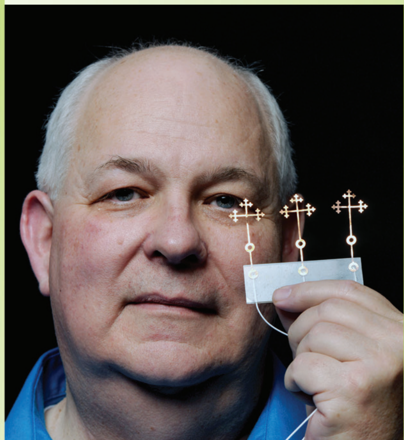
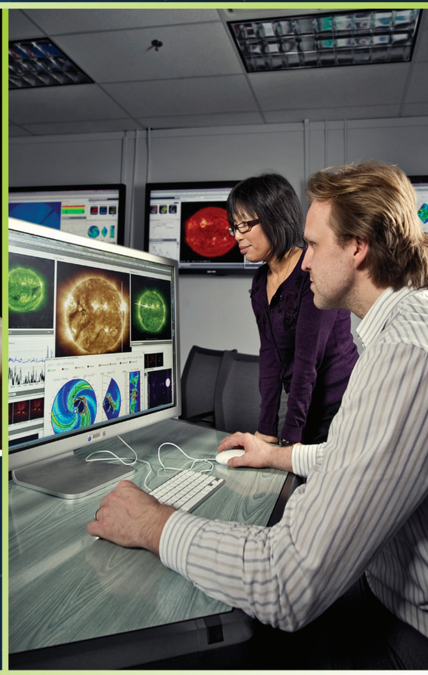
National Aeronautics and Space Administration

Delivering Innovative Results

A Report from the Goddard Office of the Chief Technologist





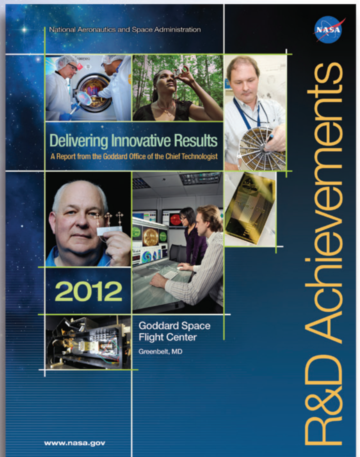
2012

R&D Achievements

Goddard Space Flight Center

Greenbelt, MD

www.nasa.gov



About the Cover

The cover photos depict technological developments in many of the center's lines of business: astrophysics; communications and navigation; crosscutting technologies; Earth science, heliophysics, planetary and lunar science, and suborbital platforms and launch services.

2012 Table of Contents

Peter Hughes
Chief Technologist

"Once a mind is expanded with a concept or idea, it can never be satisfied to go back to where it was. You've got to be a risk taker. It means you are willing to challenge yourself, to go beyond your present capabilities and comfort zone, to reinvent yourself. We can go outside right now and find pigeons, but it takes time to find eagles."

— Oliver Wendell Holmes

Chapter One

Message from the Chief Technologist:
Delivering Innovative Results

Years of Internal Research and Development (IRAD) projects have shown no shortage of creative, highly motivated technologists at the Goddard Space Flight Center. We are fortunate. Many of the miniaturized detectors, nanomaterials, extreme electronics, and other technologies now allowing NASA to make some of its most tantalizing discoveries originated here.

We also are fortunate that our senior leadership at Goddard understands the value of research and development and that NASA Headquarters, through the Office of the Chief Technologist's Center Innovation Fund (CIF), is taking risks and dedicating much-needed resources to help develop over-the-horizon technologies that NASA will need in the future.

Record Number of Proposals Funded

As a result, we were able to support a record number of proposals through our IRAD and CIF programs in FY12. Of those, 41 percent were considered early-stage innovations — that is, higher-risk technologies that promise orders-of-magnitude increases in capability. Some may supplant current approaches or designs for future missions.

Risk taking, however, was not the goal in 2012. Results were and continue to be.

We take to heart our responsibility to invest our limited research dollars wisely, choosing technologies that not only map to our strategic lines of business — those areas in which we have traditionally excelled (see page 4) — but also those that offer the greatest impact and/or the greatest probability of success.

The ability to apply past technology innovations to create wholly new instrument concepts and applications also is important. In FY12, more and more innovators were successfully leveraging IRAD-funded technologies to develop completely new solutions, underscoring yet again the value of our R&D program. This was particularly true of carbon nanotube and single-crystal-silicon mirror technologies. We also established new strategic partnerships with external innovators, demonstrated important high-risk capabilities, and secured significant funds or other commitments to further advance our technologies.

This report chronicles some of the successes made possible by our IRAD and CIF programs. Driven by our lines of business and NASA's strategic direction, our investments are resulting in promising new technologies that should keep NASA at the cutting edge of science and technology. We believe calculated risk and continued technological innovation are central to our success.

Chapter Two

Keystone of a Strong Foundation:

Strategic Alignment to Core Values

The secret to our R&D success is the discipline we employ to identify investment priorities, unmet needs, and target opportunities. All winning proposals — whether they receive IRAD or CIF funding — all meet specific selection criteria.

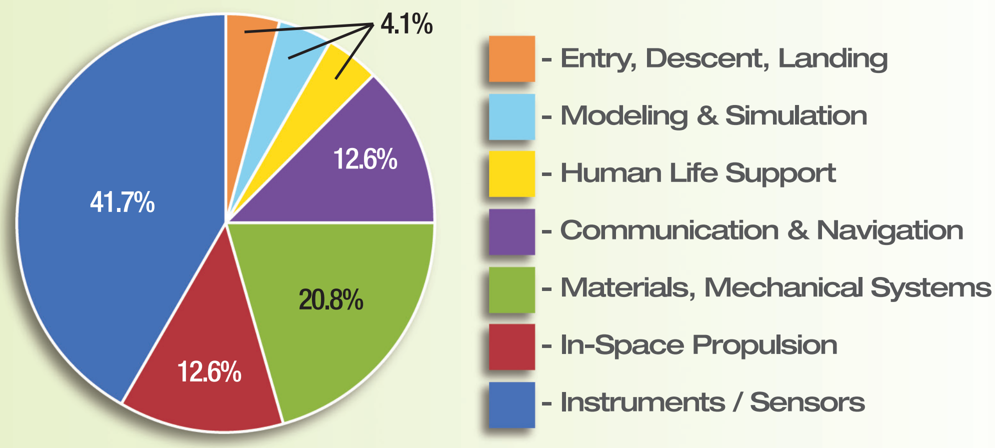
IRADs must map to one or more of Goddard's strategic lines of business (see description of each on page 4). CIFs, meanwhile, must address one or more of NASA's key technology areas identified in NASA's Space Technology Roadmap, developed through an extensive Agency-wide effort (see graphic below). Additionally, our CIF-funded proposals must demonstrate exceptionally innovative, crosscutting technologies with lower technology-readiness levels (TRLs).

LOB Teams Play Key Role

Also critical to our success are our lines of business (LOB) management teams, which play a key role identifying and selecting promising new technologies and encouraging our technologists to compete for IRAD and CIF resources.

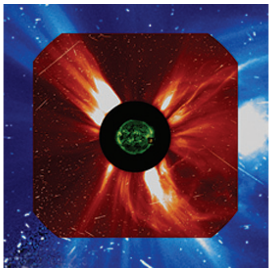
Under our two-step selection process, LOB review teams, made up of focus area leads, assistant chiefs for technology, and subject-area experts, review proposals solicited under our annual call for proposals to make sure they meet either the IRAD or CIF selection criteria. Representatives from the science, engineering, and projects directorates, as well as Goddard's senior management, then review the recommended portfolio to make sure we have selected a well-rounded portfolio that addresses the Center's priority research and technology-development needs.

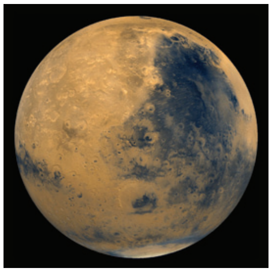
Goddard CIF Projects by Technology Areas

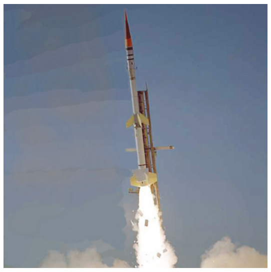



Astrophysics


Earth Science


Heliophysics


Planetary and Lunar Science


Suborbital Platforms and Launch Services

Nuturing Exceptional Innovation

Although relatively new, the CIF program already has distinguished itself for the forward-reaching technologies it is designed to nurture.

For example, nine research efforts were publicized in our quarterly magazine, CuttingEdge, and later published on NASA's Web Portal, resulting in a myriad of media pickups, including msnbc.msn.com, photonics.com, R&D Magazine, Science Daily, Popular Science, SpaceRef, Space.com, eScience News, Yahoo News, Gizmodo, National Geographic Education, GizMag, Nexgadget.com, and RedOrbit, just to name a few. The Atlantic Magazine also interviewed one of our innovators and plans to publish an article in 2013.

FY 12 Goddard Lines of Business: Our Strategic Path to Success

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 Technologies

Addresses capabilities that touch on two or more strategic LOBs, everything from nanomaterials, electronics and detectors, to system architectures.

Earth Science

Supports technologies and advanced science instruments needed to observe and understand changes in Earth's climate system.

Heliophysics

Focuses on capabilities essential for understanding solar structure and magnetic activity, solar wind, solar disturbances, and their effects on Earth's upper atmosphere.

Planetary and Lunar Science

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

Suborbital Platforms and Launch Services

Supports mechanisms typically used to place payloads into suborbital altitudes, including sounding rockets, balloons, manned and unmanned aircraft, and Smallsats. Range services include assets for conducting, launching, and operating missions.

Chapter Three

Distinguished IRAD and CIF Achievements

It often takes years for technologies to mature; therefore, we use a variety of metrics to gauge our effectiveness.

The ultimate and most tangible is whether Goddard-developed technologies are chosen for inclusion in new mission or instrument opportunities. Another is whether the technology receives follow-on funding from external sources to continue its maturation or if other instrument developers infuse an R&D-funded technology into their own concepts. The ability to leverage past R&D-funded technologies to create wholly new technologies is the quintessential definition of innovation.

Other metrics include flight demonstrations, hardware deliveries, patent filings, and the development of enhanced testing capabilities to advance other cutting-edge technologies. In FY12, many investigators distinguished themselves under these success criteria. This chapter details their accomplishments.

New Missions and Flight Demonstrations

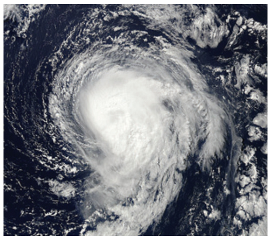
The crowning achievement of any technology program is an investment that leads to the award of a new spaceflight mission or instrument. Another is securing a flight demonstration on NASA high-altitude aircraft, sounding rockets, Cubesats, and scientific balloons.

SPICE for ESA Mission

Principal Investigator Joseph Davila has teamed with the Southwest Research Institute to build the Spectral Imaging of the Coronal Environment (SPICE) instrument, a payload on the European Space Agency's (ESA) Solar Orbiter mission. The team received $4.8 million in ESA funding to develop SPICE, which will measure with unprecedented spatial and spectral resolution different wavelengths of light emitted from the sun to evaluate its plasma properties and composition. *(Investment Area: Heliophysics)*

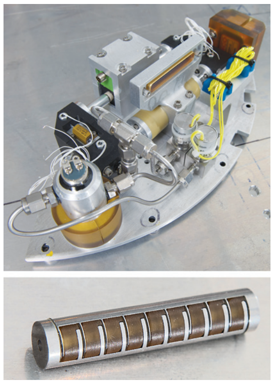
BUGS for HAWC+

A Goddard team, led by Principal Investigator Christine Jhabvala, received $2.5 million in NASA funding to upgrade, integrate, and test larger-format Backshort Under Grid (BUG) detector arrays for the High-resolution Airborne Wideband Camera (HAWC+), an instrument upgrade to the Stratospheric Observatory for Infrared Astronomy mission. Jhabvala demonstrated the BUG detector technology, developed in part with IRAD funding, on a 30-meter telescope in Spain a few years ago — a success that contributed to the technology's selection for HAWC+. *(Investment Area: Astrophysics)*



The Goddard-led Hurricane and Severe Storm Sentinel mission team studied Nadine with a number of instruments, including the IRAD-developed Cloud Physics Lidar.

University of Maryland graduate student Heather Arkinson monitored the IRAD-funded In-Situ Airborne Formaldehyde Instrument. The image on the right shows the new air-sampling system that more efficiently draws in air and prevents particles from contaminating formaldehyde measurements.



This is a prototype EHD pump that Principal Investigator Jeffrey Didion validated during a flight experiment in 2012. (Photo Credit: Chris Gunn)

HS3 Mission Debuts

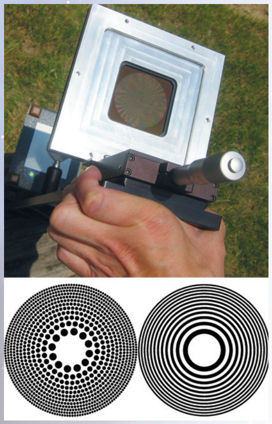
The Goddard-led Hurricane and Severe Storm Sentinel (HS3) investigation made its debut in September, carrying, among other instruments, the IRAD-developed Cloud Physics Lidar, developed by Principal Investigator Matt McGill. The five-year HS3 mission is dedicated to gathering difficult-to-obtain measurements of wind speeds, temperature, humidity, and aerosol concentrations in and around hurricanes to learn how they intensify. Next year, the team plans to add another Global Hawk aircraft and equip it with another IRAD-developed instrument, the High-altitude Imaging Wind and Rain Profiler (HIWRAP). HIWRAP is expected to carry an upgraded Ka-band transceiver, which Goddard technologists developed with IRAD funds. The Goddard-developed Tropospheric Wind Lidar Technology Experiment (TWiLiTE) instrument also will make its HS3 debut in 2013. In fact, Principal Investigator Cathy Marx completed the assembly and testing of a hybrid wind lidar transceiver for TWiLiTE in FY12. *(Investment Area: Earth Science)*

A New Way to Track Formaldehyde

Scientist Tom Hanisco and his team developed and demonstrated in FY12 the first automated, lightweight, laser-induced fluorescence device for gathering difficult-to-measure formaldehyde in the lower troposphere and then again at higher altitudes. Prior to the instrument's development, only one other airborne instrument could measure this important atmospheric organic compound. However, unlike Hanisco's In-Situ Airborne Formaldehyde Instrument, it is large and requires a technician onboard to operate it. According to Hanisco, more flight opportunities are likely for his new automated instrument. *(Investment Area: Earth Science)*

EHD Making Hot, Cool

The microscale electrohydrodynamic (EHD)-based thermal control device is a crosscutting technology that promises to make it easier and more efficient to remove heat from small spaces, vastly expanding the capabilities of advanced instruments and microprocessors. In FY12, Principal Investigator Jeffrey Didion validated a micro-scale EHD pump during a flight experiment, proving the device works in variable gravity. The team now plans to develop another device for further testing on the International Space Station. The technology could be used in electronic cards, lab-on-a-chip scientific instruments, quick-response spacecraft, and power electronics in aircraft and automobiles. *(Investment Area: Crosscutting Technology)*



Shown here is a glass photon sieve, a technology that Principal Investigator Adrian Daw will demonstrate on an Air Force-sponsored FalconSat-7 mission.

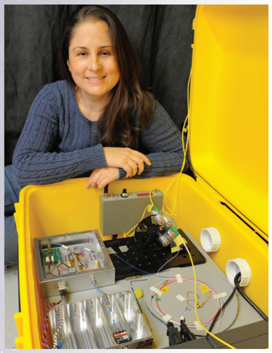
Securing Berths on Cubesat Missions

As a result of his IRAD, Principal Investigator Shrikanth Kanekal has been offered a flight opportunity on a Spanish Cubesat mission to demonstrate the Compact Relativistic Electron and Proton Telescope (CREPT). The IRAD-funded CREPT measures energetic electrons and protons to better understand the physical mechanism of electron microbursts and their role in the loss of energetic electrons in Earth's radiation belts.

Principal Investigator Adrian Daw also secured berths on two Cubesat missions. On one, a Goddard-led mission, Daw will fly the Flare Initiation Doppler Imager, which will study the processes that initiate solar flares. The other, an Air Force-sponsored FalconSat-7 mission, will demonstrate the "photon sieve," a technology that discerns intriguing components of the sun's chromosphere that cannot be resolved with existing spacecraft or ground-based observatories. *(Investment Area: Heliophysics)*

HEROES for HOPE

Principal Investigator Steven Christe received $200,000 in funding from NASA's Hands-On Project Experience (HOPE) program to refit and refly the High Energy Replicated Optics to Explore the Sun (HEROES) instrument, a joint venture between the Marshall Space Flight Center and Goddard. The balloon payload is a hard X-ray telescope that will study solar flares and provide new insights into the functioning of the sun's magnetic energy. At night, the telescope's eye will turn outward to the stars, observing a variety of astrophysical targets. *(Investment Area: Heliophysics)*



Principal Investigator Emily Wilson Steel carried out a field campaign in 2012 to demonstrate for the first time her patent-pending, suitcase-size instrument that measures three important carbon-cycle gases. (Photo Credit: Pat Izzo)

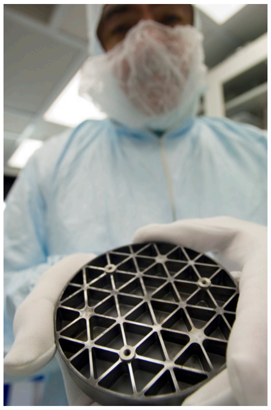
Science in a Suitcase

Principal Investigator Emily Wilson Steel carried out a field campaign in Wisconsin to demonstrate for the first time the Mini-Laser Heterodyne Radiometer, a suitcase-size instrument that scientists could deploy virtually anywhere to measure three important carbon-cycle gases. Also in FY12, Steel applied for a patent and is now tweaking the instrument's design to further reduce its size and ruggedize its components. Ultimately, the goal is to commercialize the instrument. *(Investment Area: Heliophysics)*

DBSAR for Planetary Studies

An IRAD-funded technology originally developed for Earth science is now being applied to planetary science. Principal Investigator Lynn Carter has developed software and analytical techniques to apply Goddard's Digital Beamforming Synthetic Aperture Radar (DBSAR) to planetary studies. DBSAR can simultaneously synthesize and process multiple radar beams and produce high-resolution data over larger areas. In FY12, Carter and her team collected data over the Appalachian Mountains to test these techniques. She now is using those results to apply for follow-on funding. Her goal is to ultimately fly DBSAR in space. *(Investment Area: Planetary and Lunar Science)*

This photo shows examples of four different lengths of the microchannel component that is at the core of Principal Investigator Stephanie Getty's "lab-on-a-chip" liquid chromatograph. Getty is developing the technology under NASA follow-on funding to detect and analyze organic compounds, including amino acids. (Photo Credit: Chris Gunn)



Technologist Vince Bly, shown here holding a light-weighted, single-crystal-silicon mirror, is working with scientist Will Zhang to apply the technology to the fabrication of X-ray mirrors. (Photo Credit: Chris Gunn)

Follow-On Funding to Advance Technology-Readiness Levels

The IRAD program is not meant 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 FY12, these funding sources came from NASA's Office of the Chief Technologist (OCT), the Earth Science Technology Office (ESTO), the Planetary Instrument Definition and Development Program (PIDDP), the Astrobiology Science and Technology Instrument Development (ASTID) program, the Astronomy and Physics Research and Analysis (APRA) program, and the Strategic Astrophysics Technology (SAT) program, among others.

Mass Spectrometers for Detecting Organic Compounds

The FY12 "Innovator of the Year," Stephanie Getty (see profile on page 13), won a total of $2.2 million from NASA's PIDDP and ASTID programs to develop new instruments for detecting and analyzing organic compounds, including life-sustaining amino acids, on extraterrestrial bodies. Both instruments borrow heavily from instrument components she and her colleagues developed under previous IRAD-funded efforts. Getty's winning efforts underscored the importance of leveraging R&D successes to create wholly new instrument concepts. *(Investment Area: Planetary and Lunar Science)*

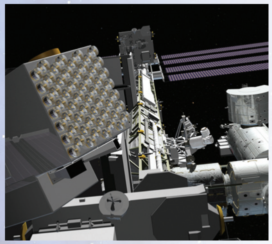
New Approaches for Fabricating X-ray Mirrors

Constructing super-thin curved X-ray mirrors from large blocks of single-crystal silicon (SCS) is the goal under a three-year, $800,000 APRA award to Principal Investigator Will Zhang and his partner, Goddard technologist Vince Bly. The effort leverages Bly's initial work in fabricating mirrors from SCS and underscores the power of collaboration and leveraging past IRAD investments. (See page 14 for other applications of the single-crystal-silicon mirror.) If the research effort succeeds, the team says the application could revolutionize X-ray astronomy because it would reduce the cost of manufacturing X-ray mirrors.

Zhang also received a $4.4 million SAT award to pursue more efficient approaches for fabricating glass mirror segments, and more importantly, aligning and assembling them inside high-precision mirror modules. Ultimately, the hope is to improve the angular resolution of X-ray optics by a factor of five. *(Investment Area: Astrophysics)*

X-ray Calorimeter Array

The X-ray astrophysics community is developing several mission concepts to meet the call for a more affordable flagship X-ray observatory. Goddard's X-ray calorimeter technology, the X-ray Microcalorimeter Spectrometer (XMS), had been referenced as the baseline for the proposed International X-ray Observatory, and is now positioned to be competitive for other mission concepts. Principal Investigator Caroline Kilbourne received $2 million in SAT funding to continue advancing the XMS detector to a technology-readiness level of six. *(Investment Area: Astrophysics)*



This artist's rendition shows Principal Investigator Keith Gendreau's proposed SEXTANT intrument, which he hopes to fly on the International Space Station to demonstrate pulsar-based navigation and the world's first X-ray communication system. The instrument also would be used to investigate the exotic states of matter within neutron stars.

Sextant: Three-In-One Instrument

Principal Investigators Keith Gendreau and Zaven Arzoumanian received funding from NASA's Office of the Chief Technologist to advance a novel three-in-one instrument now being developed as a payload on the International Space Station. The so-called Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) instrument consists of 56 compact X-ray telescopes, advanced detectors, and other technologies to investigate the exotic states of matter within neutron stars and reveal their interior and surface compositions. Implementation of SEXTANT also advances technology. The team plans to demonstrate pulsar-based navigation and the world's first X-ray communication system in space — all from the same platform. *(Investment Area: Astrophysics and Communications and Navigation)*

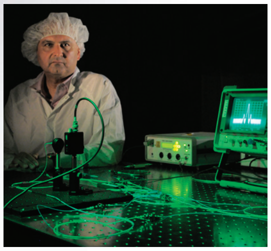
SpaceCube Experiment 2.0

A total of $1.1 million in ESTO and Air Force funding is being used to advance SpaceCube 2.0, a next-generation flight data-processing system that is up to 25 times faster than the current state-of-the-art. The technology is a successor to SpaceCube 1.0, which Goddard demonstrated for the first time in 2009. Among other enhancements, the team is developing special radiation-hardened-by-software techniques to create a more robust flight processor that is less susceptible to radiation-induced upsets. *(Investment Area: Crosscutting Technology)*

The Visible Nulling Coronagraph combines an interferometer with a coronagraph to image and characterize Jovian-size planets. In this photo, Principal Investigator Rick Lyon (foreground), Udayan Mallik (left), and Sigma Space's Pete Petrone (right) are monitoring the progress of wavefront control using the technology, which is operating inside a vacuum tank. (Photo Credit: Chris Gunn)

Compact Achromatic Visible Nulling Coronagraph

With $730,000 in SAT funding, a team led by scientist Rick Lyon is advancing the compact achromatic Visible Nulling Coronagraph (VNC), a hybrid instrument combining an interferometer with a coronagraph for imaging and characterizing planets in other solar systems. Given budget constraints, the team is adapting the technology to fly as a balloon payload. In the meantime, the team received an additional $228,000 to advance one of the VNC's enabling technologies, a multiple-mirror array that the Berkeley, Calif.-based Iris AO, Inc. is developing under a NASA Small Business Innovative Research grant. *(Investment Area: Astrophysics)*



Goddard scientist Babak Saif is shown here with a laser system he designed for an atom interferometer for detecting gravitational waves. (Photo Credit: Pat Izzo)

Atom Optics: Detecting the Imperceptible

Atom interferometry or atom optics is a potentially pioneering technology for detecting theoretical gravitational waves or ripples in space-time caused by cataclysmic events, including the Big Bang itself. With their CIF support, Goddard technologist Babak Saif and his team, including Stanford University and the privately owned, California-based AOSense, Inc., designed, built, and tested a new laser system, one of the critical components in a next-generation atom interferometer. As a result of the team's progress, it won $100,000 in NASA Innovative Advanced Concepts funding to further define an atom interferometry-based gravity wave detector. *(Investment Area: Astrophysics)*

Strategic Collaborations and Commercial Infusion

Research and development can be expensive and resource intensive. To help offset the costs of R&D, Goddard innovators are encouraged to seek partnerships. Ultimately, these strategic partnerships can lead to the infusion of cutting-edge technologies into spaceflight opportunities and commercial products. In FY12, Goddard innovators forged strategic partnerships with a variety of organizations and worked with private industry to commercialize technologies.

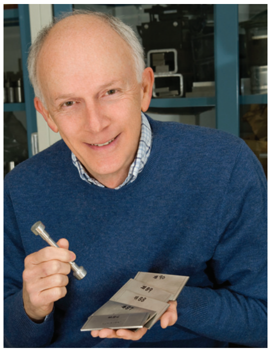
"Brazing" Methodology and Rolls Royce

Current and future interplanetary missions operating in extreme environments use "brazing" to join dissimilar materials or assemblies that cannot be joined by any other means. A good example is the Goddard-developed Sample Analysis at Mars instrument suite, which has 200 brazed joints. Principal Investigator Yury Flom used IRAD support to create a methodology for reliably designing and analyzing brazed assemblies — an important capability given the fact that the failure of these joints can result in structural damage, the loss of scientific instruments, and the failure of an entire mission. As a result of Flom's work, the Rolls-Royce Corporation is interested in using the methodology and is preparing a draft Reimbursable Space Act Agreement. *(Investment Area: Crosscutting Technology)*

Principal Investigator John Hagopian is now working with Goddard's Innovative Partnership Program Office to commercialize a super-black, carbon-nanotube coating, which is now being applied to a number of spaceflight applications. (Photo Credit: Chris Gunn)

Commercializing Carbon-Nanotube Coating

Principal Investigator John Hagopian, who has succeeded in developing a multi-walled carbon-nanotube coating that is the "blackest" material ever developed over a range of wavelength bands, is now actively working with the Army Research Laboratory, Rensselaer Polytechnic Institute, the Applied Physics Laboratory, and several Goddard scientists to apply the technology to a number of spaceflight applications. Among its many potential uses (see page 19), the IRAD-funded technology is ideal for suppressing stray light that can contaminate measurements. Also in FY12, Hagopian began working with Goddard's Innovative Partnership Program Office to commercialize the patent-pending technology. *(Investment Area: Crosscutting Technology)*



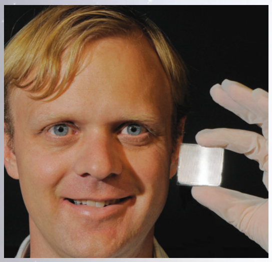
Principal Investigator Timothy Stephenson has developed a new alloy that combines the strength of ceramics with the toughness of metals. He is shown here with samples of the new material. (Photo Credit: William Hrybck)

New Alloy for Satellite Skeletons

Principal Investigator Tim Stephenson has developed a new material that combines the strength of ceramics with the thermal-dimensional stability of Invar, a 100-year-old metal alloy. Developed with IRAD funding, the material is ideal for building super-stable, lightweight "skeletons" that support satellite mirror and other instruments. As a result of his progress, Materion Brush Beryllium and Composites, based in Elmore, Ohio, is interested in working with NASA to develop these products for its Advanced Metal Composites Division. *(Investment Area: Crosscutting Technology)*

ODTBX

Principal Investigator Russell Carpenter in FY12 used CIF support to incorporate a new particle filter (PF) algorithm, developed by graduate student Alinda Mashiku, into Goddard's Orbit Determination Toolbox (ODTBX). ODTBX is a premiere facility for analyzing orbits and is credited with helping scientists win the OSIRIS-REx mission. The new ODTBX PF will allow Goddard to better compete for missions, offering significant advantages over current state-of-the-art navigation methods. As a result of the algorithm's success, the Air Force Research Laboratory and the University of Colorado-Boulder have teamed with Carpenter to investigate two related technologies: Gaussian mixtures and polynomial chaos. *(Investment Area: Communications and Navigation)*



Goddard scientist Michael McElwain is developing an instrument that could image and characterize Earth-like planets if coupled to a powerful starlight-suppression technology. He is shown here holding a critical component of that instrument, a new lenslet array. (Photo Credit: Pat Izzo)

Critical Support Capabilities and Materials

Some technologies are not meant to provide scientific data; their sole purpose is to provide technologists and others with capabilities that assist them in their quest to develop advanced instruments or to interpret data needed by the public. These capabilities include everything from specialized laboratories and instrument subsystems to new materials that meet specific spaceflight needs.

PISCES

Principal Investigator Michael McElwain, a recipient of NASA's prestigious Nancy Grace Roman Technology Fellowship, is developing an instrument that could image and characterize Earth-like planets if coupled to a powerful telescope equipped with starlight-suppression technology. As part of his IRAD-funded effort, he has designed a tabletop-size laboratory instrument called the Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies (PISCES) that would serve as the camera on the Jet Propulsion Laboratory's (JPL) High-Contrast Imaging Testbed — a facility JPL is building to test the candidate starlight-suppression technologies. PISCES, which McElwain plans to deliver in 2015, also would serve as the foundation for a future planet-finding mission. *(Investment Area: Astrophysics)*

Goddard technologist Nithin Abraham, a member of the team that has developed a low-cost, low-mass technique for protecting sensitive spacecraft components from outgassed contaminants, studies a paint sample in her laboratory. (Photo Credit: Pat Izzo)

New Sprayable Paint to Protect Spacecraft Components

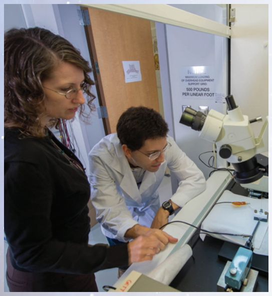
Outgassed solvents, epoxies, lubricants, and other materials can damage spaceflight instruments and components. That is why NASA engineers are always looking for new techniques to prevent these gases from adhering to instrument and spacecraft surfaces and potentially shortening their lives. A team led by Principal Investigator Sharon Straka has developed a low-cost, patent-pending, easy-to-apply solution that adsorbs these gaseous molecules and stops them from affixing. Several private companies and government agencies have expressed interest in using the material and NASA's ICESat2 ATLAS project is evaluating its use. *(Investment Area: Crosscutting Technology)*

6MeV Gamma Facility

Principal Investigator Stan Hunter has developed the 6 MeV Gamma Facility to characterize and test a wide range of gamma-ray instruments, including pixelated cadmium-zinc-telluride detectors for planetary science and Compton and pair-production imaging telescopes for astrophysics. This new in-house capability will help detector developers increase the technology-readiness of their concepts, giving them a competitive advantage when competing for follow-on technology-development funding. *(Investment Area: Astrophysics)*

Infrared Microscope

Principal Investigator Ramsey Smith has assembled an infrared microscope that NASA colleagues can use to not only analyze geological samples but also assure the quality of spacecraft components they develop. Smith says the new capability will be used to develop remote-sensing and in-situ spacecraft instruments. Smith will be characterizing bandpass filters, a new technology now being developed by Principal Investigator Ari Brown (see page 18). *(Investment Area: Crosscutting Technology)*



Stephanie Getty and her research associate, Adrian Southard, prepare an electrospray nozzle for characterization testing. The component is critical to a new instrument she and her team are developing for detecting and analyzing organic compounds, including amino acids. (Photo Credit: Chris Gunn)

"Stephanie is an innovator. The fact that she has won two NASA technology proposals in the same year is a testament to her ability to think outside of the box and demonstrates her top-notch proposal-writing skills."

— Anne Kinney, Solar System Exploration Division director

Chapter Four

Goddard's Top Innovator

Each year, we select the one person who exemplifies the best in research and development. In 2012, that recognition went to technologist Stephanie Getty.

Getty received our top award because of her can-do spirit and remarkable ability to devise, build, and test innovative instrument components for detecting organic compounds, including amino acids, on comets, asteroids, and the icy moons in the outer solar system. Getty, who has become one of Goddard's most productive and prolific researchers, has consistently demonstrated the rare ability to leverage her ideas with other research and development successes to create wholly new instrument concepts — the quintessential definition of innovation.

Hired in 2004 to apply nanotechnology solutions to instrument designs, she unfailingly applied for and won research funding to develop miniaturized instrument components, including a miniaturized electron gun to ionize gas molecules so that a spectrometer can measure their masses and a chemical field effect transistor to analyze liquids on planetary bodies — technologies that she has been able to leverage.

Although Getty has applied her skills to a number of technology-development efforts, she began focusing in recent years on one goal in particular. "I knew I wanted to take the devices I developed to gather measurements that would support planetary science," Getty said.

In 2012, her wide-ranging research efforts paid off. She received $2.2 million in NASA follow-on funding to advance two new instrument concepts for detecting and analyzing organic compounds, including life-sustaining amino acids, on extraterrestrial bodies. Both instruments borrow heavily from instrument components she and her colleagues developed under previous IRAD-funded efforts.

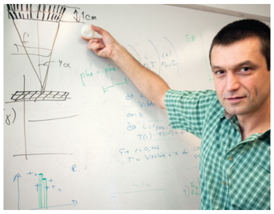
Chapter Five

Technologies to Watch

Research and development is a high-risk endeavor. In some cases, the research does not 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 IRAD-funded efforts that are early-stage, often higher-risk technologies that could one day result in Goddard creating new opportunities and helping NASA carry out its science and exploration missions.

Astrophysics

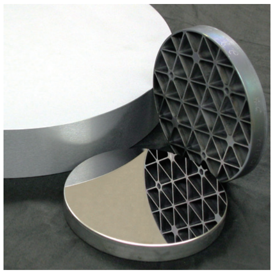
Scotch®-Tape Mirror



Principal Investigator Maxim Markevitch is using R&D funding to pursue the feasibility of fashioning a low-cost X-ray mirror from plastic tape and tightly rolling it like the sticky adhesive ubiquitous in most homes and offices. The whiteboard drawing shows the shape of the X-ray mirror roll. (Photo Credit: Debora McCallum)

The inspiration behind this novel concept to develop an X-ray mirror using a never-before-tried technique came literally from a roll of Scotch® tape. Scientist Maxim Markevitch, who has assembled a team of Goddard's preeminent experts in the field of X-ray optics, is using CIF support to investigate the feasibility of fashioning a low-cost, grazing-incidence mirror from plastic tape, which would be coated with multiple layers of reflective material and then tightly wound into a roll. The team's ultimate goal is flying a prototype on a balloon and then proposing the technology for an Explorer mission or mission of opportunity.

Single-Crystal-Silicon Mirrors for Gravity-Wave Detection



This is a sample single-crystal-silicon mirror. Among other uses, the technology is being investigated for use on an instrument that could detect gravitational waves. (Photo Credit: Chris Gunn)

In yet another application of the IRAD-supported single-crystal-silicon mirror technology, Principal Investigator Peter Hill is working with Goddard astrophysicist Jeff Livas and technologist Vince Bly to apply this technology to gravitational-wave detection, among other applications. The goal under Hill's IRAD was designing a novel approach for manufacturing large, lightweight, and environmentally stable mirrors. Work will continue under an FY13 IRAD. The mirror technology already is being applied to efforts to miniaturize the Goddard-developed Composite Infrared Spectrometer-Lite (see page 19). In addition, Principal Investigator Will Zhang has received NASA technology-development funding to investigate its use for X-ray mirror fabrication (see page 8).

Wafer-Sized Spectrometer

MicroSpec is a revolutionary compact submillimeter spectrometer that is 10,000 times more sensitive than competing instruments. With CIF support, which augmented funding received in FY11 under NASA's Astronomy and Physics Research and Analysis program, scientist Harvey Moseley and his team continued advancing instrument components that would fit onto a silicon chip measuring just four inches in diameter. The reduction in mass and volume promises a high-performance system ideal for future missions.

First Image Telescope for Observing Charge Exchange

X-ray emissions resulting from a physical phenomenon called "charge exchange" occur in planetary atmospheres, comets, interplanetary wind, the Earth's exosphere, supernova remnants, and galactic halos. A team led by Principal Investigator F. Scott Porter and his team have designed, fabricated, and tested a laboratory prototype of the first end-to-end, wide-field X-ray imager capable of observing this effect, particularly in the soft X-ray regime.

ExpPlanetSAT: Finding Earth-like Planets with a Small Budget

Principal Investigator Stephen Rinehart used CIF resources in FY12 to develop ExoPlanetSat (EPS), a proposed mission for studying exoplanets with a constellation of 20 to 30 nanosatellites. Rinehart completed EPS's first-cut thermal model and identified key test facilities appropriate for low-cost, high-risk nanosatellites. The main long-term goal is validating the concept and reducing risk before building and flying the constellation.

Communications and Navigation

Navigator GPS Weds TDRSS Transceiver on SpaceCube

With FY12 IRAD funding, Principal Investigator Monther Hasouneh made good progress marrying three major Goddard-developed technologies: SpaceCube, Navigator, and the Goddard Enhanced Onboard Navigation System software. Hasouneh is designing a device that combines the Navigator GPS receiver with a Tracking and Data Relay Satellite System radiometric-measurement transceiver, which then would be implemented on the SpaceCube processor. The technology promises to provide superior navigation capability for a range of space applications.

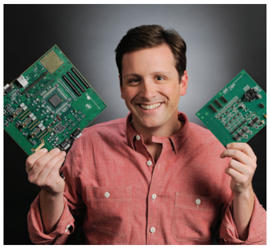
Crosscutting Technologies

Graphene Portfolio Expands

Goddard technologist Mahmooda Sultana is investigating additional applications for graphene, a trailblazing technology with unique physical characteristics that make it ideal for use in space. (Photo Credit: Pat Izzo)

Principal Investigators Mahmooda Sultana and Mary Li are now developing with CIF and IRAD funds tiny sensors made of a graphene, a potentially trailblazing material heralded as the next best thing since the discovery of silicon. The sensors would detect trace elements in Earth's upper atmosphere and structural flaws in spacecraft. Just one atom thick, graphene is composed of carbon atoms arranged in tightly bound hexagons best visualized as atomic-scale chicken wire. The effort expands on the team's previous IRAD-funded efforts to use graphene as transparent conductive electrodes for large detector arrays, another IRAD-funded research effort.

In another CIF-supported effort, Principal Investigator Anthony Yu is investigating the use of graphene as an absorber for passive-mode locking-laser systems, which would enable the development of more precise, long-range laser instruments. In FY12, Yu successfully developed new processes to grow and transfer graphene layers to an optical substrate. Though the technology shows great promise for this application, Yu reports that further improvements are necessary.



Jonathan Pellish holds in his right hand a Goddard-developed digital test board. In his left is the IRAD-developed daughter card containing the analog-based data-processing integrated circuit. The daughter card snaps into the digital test board and will be used to test a number of spaceflight-processing applications. (Photo Credit: Pat Izzo)

Goddard technologist Vivek Dwivedi (right) and his University of Maryland collaborator, Raymond Adomaitis (left), are shown here with a sample and the reactor that they will use to apply thin films onto the substrate using atomic layer deposition. (Photo Credit: Chris Gunn)

Scientists Scott Barthelmy, Gerry Skinner, and Jordan Camp are shown here with their prototype "Lobster Transient X-ray Detector," a crosscutting instrument that would detect transient X-rays and ammonia leaks on the International Space Station. (Photo Credit: Debora McCallum)

Fast Forward to the Past

Principal Investigator Jonathan Pellish is using IRAD funding to investigate a computing technology of yesteryear, believing that it could potentially revolutionize everything from autonomous rendezvous and docking to remotely correcting wavefront errors on large, deployable space telescope mirrors. The new technology is an analog-based microchip, developed by Analog Devices Lyric Labs, of Cambridge, Massachusetts. Instead of relying on ones and zeros that computing systems then translate into something meaningful to users, this technology accepts inputs and calculates outputs that are between zero and one. One of the first applications the group is targeting is wavefront sensing and control.

Coating Technology One Atomic Layer at a Time

Atomic Layer Deposition is a rapidly evolving technology for coating plastics, semiconductors, glass, Teflon, and a plethora of other materials. A team, led by engineer Vivek Dwivedi, experimented with the technique to solve three challenges. The team coated an X-ray mirror with iridium, developed a highly emissive, vanadium-oxide-based coating that could be used on "smart radiators," and manufactured boron-nitride nanotubes to protect spacecraft components from the harmful effects of high-energy solar particles and micrometeorite impacts. The experimentation proved the technique is viable for spaceflight applications.

Lobster Eye X-ray Optics

With CIF funding, Principal Investigator Jordan Camp and his team are applying a technology that mimics the structure of a lobster's eyes to develop a new detector that could help revolutionize X-ray astronomy and keep astronauts safe on the International Space Station (ISS). From its perch on the orbiting outpost, the Lobster Transient X-ray Detector would detect with unprecedented accuracy transient X-rays — those fleeting, hard-to-capture photons produced during black-hole and neutron-star mergers — and check for potentially harmful ammonia leaks on ISS.

Patent Filed for Etalon Spectrometer

In FY12, Principal Investigator Molly Fahey developed mathematical and optical models, ultimately demonstrating an experimental prototype of a recirculating etalon spectrometer. The instrument's optical design, for which Fahey plans to file a patent application, recirculates the reflected light from a fixed Fabry-Perot etalon to provide a high signal-to-noise ratio even for very weak received light. Fahey believes the technology could dramatically improve both passive and active spectroscopic instruments.

Earth Sciences

Using Satellite Constellations to Study the Earth Radiation Budget

Principal Investigator Warren Wiscombe has fleshed out a concept to collect Earth radiation-budget measurements by placing flux radiometers as hosted payloads on massive constellations, such as the Iridium network. One of the advantages of using an already-existing constellation — aside from lower costs — is the fact that the entire Earth is viewed simultaneously, 24 hours a day, thus providing diurnal-cycle measurements for the first time. Wiscombe envisions using Vertically Aligned Carbon Nanotube (VACNT) detectors as the flux radiometer and plans to fly this novel technology prototype on commercial suborbital vehicles. The flights would advance VACNT detectors from a technology-readiness level of three to seven.

Global Hawk Airborne Precursor

With IRAD and NASA instrument-development funding, Principal Investigator Haris Riris continued work on an airborne lidar that would measure the column abundance of carbon dioxide and methane in the atmosphere, a key measurement in climate studies. In FY12, Riris and his team investigated potential lasers and aircraft platforms and completed the mechanical design of a dual methane/carbon-dioxide lidar.

Blackbody Calibrator

IRAD funding of new carbon nanotube-based technologies is a gift that keeps giving. In FY12, Principal Investigators Ramsey Smith and John Hagopian studied the feasibility of using carbon nanotubes to develop a reliable, highly stable onboard blackbody calibrator for Earth-science investigations, particularly for a future Landsat thermal imager. Carbon nanotubes, which are grown in a furnace and demonstrate unique properties applicable to a range of spacecraft applications, already are being demonstrated for suppressing stray light (see page 10).

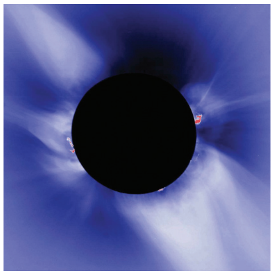
Superconducting Gravity Gradiometer

Principal Investigator Dan Sullivan and his team used IRAD funds to explore the viability of developing and ultimately flying a superconducting gravity gradiometer to measure with unprecedented accuracy Earth's gravity fields, enabling science in such areas as hydrology, climate change, seismic activity, and weather patterns. In FY12, the team simulated the proposed instrument's capabilities, finding that it offered great promise as a tool for mapping planetary gravity fields.

Heliophysics

Solar ENA Imaging Coronagraph

With FY12 CIF support, a Goddard team led by Principal Investigator Albert Shih developed the Solar Energetic Neutral Atom (ENA) Imaging Coronagraph — a technology needed to detect ENAs and, more particularly, solar energetic particles. The only ENA observations to date suffered from low sensitivity and did not include imaging. The Solar ENA Imaging Coronagraph offers those capabilities and will provide a new observing window, allowing scientists to better understand particle acceleration and energy release. In FY12, the project evaluated the instrument's proposed design and now will concentrate on developing a mechanical design.



Principal Investigator Steven Christe is advancing technology that could revolutionize the study of the solar corona.

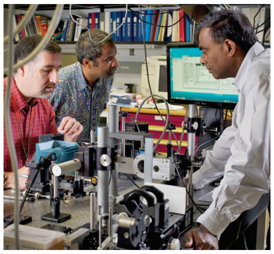
Microcalorimeters for Solar Observations

With CIF funding, Principal Investigator Steven Christe and his team developed and tested the first generation 32 X 32 microcalorimeter array that could revolutionize the study of the solar corona. With the support, the team designed, fabricated, and tested large-format, closed-packed arrays of transition-edge sensor (TES) microcalorimeters on a 75-micron pitch — the first-ever test of a small TES pixel. The technology is especially applicable to sounding rocket missions.

Planetary and Lunar Science

Miniaturizing Fourier Transforms Spectrometers

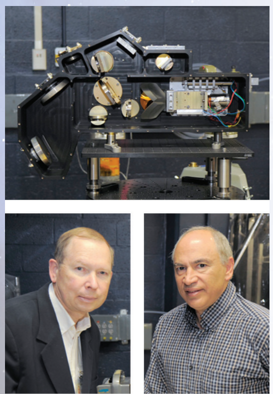
The Miniaturized Fiber Optic Coupled Fourier Transform Spectrometer (FTS) is a potentially revolutionary low-power, low-mass instrument that could dramatically reduce the size of more traditional spectrometers used to study far-flung worlds in our solar system. The technology, which is sensitive to the mid- and long-infrared wavelength bands, is a greatly scaled down version of the Michelson-type FTS. With CIF support, Principal Investigator Shahid Aslam and his team investigated techniques to reduce critical instrument components so that they fit onto a silicon wafer and do not require moving parts to operate. The team wants to replace the mirrors and associated hardware commonly found on spectrometers with a microscale photonic system featuring 60 hollow waveguides, or tunnel-like circuits, 10 times thinner than a human hair.



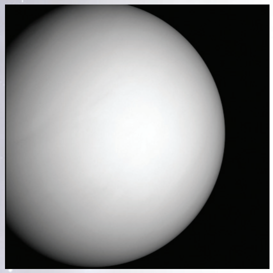
ABOVE: George Shaw (left), Shahid Aslam (center), and Tilak Hewagama (right) are testing their spectrometer-on-a-chip (LOWER) that could dramatically reduce the size of future instruments. (Photo Credit: Chris Gunn)

Bandpass Filter Array for the Far Infrared

Principal Investigator Ari Brown used his FY12 IRAD to advance a new technology that filters out far- to mid-infrared signals that propagate from electronic wiring. These signals contaminate the far-infrared wavelength light that scientists actually want to gather from astronomical sources, including planets in the outer solar system. In addition, Brown will be collaborating with Principal Investigator Ramsey Smith, who will characterize the bandpass filters with his recently developed Infrared Microscope (see page 12).



Scientist John Brasunas (left) and technologist John Hagopian (right) are investigating the use of single-crystal- silicon mirrors and other advanced technologies for the Composite Infrared Spectrometer-Lite (top). (Photo Credit: Pat Izzo)



The MESSENGER spacecraft snapped a series of images as it approached Venus. Principal Investigator Lori Glaze collaborated with the Ames Research Center to design the Venus Intrepid Tessera Lander mission.

Silicon Mirrors for CIRS-Lite

Principal Investigator John Brasunas also is investigating the use of single-crystal-silicon (SCS) mirrors (see page 10) for use on a follow-on to Cassini's highly successful Composite Infrared Spectrometer (CIRS). Known as CIRS-Lite, the instrument may potentially fly several advanced technologies, including a carbon nanotube-based detectors, calibrator, and radiator. Brasunas plans to finish fabricating the SCS secondary mirror and begin cryogenic testing of the CIRS-Lite telescope. The instrument-development effort is aimed at reducing the size and mass of the instrument and keep Goddard at the forefront of planetary science.

Science-Enabling Atmospheric Entry at Venus

With FY12 CIF resources, Principal Investigator Lori Glaze collaborated with colleagues at the Ames Research Center to develop an integrated delta design of the Venus Intrepid Tessera Lander (VITaL) mission, which implements the Advanced Dark Energy Physics Telescope (ADEPT) entry system. VITaL is a high-mass, large-volume lander that will benefit from ADEPT.

Portable Electrostatic Detector

The Exploration Portable Electrostatic Detector is a ruggedized portable electrometer that Principal Investigator Telana Jackson began developing several years ago. Designed initially as a device to measure tribo-charging on the surface of the moon, the technology now is being adapted for potential use on Goddard's OSIRIS-REx and as a payload to measure Martian dust storms. Jackson conducted field studies in Arizona and is in discussions with other Goddard scientists to include the instrument in their missions.

Multi-Channel Digitizer

Principal Investigator Gerry Quilligan completed the design of a new radiation-hardened-by-design, application-specific integrated circuit for thermal instruments or radiometers. In FY12, he delivered the prototype to Towerjazz Semiconductor for manufacturing. The 16-channel thermopile readout chip is intended for use in missions to Jupiter and other outer solar-system bodies.

HOMER Prototype Flight Laser

Principal Investigator Bryan Blair in FY12 completed a life test of the second-generation High Output Maximum Efficiency Resonator (HOMER), a 10-year-old laser system. The instrument measures vegetation canopy and is now being enhanced to make it more competitive for future missions, including those to Venus, Mars, or another moon-like planetary body. With IRAD funding, the instrument successfully underwent vibration and thermal-vacuum testing and a 15-billion-shot life test.

Suborbital Platforms and Launch Services

Cancelling Gyro Errors

Gyroscopes are important because they measure the rate of motion as an observatory moves and helps ensure that it maintains correct pointing during observations. However, they are prone to errors. Technologist Joseph Galante and his team are using CIF support to develop the Nonlinear Adaptive Filter (NAF), an innovative technology for determining gyro errors and cancelling the errors' effect on attitude estimates. By completely cancelling gyro errors, NAF greatly enhances sensor performance. With its funding, the team developed low- and high-fidelity simulations, which the team carried out in the spring and summer of 2012. As a result, Goddard heliophysicist Adrian Daw and others are considering using the technology in future Cubesat missions (see page 7).

High-altitude balloons like this one will give scientists a new platform from which to observe other solar system bodies. Principal Investigator Terry Hurford is studying designs for a reusable balloon-borne telescope.

Dedicated Balloon-Borne Platform for Planetary Observation

High-altitude balloons could fill a gap in planetary science, giving scientists a platform from which to carry out long-term monitoring of other solar-system bodies — a task now performed by amateur astronomers. In FY12, Principal Investigator Terry Hurford used IRAD funding to study concept designs for both a dedicated and reusable planetary balloon-borne telescope, combined with a dual visible/infrared wavelength camera. Hurford is seeking follow-on funding from a variety of sources to further advance the concept.

Cube/Small Satellite Antenna Design

Principal Investigator Serhat Atunc used R&D funding to study alternatives to standard omnidirectional antennas. The next-generation antennas, specifically those for Cubesats, would operate at frequencies compatible with the Near-Earth Network, better positioning Goddard to provide lower-cost, small-satellite missions.

Education

Though education is not one of Goddard's official lines of business, we do set aside resources for principal investigators who apply technology for educational purposes.

Adapting ILIADS for K-12 Students

Principal Investigator Troy Ames used IRAD resources in FY12 to adapt a geospatial-information-system software application for use in middle schools and informal learning venues, such as museums. The software, the Integrated Lunar Information Architecture for Decision Support (ILIADS), is a sophisticated interactive tool engineers and scientists can use to perform scientific analyses on mapped lunar data collected by NASA's Lunar Reconnaissance Orbiter. In collaboration with Angela Cristini, a professor at Ramapo College in New Jersey, Adams helped develop a 10-part lesson plan infusing ILIADS in New Jersey's math and science curriculum.

ROVER for Environmental Research

The Remotely Operated Vehicle for Environmental Research (ROVER) is a multidisciplinary educational project that involves students and faculty at the University of Maryland Eastern Shore. Principal Investigator Geoff Bland designed and fabricated a prototype system and a UMES team subsequently constructed a second ROVER. Bland says ROVER systems will be included in research activities, particularly those sponsored by the Center for the Integrated Study of Coastal Ecosystem Processes and Dynamics in the Mid-Atlantic Regions.

The IRAD year culminated with the annual "Poster Session," which showcased the work of this year's IRAD and CIF principal investigators. This chapter tells the story in photos.

(Photo Credit: Pat Izzo)

Chapter Six

The Final Event:

Scenes from the FY12 IRAD Poster Session

Chief Technologist Peter Hughes welcomes visitors and participants before awarding this year's "Innovator of the Year" award to technologist Stephanie Getty.

Chief Technologist Peter Hughes (right) presented this year's "Innovator of the Year" award to technologist Stephanie Getty (center). Goddard Deputy Director for Technology and Research Investments Christyl Johnson (left) was on hand during the awards ceremony.

Engineer Ken Segal, who has been instrumental in promoting the use of composites in spacecraft design, holds the upper skin of a telescope housing made entirely of composite materials. The structure was originally designed for the Tropospheric Wind Lidar Technology Experiment, an instrument that could fly next year as part of NASA's Hurricane and Severe Storm Sentinel mission.

No, these aren't toys. Principal Investigator Steven Kenyon created these devices using an emerging technology called "Direct Metal Laser Sintering." With this 3-D manufacturing process, engineers and scientists may be able to fabricate novel instruments considered impractical or even impossible before. In his right hand, Kenyon holds a modulated X-ray source; in his left, a 3-D representation of the magnetic field emanating from a pulsar.

Jaime Esper (left), developer of a new microsatellite that he demonstrated last year, explains its inner-workings to AETD Chief Technologist Michael Johnson.

Scientist Peter Hildebrand (right) holds the joystick that operates the Remotely Operated Vehicle for Environmental Research (ROVER), which Wallops Flight facility technologist Geoff Bland (left) developed under his FY12 IRAD. The ROVER will be used in coastal ecosystem research by students and faculty at the University of Maryland- Eastern Shore.

The aquatic lotus plant inspired a Goddard team to develop a special coating preventing dirt and bacteria from sticking to and contaminating spaceflight gear. Technologist Kristin McKittrick shows scientist Bill Farrell how well the lotus coating actually works. She doused two samples with a gritty material reminiscent of lunar dust. The material literally fell off the lotus-coating sample on the left. Only water removed it from the coating-free sample on the right.