a set of NASA-developed microthrusters and a Goddard-developed algorithm, is demonstrating a technique called "drag-free" control. In addition to developing the computer code, Goddard scientists designed, modeled, and analyzed different experiments that scientists could carry out with the NASA payload. (Investment Area: Astrophysics)



Cataclysmic events, such as a binary-star merger depicted in this artist's rendition, are believed to create gravitational waves that cause ripples in space-time.



LISA Pathfinder, which will use a Goddard-developed algorithm, will demonstrate technologies essential for detecting gravitational waves.

Molecular Adsorber Coating (MAC)

The patent-pending MAC was applied to custom-designed panels installed in Chamber A, the thermal-vacuum test facility at NASA's Johnson Space Center where the James Webb Space Telescope underwent testing in 2015. The coating entraps potentially harmful outgassed molecular contaminants. In this application, MAC was used to capture outgassed contaminants that existed inside the vacuum chamber — not from the observatory's components. (Investment Area: Cross-cutting Technology and Capabilities)

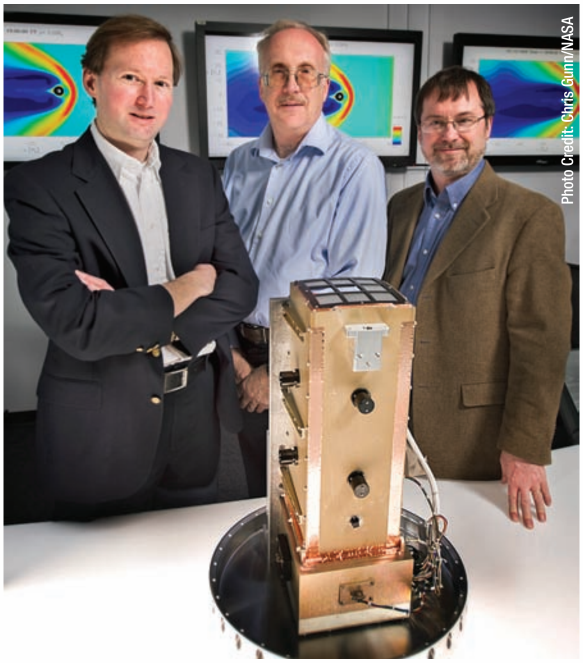
Goddard engineer Nithin Abraham places a MAC panel at the very bottom of Chamber A, a Johnson Space Center thermal-vacuum test facility used to test the James Webb Space Telescope.

Integrated Data Encoder for High Data Rate Ka-band Modulator

Space communications traditionally have used the S- and X-band, but as demand for higher data rates increases, missions have pushed to advance Ka-band technologies. Principal Investigator Wei-Chung Huang and Englin Wong reported that the Wide-Field Infrared Survey Telescope project has chosen a Ka-band modulator that the team developed and plan to fund additional improvements.
(Investment Area: Communications and Navigation)

Solar Wind Magnetosphere Ionosphere Link Explorer (SMILE)

The successful demonstration of the first wide-field-of-view soft X-ray camera that incorporated a never-before-flown X-ray focusing technology has led to a possible European-led mission that will employ the same measurement technique. An instrument similar in concept to the Goddard-developed Sheath Transport Observer for the Redistribution of Mass (STORM) now could be used in SMILE. STORM was demonstrated in a highly successful sounding rocket mission in 2012 during which the instrument revealed details about "charge exchange," a phenomenon that happens when solar wind sweeps across the solar system.
(Investment Area: Astrophysics, Heliophysics, and Planetary Science)



Principal Investigators Michael Collier (left), David Sibeck (center), and Scott Porter (right) created NASA's first wide-field-of-view soft X-ray camera that they flew on a sounding-rocket flight in 2013. The European Space Agency may use a similar instrument concept for a mission called SMILE.

Technology Demonstrations

Before a technology can fly in space or on one of NASA's other research platforms, technologists must demonstrate that their concepts work — whether in a field campaign or in the laboratory or some other relevant environment. In FY15, Goddard technologists took advantage of several opportunities to advance the technology-readiness levels of their concepts.

"Our instrument is filling a gap, but it's doing more that. In so many respects, it is more robust, rugged and capable. At last we have another tool in the tool belt."

— Amber Emory, X-BADGER Principal Investigator

Observatory for Planetary Investigation from the Stratosphere (OPIS)

In October 2014, Principal Investigator Terry Hurford successfully demonstrated a balloon-borne instrument called OPIS, which, among other things, imaged Jupiter from its berth aboard a balloon gondola. To carry out its observation, OPIS relied on a pointing system called the Wallops Arcsecond Pointer (see page 15). The successful demonstration resulted in the team securing a long-term role on NASA's 5-year Gondola for High-Altitude Planetary Science (GHAPS) project, aimed at developing a high-altitude platform for planetary science. Until now, planetary scientists did not avail themselves of research balloons due to the difficulty of pointing and holding a telescope to a solar-system target.

In a related effort, Principal Investigator Avi Mandell successfully developed a new telescope structure for OPIS — a development that positions Goddard to win future flights using a range of different instrument designs. The upgrade significantly enhances OPIS's sensitivity.
(Investment area: Suborbital Platforms and Range Services and Planetary Science)

Principal Investigator Terry Hurford poses with a 21-inch-diameter mirror that was repurposed for his OPIS telescope.

X-band Atmospheric Doppler Ground-based Radar (X-BADGER)

A formerly inoperative Doppler radar system received a facelift, its first set of wheels, a new name, and is now filling an important gap in ground-based precipitation measurements. Now rechristened X-BADGER, the instrument debuted during a 6-week ground campaign in Kansas and then participated in another later in 2015 in the Pacific Northwest.
(Investment Area: Earth Science)

Amber Emory and her colleague, Michael Coon, stand outside the newly mobile X-BADGER instrument that debuted during a ground campaign in 2015.

Follow-On Funding to Advance Technology-Readiness Levels

"This is a complex development and would not be possible without IRAD support. It has resulted in our keeping a very strong scientific and technical team together. The IRAD program basically kept us in the game."

— Harvey Moseley, MicroSpec Principal Investigator

The IRAD and CIF programs are not meant or able to provide cradle-to-grave support. Therefore, a key success metric is whether principal investigators succeed in securing follow-on funding to further advance their technologies. In FY15, these funding sources came from a variety of NASA R&D programs, including the Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST), Astrophysics Research and Analysis (APRA), Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO), Strategic Astrophysics Technology (SAT), and SAT Technology Development for Exoplanets Mission (TDEM).

COMPAIR: Steps to Measure Medium-Energy Gamma-Ray Emission

Under this 5-year, $4.5-million APRA award, a Goddard team will be building a prototype detector for a possible gamma-ray mission in the future. The team also plans to demonstrate the technology during a balloon flight. (Investment Area: Astrophysics)

Telescope Dimensional Stability Study for a Space-Based Gravitational Wave Mission

This SAT award, valued at $2.68 million, will help demonstrate the dimensional stability of a telescope for a space-based gravitational-wave mission. To measure gravitational waves, NASA will need to make a high-precision displacement measurement through a telescope; therefore, the optical device will have to be highly stable, said Principal Investigator Jeffrey Livas. (Investment Area: Astrophysics)

Development of the Three-Dimensional Track Imager for High-Sensitivity Medium-Energy Gamma-Ray Polarimetry

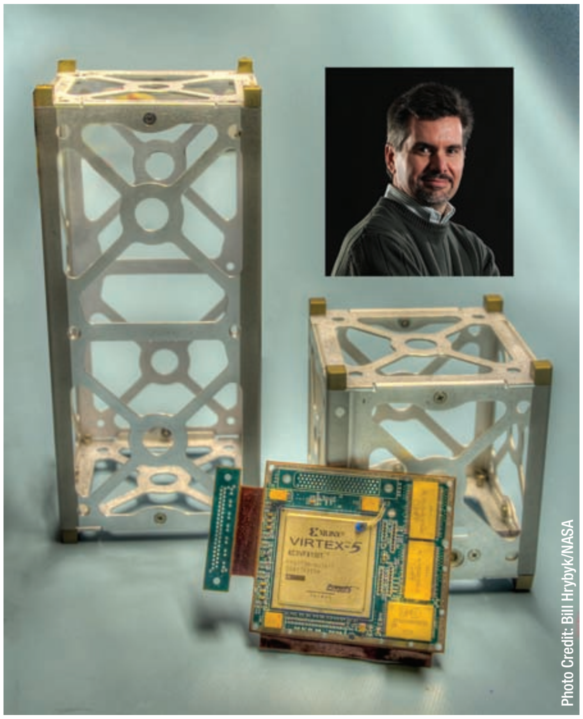
Under this $1.65-million APRA award, Principal Investigator Stanley Hunter will develop a 30-centimeter prototype of the Advanced Energetic Pair Telescope. During this effort, Hunter and his team will demonstrate the silicon microwell detector, the front-end electronics, and onboard processing.
(Investment Area: Astrophysics)

High-Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization Measurements

Principal Investigator Edward Wollack will use his $1.2 million in SAT funding to advance new detectors essential for measuring the cosmic microwave background in search of evidence proving the inflation theory. Wollack has developed and demonstrated detectors that use a unique single-crystal silicon material and symmetrical design. His goal is to implement these detectors in large focal planes.
(Investment Area: Astrophysics)

SpaceCubeX: A Hybrid Multicore PU/FPGA/DSP Flight Architecture for Next-Generation Earth Science Missions

Principal Investigator Tom Flatley received $1.4 million in AIST funding to mature a next-generation spaceflight processor called SpaceCubeX, the next member in the growing SpaceCube family. SpaceCubeX specifically is being designed to provide high-performance, modular, and scalable onboard processing for future Earth science missions. According to Flatley, the FY13 IRAD Innovator of the Year, these missions are expected to need 100-1,000 times more processing power than previous Earth science missions.
(Investment Area: Earth Science)



A next-generation spaceflight processor called SpaceCubeX, one in a growing family of SpaceCube products, is being developed by Principal Investigator Tom Flatley.

Next-Generation UAV-Based Spectral Systems for Environmental Monitoring

AIST also awarded Principal Investigator Dan Mandl $1.1 million in funding to advance a new system to measure seasonal changes in vegetation. The capability specifically is being designed for use on unmanned aerial vehicles (UAVs).
(Investment Area: Earth Science)

CdTe Detectors for the Next-Generation of High-Resolution Hard X-ray Telescopes

Under this $1.2-million APRA-funded effort, Principal Investigator Steven Christe and his team will develop next-generation, high-spatial resolution, high-energy CdTe detectors for solar hard X-ray imaging — an effort based on progress the principal investigator made in FY14 and FY15.
(Investment Area: Heliophysics)

Magnetically Coupled Microcalorimeter Arrays for X-ray Astrophysics

Magnetically coupled microcalorimeters are one of the technologies with the greatest potential to meet the requirements of a next-generation X-ray mission. Principal Investigator Simon Bandler received $1.1 million in APRA funding to continue research into this technology.
(Investment Area: Astrophysics)

Advanced Resolution Organic Molecular Analyzer (AROMA)

NASA's PICASSO program selected Principal Investigator Ricardo Arevalo to advance AROMA, an instrument capable of measuring trace levels of organic and inorganic compounds using tandem mass spectrometry. To carry out his work under this $1.08-million award, Arevalo is integrating a technically mature, highly capable linear ion trap with a high-resolution orbitrap mass analyzer.
(Investment Area: Planetary Science)

MACROS: Molecular Analyzer for Complex, Refractory Organic-Rich Surfaces

Another FY15 PICASSO program awardee, Principal Investigator Stephanie Getty, will use $940,000 in funding to advance an analyzer she expects will do a more comprehensive job of determining the composition of planetary samples. Getty is the FY12 IRAD Innovator of the Year.
(Investment Area: Planetary Science)

Next-Generation Visible Nulling Coronagraph (VNC)

Principal Investigator Matthew Bolcar will use $1.04 million in TDEM funding to investigate the use of freeform optics (see page 22) in the novel VNC. VNC combines an interferometer with a coronagraph as a way to cancel bright starlight, thereby revealing the presence of orbiting planets. The prototype instrument currently employs internal optics. The goal is to determine whether emerging freeform optics would perform better in this application.
(Investment Area: Astrophysics)

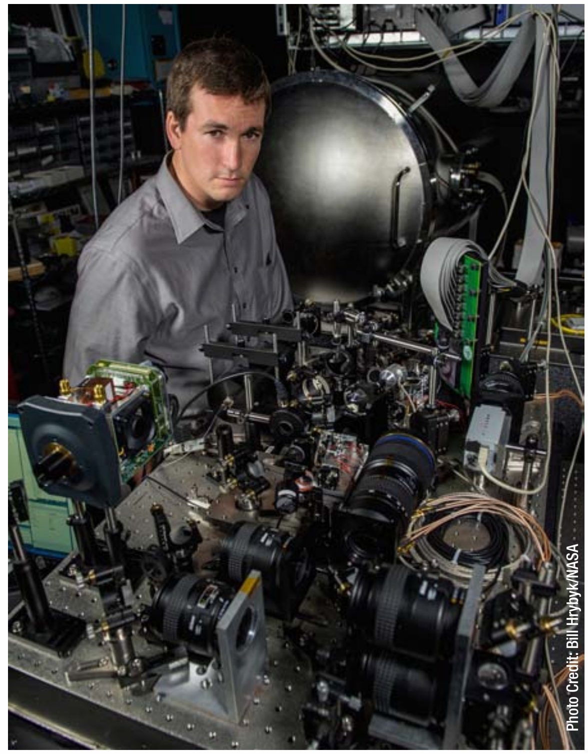


Photo Credit: Bill Hrybyk/NASA

Technologist Brian Hicks stands next to the latest incarnation of the Visible Nulling Coronagraph being designed and tested for a next-generation astrophysics observatory.

MicroSpec: An Integrated Spectrometer for Terahertz Space Spectroscopy

Principal Investigator Harvey Moseley, who has been advancing a miniaturized, far-infrared spectrometer for the past several years, won $541,000 in APRA funding to continue the instrument's development. Called MicroSpec, the instrument would be a logical follow on to those flown on such missions as the Cosmic Background Explorer, Infrared Space Observatory, and the Spitzer Space Telescope.

Meanwhile in FY15, Principal Investigator Ari Brown continued development of microwave kinetic inductance detectors that are ideally suited for MicroSpec and other applications.
(Investment Area: Astrophysics)

Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

Under this $870,000 APRA award, Principal Investigator Stephen Rinehart will continue assembling BETTII, which will demonstrate spatial interferometry from a high-altitude balloon. Slated for a 2016 launch, BETTII will observe the far-infrared band of the spectrum, taking data every 10 milliseconds of clustered stars to learn more about coevolution, the science of how stars evolve in close proximity to one another. The flight could lay the foundation for flying an interferometer in space.
(Investment Area: Astrophysics)

Goddard scientist Stephen Rinehart is developing NASA's first spatial interferometer, an instrument expected to fly as a balloon mission.

Airborne System for Direct Validation of Regional Carbon Flux Estimates

With $400,000 in NASA Headquarters funding, Principal Investigator Randy Kawa is planning to demonstrate an airborne system to directly measure greenhouse-gas fluctuations in the atmosphere. The successful demonstration aboard a C-23 Sherpa aircraft in 2016 is expected to cement Goddard as the leading institution for integrated carbon-cycle science, including everything from space measurements to Earth science modeling and data simulation.
(Investment Area: Earth Science)

Multi-Axis Heterodyne Interferometry (MAHI)

Under this $326,000 APRA, Principal Investigator Ira Thorpe will demonstrate a technique to measure the position of a moving target in three axes — linear displacement, tip, and tilt — using a single optical beam. The most direct application of this technology is measuring the position of a free-flying test mass in a future gravitational wave detector. It also could be used to position mirror segments in a large-aperture observatory.
(Investment Area: Astrophysics)

Critical Support Capabilities

Goddard-developed technologies do not always find berths on spacecraft or instrumentation. Their sole purpose is assisting scientists in the interpretation of data or providing NASA with capabilities needed to fly missions.

"The entire idea behind GMAT was to develop a tool that was highly customizable, openly available, autonomous, and fast. I think we succeeded and that's rewarding."

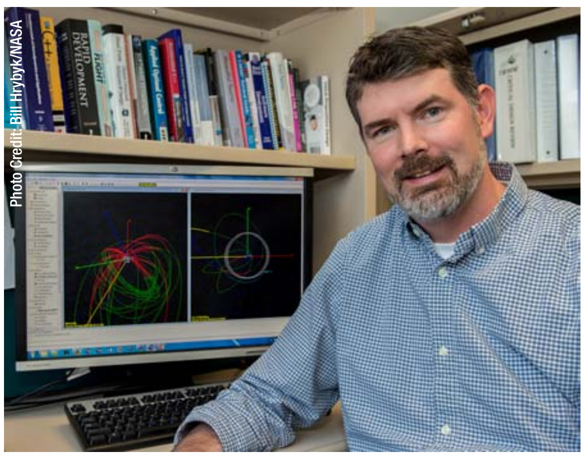
— Steven Hughes, Goddard Engineer

Fast, Autonomous Chemical Interplanetary Mission Design via Hybrid Optimal Control

Principal Investigator Jacob Englander added capabilities to a fast, autonomous tool for creating possible orbital trajectories for missions using chemical propulsion. The tool is able to choose launch parameters, flight times, propulsive maneuvers, gravity assists, and arrival conditions. It is now ready for use by mission-proposal teams.
(Investment Area: Communications and Navigation)

General Mission Analysis Tool (GMAT)

Since its development, the world's only enterprise, open-source space-mission design tool has earned plenty of accolades. This modeling program earned another in 2015. Having already supported such missions as NASA's Transiting Exoplanet Survey Satellite, which currently is in development, and the recently launched Magnetospheric Multiscale mission (see page 9), GMAT also contributed to the award of Lunar IceCube, one of the first CubeSat missions to explore beyond low-Earth orbit (see page 17).

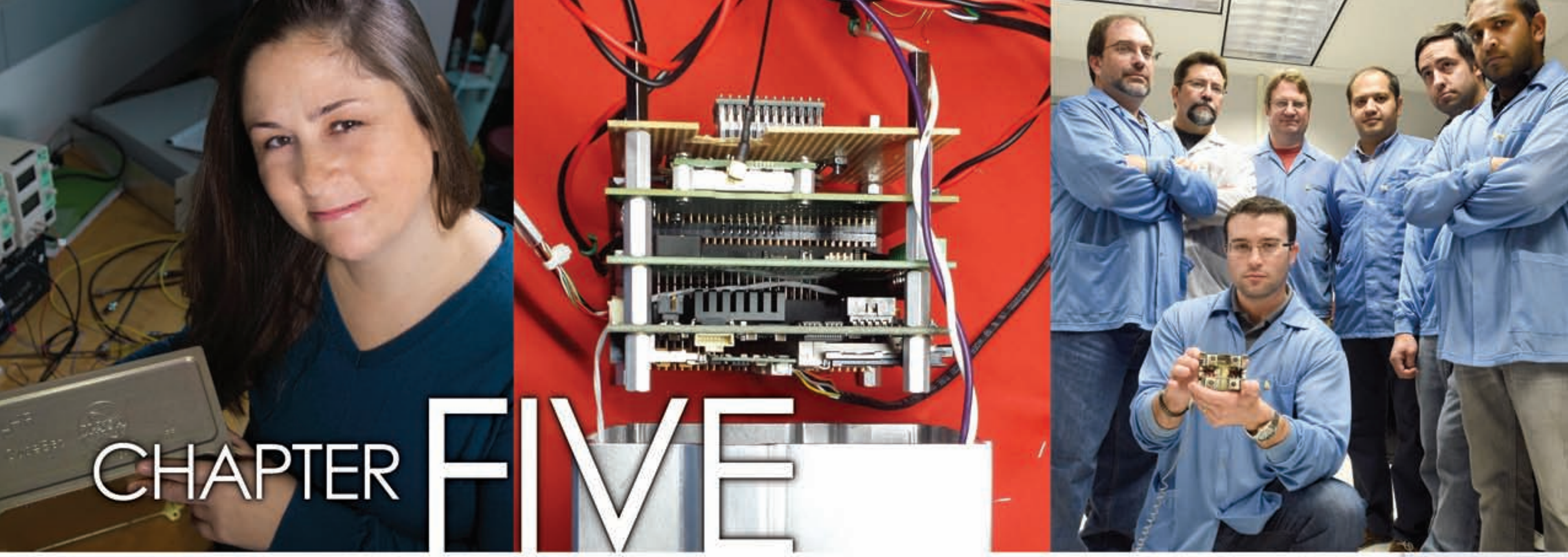


Goddard engineer Steven Hughes and his team created the world's only enterprise, open-source design capability that was used to determine the orbital trajectory of Lunar IceCube, a new CubeSat mission.

Range Services

In FY15, the Wallops Flight Facility (WFF) supported a number of high-profile demonstrations, including the successful balloon launch of a test article associated with NASA's Low-Density Supersonic Decelerator. WFF also supported the successful balloon launch of the Goddard-developed Observatory for Planetary Investigations from the Stratosphere (OPIS) using the Wallops Arcsecond Pointer (WASP). WASP can point a balloon-borne scientific instrument at targets with sub-arcsecond accuracy.

(Investment Area: Suborbital Platforms and Range Services)



Year of the CubeSat: Goddard Reaps Rewards in Small-Satellite Technology-Development Efforts

"I believe the future looks bright for science on CubeSats due to their fantastic versatility. That's why it was so important to be one of the teams to participate in the first launch of deep-space CubeSats. Once we understand how to design these platforms, the possibilities are endless as to what we can do with them."

— Dennis Reuter, Co-Developer of Lunar IceCube's BIRCHES

Gaining faster, less-expensive access to space has become the clarion call for NASA and other organizations. An increasingly popular option is deploying smaller spacecraft that are less expensive to build and deploy.

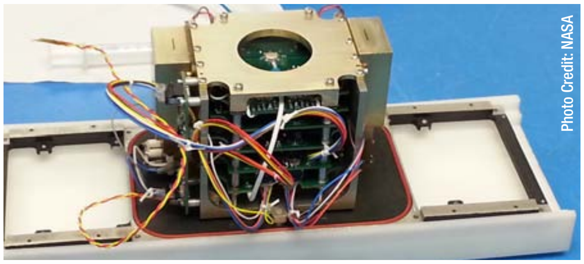
Although Goddard has invested in small-satellite technology for at least a decade, FY15 was particularly noteworthy. In addition to winning new CubeSat missions that span the spectrum in applications, Goddard technologists received NASA technology-development funding to further advance their concepts or demonstrated their technologies on balloon flights. One miniaturized instrument — actually, the smallest of its kind — is now returning valuable data. Technologists also assisted university-led teams to create technologies that will benefit all who plan to use these platforms in the future.

Our investment in these technologies not only is benefitting CubeSats and smallsats, but also the much larger flagship-style missions that would profit from miniaturized instruments and components, which consume less mass, power, and volume.

Mission Success

ExoCube Mini Ion-Neutral Mass Spectrometer (Mini-INMS)

Scientist Nikolaos Paschalidis (see page 6), who conceived and built the Mini-INMS in just 9 months, is now obtaining important data analyzing the composition of Earth's dynamic neighborhood. The instrument, one of the payloads on the National Science Foundation-sponsored ExoCube mission launched in 2015, more particularly is measuring the densities of a variety of particles in the upper reaches of Earth's atmosphere, observing how these densities change in response to daily and seasonal changes. These data include the first direct hydrogen measurements in the region by a mass spectrometer, and the first of oxygen, helium, and nitrogen since the early 1980s. An improved version of the instrument also will fly on the debut flight of the Goddard-developed 6U CubeSat called Dellingr. (Investment Area: Heliophysics)



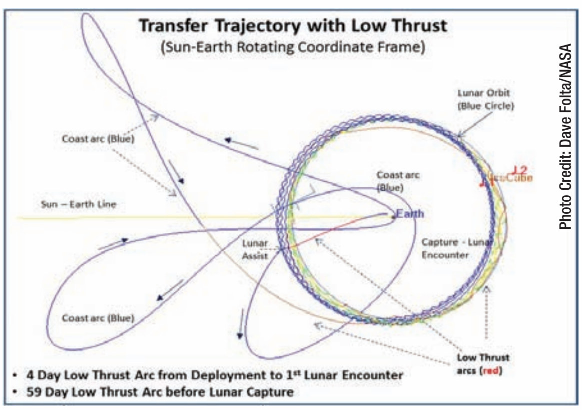
This is the smallest space-weather spectrometer ever built. Launched onboard the ExoCube mission in January 2015, the Mini Ion-Neutral Mass Spectrometer has provided some of the first direct measurements of upper atmospheric particles since the 1980s.

New Missions

Lunar IceCube

NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) chose Lunar IceCube as one of 12 secondary payloads to deploy during the first planned flight in 2018 of NASA's Space Launch System. Morehouse State University is leading Lunar IceCube; however, Goddard is providing the 6U spacecraft's only instrument, the Broadband InfraRed Compact High Resolution Explorer Spectrometer (BIRCHES). The miniaturized instrument will investigate the distribution of water and other volatiles as a function of time of day, latitude, and regolith age and composition. (Investment Area: Planetary Science)

Assisting in that mission win was an initial trajectory design by Goddard orbital engineer Dave Folta, who developed advanced tools for modeling lunar orbits for spacecraft equipped with both chemical and low-thrust propulsion systems. Lunar IceCube, powered with miniaturized electric thrusters, will take a circuitous route to arrive in lunar orbit 3 months after launch. As the mission progresses, Folta's team will refine the trajectory. (Investment Area: Communications and Navigation)



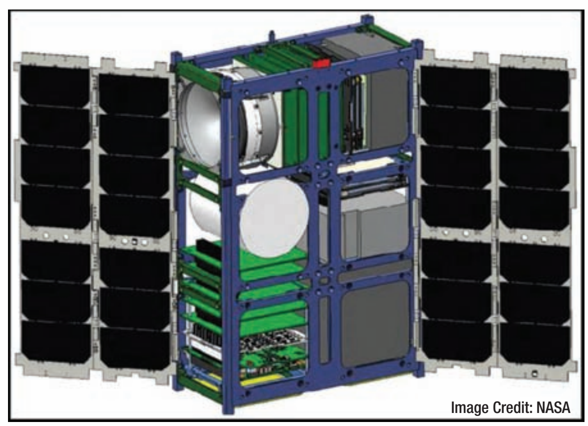
Getting to the moon will require that Lunar IceCube take a circuitous route. Goddard orbital engineer Dave Folta created a complex trajectory using an advanced modeling tool.

In a related development, Lunar IceCube plans to use a new IRAD-developed hardware-in-the-loop testbed specifically designed for CubeSat missions. Principal Investigators Cinnamon Wright and Paul Mason created the CubeSat Hardware In the Loop Test Bed to increase the reliability of future CubeSat missions by providing testing capabilities that would help identify any weaknesses in the design and satellite construction. (Investment Area: Suborbital Platforms and Range Services)

Goddard scientists Avi Mandell and Dennis Reuter are developing the BIRCHES instrument for the new Lunar IceCube mission.

CubeSat Mission to study Solar Particles over the Earth's Poles Enhancement (CuSPP+)

Also selected for the NextSTEP flight opportunity is the Goddard-developed CuSPP+. Like Lunar IceCube, it will be among the first interplanetary CubeSat missions. With its suite of three miniaturized instruments, including the Miniaturized Electron and Proton Telescope (MERIT) that also received IRAD funding, the mission will study the dynamic particles and magnetic fields coming from the sun. According to CuSPP+ lead scientist Eric Christian, the mission will serve as a proof-of-concept for using CubeSats as space-weather stations.



This is an artist's rendering of CuSSP+, among NASA's first interplanetary CubeSat missions.

MERIT, which will send back counts of numbers of charged particles it encounters at different energy levels, will carry an analog-to-digital converter microchip developed by this year's Innovator of the Year Nikolaos Paschalidis (see page 6).

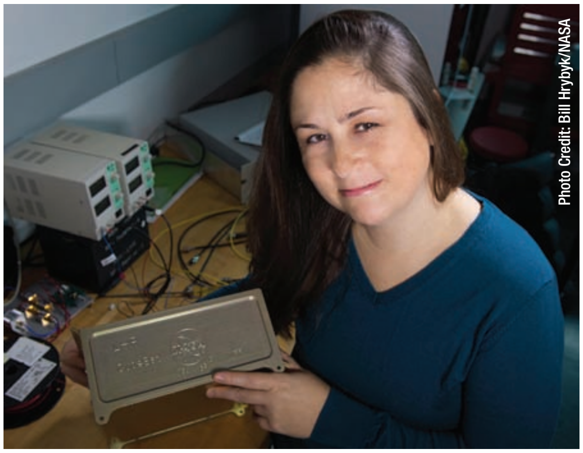
The chip helped reduce MERIT's size and power use and is essential for converting the small surge of electricity caused by a particle hitting the instrument's detector to a number that the instrument's computer can read and store. (Investment Area: Heliophysics)

CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT)

NASA's In-Space Validation of Earth Science Technologies (InVEST) program awarded a Goddard-led team a CubeSat opportunity to demonstrate new techniques for mitigating wideband radio-frequency interference that plagues passive microwave measurements below 40 GHz. The 6U CubeSat, which will be equipped with a tunable microwave radiometer covering 6-40 GHz, is expected to operate for at least 3 months. (Investment Area: Earth Science)

Miniaturized Laser Heterodyne Radiometer (Mini-LHR)

Principal Investigator Emily Wilson, who last year won $1 million in NASA research funding to carry out a multi-disciplinary field campaign to measure column carbon dioxide and methane in Alaska, will be building a 4U Mini-LHR for a 6U CubeSat now being developed by the Lawrence Livermore National Laboratory. Under the Space Act Agreement, Goddard will help the laboratory integrate the instrument into the bus. This agreement also opens the door to future collaborations with the lab. (Investment Area: Earth Science)



Scientist Emily Wilson holds the exterior shell of a CubeSat that could carry a version of her Mini-LHR. Wilson will be providing a 4U version of her instrument for a CubeSat mission sponsored by the Lawrence Livermore National Laboratory.

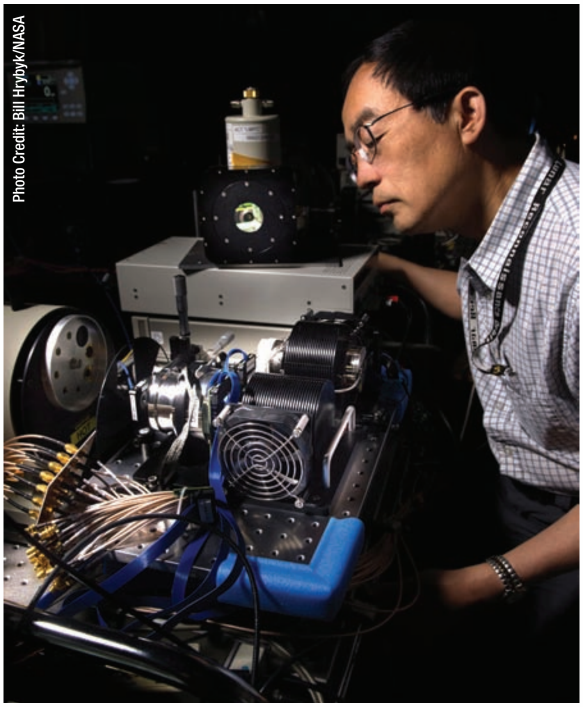
CubeSat Astronomy by NASA and Yonsei Using Virtual Telescope Alignment Experiment (CANYVAL-X)

CANYVAL-X, which is expected to launch on a Falcon 9 vehicle in 2016, will demonstrate technologies that allow two spacecraft to fly in formation along an inertial line of sight, thereby enabling a number of heliophysics and astrophysics missions. Under an international agreement, Goddard technologist Neerav Shah and his team are partnering with South Korea's Yonsei University to fly a passive 1U and an active 2U spacecraft. Aboard the larger craft are a Goddard-provided sun sensor and microthruster. These technologies are responsible for sensing and controlling the dual-spacecraft alignment.
(Investment Area: Crosscutting Technology and Capabilities)

A Goddard team, including Matt Clovin (front), (left to right) Bob Spagnuolo, Joe Roman, Phil Calhoun, Behnam Azimi, Mike Mahon, and Neerav Shah, provided the Virtual Telescope Alignment System for a CubeSat mission called CANYVAL-X.

NASA's CubeSat Demonstration of a Photon-Counting Infrared Detector

Working with the Dallas, Texas-based DRS Technologies, Principal Investigator Xiaoli Sun created the world's first photon-counting detector sensitive to the mid-infrared wavelength bands — a spectral sweet spot for a number of remote-sensing applications, including the detection of greenhouse gases on Earth, Mars, and other planetary bodies. The technology, which is about the size of a sesame seed, will be demonstrated next year on NASA's CubeSat Demonstration of a Photon-Counting Infrared Detector, a 3U CubeSat supplied by the Aerospace Corp. The instrument also has been infused into the Goddard-developed CO-2 Sounder Lidar, a prototype instrument (see page 23).
(Investment Area: Crosscutting Technology and Capabilities)

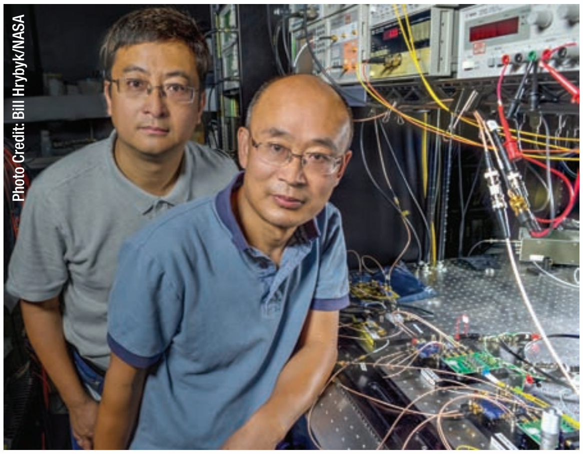


Goddard scientist Xiaoli Sun worked with his contractor partner to create the world's first photon-counting mid-infrared detector that will fly on a 3U CubeSat supplied by Aerospace Corp.

Technology Demonstrations

Space Optical Communication and Navigation System

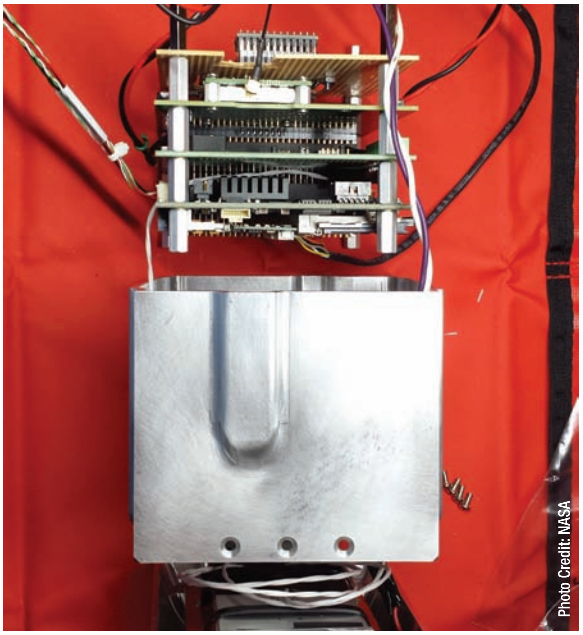
Goddard optical physicist Guan Yang has demonstrated never-before-achieved, highly precise distance and speed measurements with a miniaturized laser communication system called the Space Optical Communication and Navigation System. In laboratory testing, Yang and his team showed that the system could provide micrometer-level distance and speed measurements over a 622 megabit-per-second laser link — besting the performance of the Lunar Laser Communication Demonstration experiment on NASA's Lunar Atmosphere and Dust Environment Explorer in 2013. Yang said he is now pursuing a CubeSat opportunity to demonstrate the system in space.
(Investment Area: Communications and Navigation)



Guan Yang (right) and his research associate, Wei Lu, pose in front of the lasercom breadboard they created. They are now pursuing a CubeSat opportunity.

CAPE/MIRCA

Technologist Jaime Esper, who is advancing a CubeSat concept specifically for missions that observe physical phenomena far from terra firma, successfully tested a prototype entry vehicle — the Micro-Reentry Capsule (MIRCA) — from a high-altitude balloon mission in 2015. MIRCA is one of two components under his concept. The other is the CubeSat Application for Planetary Entry Missions (CAPE), which is a service module that would propel MIRCA to its celestial target. A drop test is planned in spring 2016.
(Investment Area: Planetary Science)



The Micro-Reentry Capsule — a prototype entry vehicle — was tested during a balloon flight in 2015.

Follow-On Awards to Advance Technology-Readiness Levels

Hydrogen Albedo Lunar Orbiter (HALO)

NASA's Small Innovative Missions for Planetary Exploration awarded scientist Michael Collier $100,000 to advance two instruments that would fly on HALO, a CubeSat mission concept to study the lunar hydrogen cycle. With the funding, Collier and his team plan to mature the Electrostatic Ion Analyzer and the Energetic Neutral Atom Analyzer. With these instruments, the team would like to discover the origin of the large quantities of water on the moon.
(Investment Area: Planetary Science)

Tradespace Analysis Tool for Designing Earth Science Distributed Missions

Technologist Jacqueline LeMoigne-Stewart, working under a $1.1-million Advanced Information Systems Technology (AIST) award, is advancing a prototype tool capable of simulating hundreds of distributed spacecraft missions — an application ideally suited for CubeSats. The Earth Science Technology Office (ESTO) believes that such formation-flying missions will reconfigure on the fly and that constellations of complementary satellites with different capabilities will work together autonomously.
(Investment Areas: Earth Science and Communications and Navigation)

Smallsat Technology Partnership Awards

Although Goddard scientists and engineers are not leading the development of four small satellite-related technologies under NASA's Smallsat Technology Partnership program, three Goddard technologists are collaborating and played a role in their being selected.

- Under the Design and Validation of High Data Rate Ka-Band Software Defined Radio for Small Satellites, Goddard engineer Wai Fong will assist the University of Vermont to develop a high-performance, compact Ka-band software-defined radio applicable to formation-flying small satellites. Currently, most spacecraft operate in the S- or X-band frequency range, which can limit bandwidth and data rates.

- The Miniaturized Phonon Trap Timing Units for Position, Navigation, and Timing of CubeSats is a University of Michigan project involving Goddard collaborator Serhat Altunc. Under this effort, the team is developing a chip-scale clock to improve the quantity and quality of data transmission from small satellites.

- Altunc also is collaborating with Utah State University in the development of the Integrated Solar-Panel Antenna Array for CubeSats. Under this project, the team will develop a compact, high-gain, low-power X-band antenna array to support high data-rate downlinks.

- Technologist Eric Cardiff is collaborating with Purdue University to further develop a film-evaporation MEMS tunable array for low-power attitude control of picosatellites beyond low-Earth orbit. Called the MEMS Reaction Control and Maneuvering for Picosats Beyond LEO, this winning proposal is a follow on to a previous program award.

Critical Support Capabilities

CubeSat/Smallsat Design Semiconductor Part Selection with Regard to Radiation

Small spacecraft built with commercial-off-the-shelf components are riskier in terms of reliability and ability to withstand the harsh space environment. Principal Investigator Michael Campola has created a Web-based tool — radome.gsfc.nasa.gov/iradapp — that provides radiation guidelines and risks associated with different types of parts. Now Campola has received follow-on funding to improve the baseline tool and integrate it with other CubeSat guidelines.
(Investment Area: Crosscutting Technology and Capabilities)

Rising Stars: Technologies to Watch

Research and development is a high-risk endeavor. In some cases, the research doesn't yield the expected outcome or result. In others, the principal investigator achieves precisely what he or she set out to accomplish. Here we spotlight just a few early-stage, often higher-risk technologies that could result in Goddard creating new opportunities and helping NASA carry out its science and exploration missions.

Astrophysics

Charge Multiplying CCD (CMCCD) for the Wide-Field Infrared Space Telescope (WFIRST) Coronagraph

Work continues in the development of single-photon detectors needed for gathering spectroscopic evidence of life on extra-solar planets. Principal Investigator Bernard Rauscher and his team are collaborating with the Lawrence Berkley National Laboratory to advance the technology.

High-Contrast Integral Field Spectroscopy Prototype Development

In another related effort, Principal Investigator Michael McElwain is advancing the Prototype Integral Field Spectrograph for Coronagraphic Exoplanet Studies for use as a science camera within the Jet Propulsion Laboratory's High Contrast Imaging Testbed. This facility will reduce risks for future missions.

Primordial Inflation Explorer (PIXIE)

PIXIE is a balloon concept for measuring the gravitational-wave signal created during inflation, a theoretical event in which the universe expanded rapidly shortly after the big bang. Detection of this signal through polarization of the cosmic microwave background is one of the highest priorities in cosmology and would profoundly affect high-energy physics. In FY15, Principal Investigator Al Kogut continued developing a range of technologies to prepare for PIXIE's balloon flight in 2016.

Communications and Navigation

NavCube

Under this FY15 IRAD, Principal Investigator Monther Hasouneh completed a number of tasks to advance a Navigator-SpaceCube GPS receiver called NavCube. The device integrates a radio-frequency card, GPS firmware, and software from a SpaceCube flight processor, providing a low-cost solution for missions operating at attitudes above and below GPS satellites.

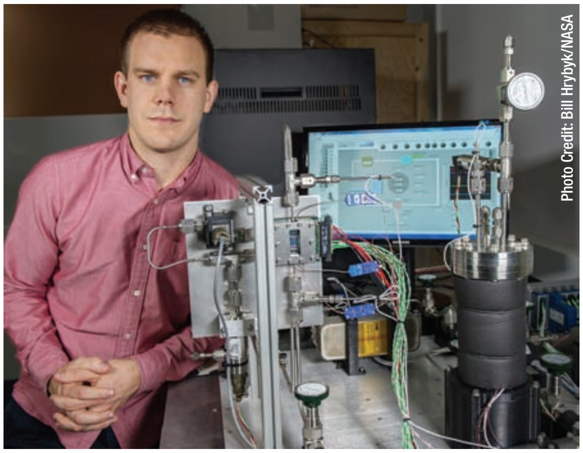
Ka-band High-Gain Antenna Design

Principal Investigator Victor Marrero-Fontanez reported that major progress was made in the development of a novel Ka-band, high-gain antenna for future missions that have stringent jitter requirements.

Crosscutting Technology and Capabilities

Cooling 3-D Circuit Technology

Future integrated circuitry is expected to look a lot like skyscrapers: units will be stacked atop one another and interconnects will link each level to its adjacent neighbors, much like how elevators connect one floor to the next. Although this emerging technology promises to greatly enhance computing power, the challenge is removing heat from these power-dense electronics — an especially tricky issue for electronics in the vacuum of space. Principal Investigator Franklin Robinson and his team are now developing a novel technique for removing heat from these tightly packed chips by flowing a coolant through embedded channels within or between the chips.



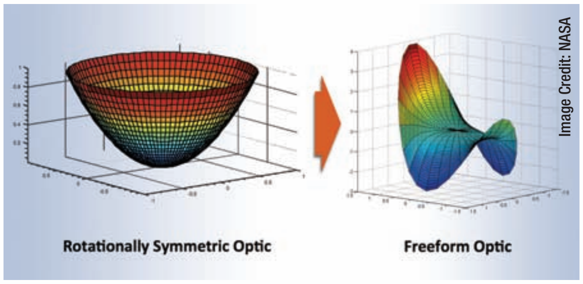
Technologist Franklin Robinson poses with a testbed he developed to experiment with a new cooling technique for emerging 3-D integrated circuits.

Green Propellant

Led by Principal Investigator Henry Mulkey, the Green Propellant Loading Demonstration is a pathfinder effort for missions that seek increased performance using low-toxicity green propellants. The team, in collaboration with MOOG, the Swedish National Space Board, and Ecological Advanced Propulsion System, carried out a multi-phase test handling LMP-103S at the Wallops Flight Facility in late 2015. Handling the Swedish-developed propellant does not require significant safety precautions and is being eyed as yet another green propellant for powering NASA spacecraft, which primarily use hydrazine today.

Freeform Optics

Telescope mirrors of old basically came in one shape: they were round and fit nicely inside a tube. An emerging technology with which Goddard technologists now are experimenting allows these light-gathering devices to take almost any shape, potentially improving image quality over a larger field of view — all in a smaller package. Principal Investigator Joseph Howard and his colleague, Garrett West, have established a group called the Freeform Optics Research Group Endeavor to hasten the learning curve and begin implementing this technology in spaceflight applications.



A rotationally symmetric optic is traditionally used in telescopes. The freeform optic on the right takes a different shape and is now being investigated for use on space-based instruments.

Core Flight System (CFS) Integrated Development Environment

Under this FY15 IRAD, Principal Investigator Dwaine Molock began developing an integrated development environment for CFS software to help reduce the time it takes to configure, develop, test, and deploy flight software for a given mission or project. The new capability will provide a standard set of tools and interfaces for mission engineers and/or end users to select and configure CFS components. The capability is expected to benefit CubeSat and other mission planners.

Nanomaterial 3-D Printing

Under this IRAD, Principal Investigator Mahmooda Sultana collaborated with Northeastern University to employ 3-D printing techniques to fabricate sensors made of nanomaterials — a process that greatly simplifies the sensor-development process. The technology is expected to benefit planetary and heliophysics missions.

Satellite Servicing

In FY15, Principal Investigator Michael Kienlen began studying robotic satellite servicing beyond low-Earth orbit (LEO) — an effort expected to assist in the formulation of next-generation astrophysics missions, including NASA's Wide-Field Infrared Survey Telescope-Astrophysics Focused Telescope Assets (WFIRST-AFTA). Next-generation observatories, such as WFIRST, must be serviceable, even if they are positioned millions of miles away. Meanwhile, the Goddard Satellite Servicing Capabilities Office already has begun developing a number of technologies aimed at providing servicing capabilities beyond LEO.

Engineer Michael Kienlen (left) is studying satellite servicing beyond low-Earth orbit. He is standing next to Ben Reed, deputy project manager of Goddard's Satellite Servicing Capabilities Office.

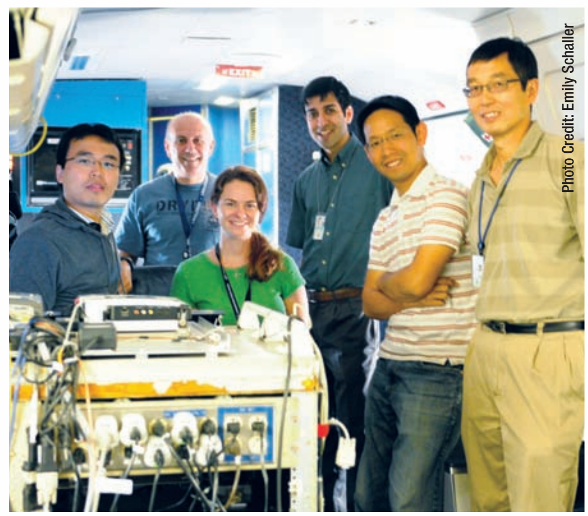
Radiation-Hardened Mixed-Signal Structured ASIC

Advancing state-of-the-art mixed-signal application-specific integrated circuit technology was the purpose of this effort led by Principal Investigator George Suarez. In FY15, Suarez, who collaborated with Sandia National Laboratories, provided the design and Sandia provided foundry services. Suarez said he and his team will characterize the chips in FY16, and if successful, they plan to infuse them into future CubeSat missions.

Earth Science

Methane Sounder

Principal Investigator Haris Riris is making excellent progress developing the Methane Sounder, which is designed to collect high-resolution, highly accurate, around-the-clock global methane measurements. The instrument operates much like its close cousin, the CO-2 Sounder Lidar (see below), and was tested in 2015 during three DC-8 aircraft campaigns in California and Nevada. Both the Methane and CO-2 Sounders are appropriate for NASA's proposed Active Sensing of CO-2 Emissions over Nights, Days, and Seasons (ASCENDS).



A Goddard team, led by Principal Investigator Haris Riris, is testing the Methane Sounder. From left to right: Kenji Numata, Riris, Martha Dawsey, Anand Ramanathan, Stewart Wu, and Steve Li.

CO-2 Sounder

Principal Investigator Jim Abshire, who is creating the CO-2 Sounder that is similar in concept to the Methane Sounder, said he succeeded in increasing its technology-readiness level for a near-term space demonstration.

EcoSAR Digital Beamforming Processing Maturation

EcoSAR is a groundbreaking, state-of-the-art, low-cost airborne synthetic aperture radar system that operates in the P-band. It is designed to measure forest biomass, and, consequently, carbon storage in dense forests. In FY15, Principal Investigator Lola Fatoyinbo developed customized EcoSAR radar and science algorithms and generated calibrated radar data products, thereby bringing the technology closer to becoming an operational instrument.

Heliophysics

Optical Design of a Miniature Coronagraph

Principal Investigator Natchimuthuk Gopalswamy improved the optical design of a miniature coronagraph and demonstrated the capability in testing. He now plans to build a prototype that he plans to fly on a balloon flight, the International Space Station, or other possible platforms.

Power Scaling of the Sodium Lidar Laser Transmitter

Determining the source of major gravity waves in the lower and middle atmosphere and how they interact with and influence winds and other phenomena are questions scientists would like to answer. Led by Diego Janches, a Goddard team is developing a space-borne sodium lidar that the team plans to deploy on the International Space Station to gather these gravity-wave measurements.

Principal Investigator Diego Janches is advancing the world's first spaceborne sodium lidar.

Photo Credit: Bill Hrybyk/NASA

Wire Electric Field Booms

In what Principal Investigator Robert Pfaff believes could establish a new era in AC/DC electric-field measurement capabilities, he and his team advanced a new wire boom that builds on previous IRAD-funded work. He and his team in FY15 validated the boom design and ultimately plans to test the technology aboard a sounding rocket.

Spherical Occulter Coronagraph CubeSat (SpOC)

Phillip Chamberlin is developing a pathfinding mission that would deploy a never-before-flown tennis ball-size titanium occulter sphere, which would fly in formation with a CubeSat equipped with an imaging spectrograph to study the sun's corona. The concept could lay the foundation for a larger, more robust mission in which Chamberlin would swap the smaller occulting sphere with an inflatable occulter that looks more like a giant beach ball. By flying two spacecraft in formation, Chamberlin believes NASA would obtain a more effective technique for studying coronal mass ejections.

Principal Investigator Phillip Chamberlin holds a sphere coated in carbon nanotubes that he would like to fly as part of a CubeSat mission to image the sun's corona.

Development of a CubeSat Electric Field Experiment

Many future science targets in heliophysics will require inexpensive, multipoint measurements of the ionosphere. Under this FY15 IRAD, Principal Investigator Doug Rowland is advancing a rigid boom for three-axis stabilized CubeSats — a spacecraft capability that would better enable electric-field measurements. He and his team developed the measurement electronics and integrated them with a prototype of a commercial deployable boom system. Work will continue in 2016.

Human Exploration and Operations

Asteroid Tomography

The primary objective of this FY15 IRAD was demonstrating the feasibility of using the Atom Inteferometric Gravity Gradiometer (AIGG) to study the internal structure of asteroids. Unlike other methods, AIGG is unencumbered by limits in how far the instrument can penetrate the surface. According to Principal Investigator Shar Etemad, Goddard's investment in this effort has provided the team an opportunity to demonstrate the feasibility of this technique.

A Multiscale, Multidisciplinary System Approach to Radiation Effects Mitigation

A team led by Principal Investigator Ruthan Lewis studied systematic, multidisciplinary, cohesive, and credible radiation-risk mitigation techniques that are essential for long-duration human missions beyond low-Earth orbit.

Planetary Science

Deep Ultraviolet Laser

A team led by Principal Investigator Barry Coyle has demonstrated a miniaturized 266-nanometer solid-state laser system. The technology's selectable pulse energy makes this design one of a kind and an excellent source for planetary mass spectrometers.

Bio-Indicator Lidar Instrument

Principal Investigator Branimir Blagojevic has completed code for the Bio-Indicator Lidar Instrument for planetary missions. According to the principal investigator, the instrument will dramatically increase the probability of finding the signatures of extraterrestrial life by carrying out atmospheric scans in and around a rover or lander.

MCD2G Design and Evaluation

The MCD2G is a second-generation radiation-hardened by design, multi-channel digital voltmeter for measuring very small signals from thermopile arrays. In FY15, Principal Investigator Gerry Quilligan designed and laid out the application-specific integrated circuit and a commercial foundry manufactured the circuits — all completed within the fiscal year. Quilligan also submitted two patent applications for his technology.

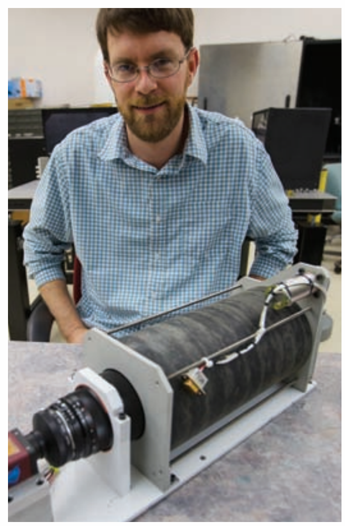
Tethered CubeSats for Multipoint Lunar and Planetary Measurements

Principal Investigator Michael Collier is developing a novel and groundbreaking approach to gather measurements close to planetary surfaces using tethered CubeSats. Initial calculations show that the approach is feasible and practical.

Suborbital Platforms and Range Services

Daytime Star Tracker

Balloon-borne instruments typically can gather data only at night and those that do operate during the day are limited in their fields of view. Scott Heatwole, an engineer at the Wallops Flight Facility, has developed a new star tracker that would locate points of reference, or stars, during daylight hours. Although previous demonstrations did not work as planned, Heatwole is now fine-tuning the algorithms and plans to retest the device in 2016 and 2017.



Wallops engineer Scott Heatwole is fine-tuning a balloon-borne precision attitude sensor that would locate points of reference, or stars, during daylight hours.

Photo Credit: Patrick Black/NASA

CubeSat Form Factor Thermal Control Louvers

Principal Investigator Allison Evans, who has submitted a patent application for her technology, is developing miniature thermal louvers to passively control thermal conditions on CubeSats and other small spacecraft. Now slated to fly on the maiden flight of a Goddard-developed 6U CubeSat, called Dellingr, Evans believes the flight will advance the louvers' technology-readiness level, ultimately offering mission planners a more capable alternative for thermal control on small spacecraft.

2015 R&D Achievements

CHAPTER SEVEN

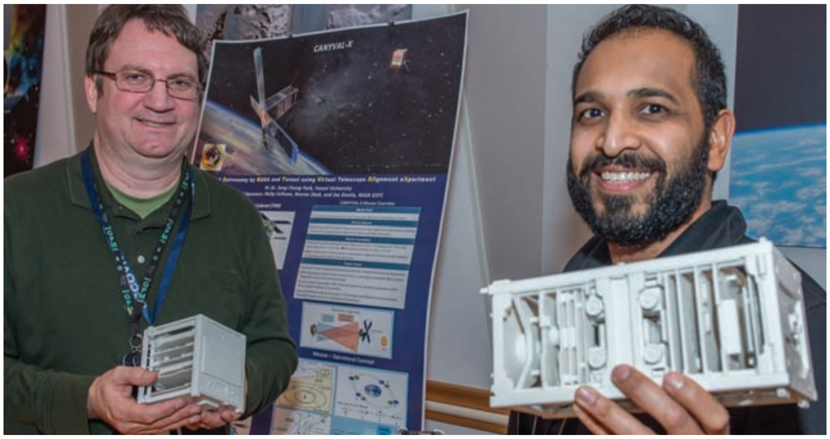
The Finale Event: Scenes from the FY15 IRAD Poster Session

The year ended with the annual "IRAD Poster Session," which showcased the work of about 90 principal investigators and attracted hundreds of visitors, including 25 high school students, who praised the event's high-caliber content. This chapter tells the story in photos, all taken by Goddard photographer Bill Hrybyk.

Goddard scientist Nikolaos Paschalidis shakes hands with Goddard Deputy Chief Technologist Deborah Amato after receiving his "IRAD Innovator of the Year" award (see page 6). Heliophysics Division Chief Michael Hesse looks on. Goddard's Office of the Chief Technologist chose Paschalidis because of his superlative and sustained contributions to the heliophysics community, conceiving, building, and flying important technologies and instruments for a range of scientific investigations, from CubeSat to flagship missions.

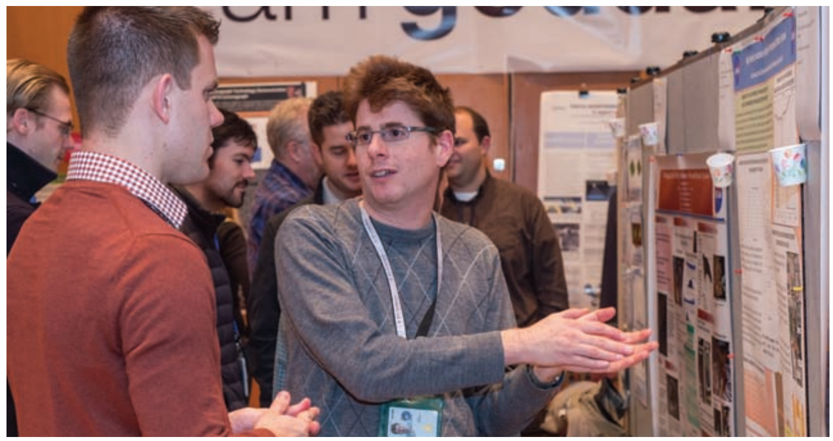
The theme of this year's event — The Full Spectrum: Smallsats to Flagships — was so chosen because it encapsulated the breadth and diversity of Goddard's premier R&D program, which is advancing technologies for both tiny spacecraft and large, high-profile missions as well as everything in between.

Tony Zheng was one of a handful of university students who participated in the FY15 IRAD Poster Session. Here he talks with visiting students who attend Bethesda-Chevy Chase High School and are members of the school's Junior Achievement program.



Engineer Phil Calhoun (left) holds a model of a 1U CubeSat, while his partner, engineer Neerav Shah, holds a model of a 2U CubeSat. Both spacecraft will fly in tandem aligned along an inertial target as part of the CANYVAL-X CubeSat mission slated to fly in early 2016.

Technologists Franklin Robinson (left) and Ari Brown are among the center's highly innovative and productive early-career professionals. Robinson is advancing cooling techniques for 3-D integrated circuits and Brown is developing next-generation microwave detectors for astrophysics applications.



Brook Lakew (left), who is the technology liaison for Goddard's Solar System Exploration Division, talks technology with technologist Damon Bradley, who received an FY15 IRAD to advance small-satellite signal-processing modules.

Alan Cudmore, who is developing a low-cost CubeSat testbed, talks with Bethesda-Chevy Chase High School students who toured Goddard during a field trip sponsored by the school's Junior Achievement program.