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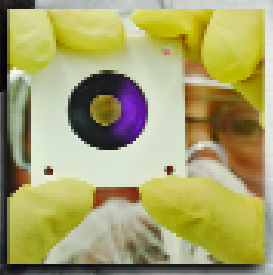
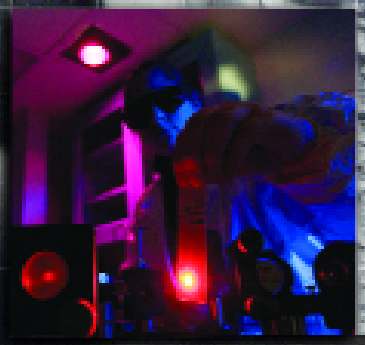


Investing for the Future

A Report on the FY 2010 Internal Research and Development Program



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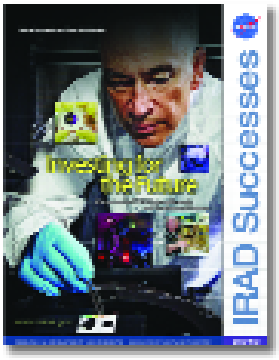
IRAD Successes

RESEARCH & DEVELOPMENT ACHIEVEMENTS • GODDARD SPACE FLIGHT CENTER

2010



About the Cover

In FY10, Goddard technologists pursued a number of emerging technologies. Pictured on the cover is John Hagopian examining a nanotech-based light-suppression technology that earned him the 2010 "IRAD Innovator of the Year" award. Inserts include a new silicon-nitride window that contributed to the center winning a role on the new Solar Probe Plus mission (top left); technician Millie Martin analyzing amino acids in interplanetary dust particles (top right); technologist Emily Wilson experimenting with laser technology (bottom left); and a Wallops technician working on a new microsatellite called SMART (bottom right).

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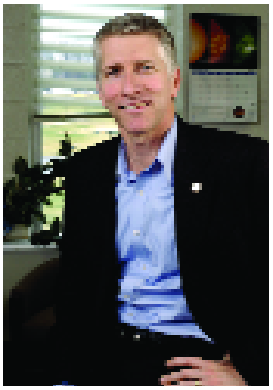


Peter Hughes
Chief Technologist

Chapter One

Message from the Chief Technologist: Forging a Path and Leaving a Trail

Ralph Waldo Emerson once said, "Do not go where the path may lead, go instead where there is no path and leave a trail." The sentiment, I believe, aptly describes the course we've chosen for our Internal Research and Development (IRAD) program.

Five years ago, we revamped our program to make it more opportunity focused and better aligned with the Center's core lines of business. Our goal was simple: We wanted to give our technologists a competitive advantage when they competed for already-identified mission and instrument opportunities. We also wanted to explore technologies that enabled whole new opportunities and missions. The strategy paid off. Over the ensuing years, our return on investment increased each year. Our technologists won an increasing number of new mission and instrument-development efforts, vastly exceeding the investment we had initially made in these technologies.

Though we still are investing in technologies that satisfy nearer-term mission opportunities — and still reaping the rewards — we have tweaked our priorities. We are investing a larger and larger share of our limited investment dollars in early-stage innovations, using the same formula of selecting only those technologies that map to Goddard's core lines of business. In fact, more than 35 percent of our FY10 portfolio included these types of investments, which are longer-term and higher-risk in nature and cover the range in capabilities, from instrument miniaturization and advanced laser technologies to nanotechnology and advanced electronics. The strategy is continuing. In FY11, 43 percent of our portfolio is made up of early-stage innovations.

We adopted this strategy even before NASA had begun advocating the development of over-the-horizon technologies. We believed, as NASA executives do today, that the strategy would blaze a new trail leading to bigger science, reduced mission risks and costs, and significantly improved scientific return.

This report chronicles some of the year's successes on Goddard's technology front, as we build our technological base to secure a new era of scientific discovery. In addition to securing new work, many of our technologists validated new capabilities during aircraft flights. They forged collaborations with industry and academic teams. They created new capabilities that will benefit technologists across the center, and they formulated concepts for future science and exploration missions. Their successes benefited Goddard and the scientific community as a whole.

We have set a path that is strategically aligned with the Center's core lines of business. Our program is highly competitive and forward reaching, designed to nurture innovative ideas that are important to the Agency's future. We are addressing both identified opportunities and to a larger extent emerging needs that will create new opportunities in the future. We are going where no path exists, yet we aim to leave a trail.

Peter Hughes
Chief Technologist

Chapter Two

A Focus on Discipline: How We Select and Manage the Technology Portfolio

R&D by its very nature is high risk. Some research initiatives succeed; others do not. That does not mean we approach R&D in a slapdash fashion. We are disciplined, guided by one basic requirement: Whether the R&D investment is being made to win a near-term opportunity, prepare us to win a longer-term opportunity, or even to explore a new approach or even a new mission, all awarded IRAD tasks must map to one or more of Goddard's official lines of business. They are selected because they fulfill a clearly defined need or create a unique new opportunity.

"Half of life is luck; the other half is discipline — and that's the important half, for without discipline you wouldn't know what to do with luck."

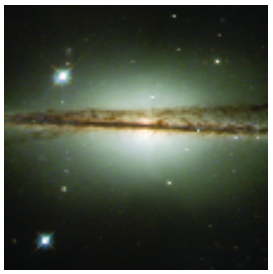
— Carl Zuckmeyer, German Writer and Playwright

The IRAD proposals we funded in FY10 were no different. All were strategically aligned, highly competitive, and chosen because they addressed technologies important to Goddard and the disciplines in which we have traditionally excelled (see page 3). A significant number also addressed crosscutting capabilities, those technologies that address two or more strategic lines of business. A significant number also represented early-stage innovations that have potential to revolutionize scientific research in the future.

High Probability of Follow-On Support and New Scientific Discoveries

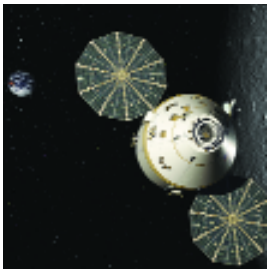
Just as important, our FY10 IRAD awardees received support because of their probability of receiving follow-on support from NASA and other government partners. The IRAD seed funding provided the impetus for what we hope will ultimately lead to new mission and instrument opportunities and breakthrough scientific discoveries — our principal objective.

Though we cannot guarantee 100-percent success for every technology funded — an unreasonable goal given the inherent risk associated with R&D — a disciplined approach to portfolio selection and management certainly increases the likelihood of success. Certainly the successes reported in this report bear out the observation.

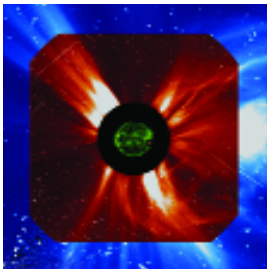


Astrophysics

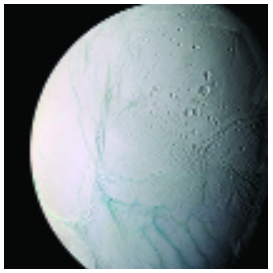
Earth Science



Exploration



Heliophysics



Planetary & Lunar Science

Goddard's Strategic Lines of Business

In FY10, all IRAD-funded technologies mapped to one or more of the following strategic lines of business, areas where Goddard has established a reputation for excellence.

Astrophysics...

...focuses on missions and technologies aimed at answering: How do galaxies, stars, and planetary systems form and evolve? What is the diversity of worlds beyond our own solar system? Which planets might harbor life? What happens to space, time, and matter at the edge of a black hole?

Communications and Navigation...

...includes systems and technologies needed for responsive communications and navigation. Investments primarily are intended to support NASA's Exploration, Space Operations, and Science Directorates.

Earth Science...

...focuses on developing technologies needed to observe and understand changes in Earth's climate system. Technologies include state-of-the-art remote sensors and aircraft-based and surface-based observational platforms.

Exploration...

...addresses technologies and systems needed for future exploration missions to the Moon and Mars. Such systems could include highly advanced sensors and platforms, autonomous rendezvous and docking, miniaturized instrumentation, imaging, and applied science for exploration.

Heliophysics...

...addresses solar structure and magnetic activity, solar wind, solar disturbances, and their effects on Earth's upper atmosphere. Wavelength coverage spans gamma rays to microwaves and includes particles and fields.

Planetary and Lunar Science...

...supports new scientific measurements to explore the solar system. Primary research areas include instruments for landers and orbiting spacecraft.

Chapter Three

Metrics for Gauging Success: A Snapshot of the Year's Notable Achievements

It often takes years for new technologies to mature and realize the ultimate goal of our R&D program; therefore, we use a variety of metrics to gauge our success along the way.

The most tangible measure is whether an IRAD-funded technology is chosen for inclusion in a new mission or instrument opportunity or receives follow-on funding from an external source, such as a NASA ROSES award, to continue the technology's maturation. Success also is measured by whether an IRAD-funded technology is licensed to a commercial company, if it is baselined for potential use in a future mission, or if it leads to a new capability that benefits other technologists in their own R&D efforts.

By these measures, FY10 was a particularly fruitful year. Our investigators received follow-on funding and found berths on various research platforms, including aircraft and high-altitude balloons. New capabilities were added and licensing agreements arranged. A sampling of their achievements is highlighted in this chapter.

New Missions and Flight Opportunities

The crowning achievement of any space-related R&D program is an investment that leads to the award of a new spaceflight mission or instrument opportunity. In FY10, IRAD-funded principal investigators won new missions and participated in a variety of flight opportunities across Goddard's focus science areas.

Niche Technology Provides Competitive Edge in Solar Probe Plus

Principal Investigator Eric Christian worked with the Goddard Detector Development Laboratory to develop an ultra-thin window, which will be used for the first time on an instrument flying on the new Solar Probe Plus mission.

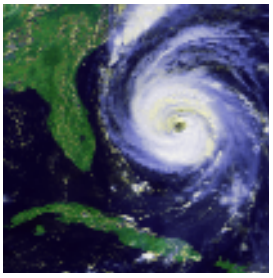
"The silicon-nitride windows gave us an edge in a very competitive field. These IRADs certainly helped."

— Scientist Eric Christian, Solar Probe Plus Technology Contributor

A super-thin silicon nitride window gave Goddard the competitive edge in its bid to build key components for Energetic Particle Instrument-High (EPI-Hi), one of the instruments flying on the Solar Probe Plus mission. Called the "mission of the century" by the heliophysics community, Solar Probe Plus will carry out five experiments after it plunges directly into the Sun's atmosphere to explore a region no other spacecraft has ever encountered.

The technology, developed by Goddard's Detector Development Laboratory in part with IRAD funds, will be placed in front of a stack of Goddard-developed solid-state detectors that need the new window to block stray ultraviolet light and micrometeroid impacts, allowing the detector assembly to gather a larger range of solar particles. In addition to the new window, Principal Investigators Eric Christian and Tycho von Rosenvinge will be providing EPI-Hi's mechanical structures and an electronics box — work valued at about $2.3 million.

Its importance to space science is not limited to studies of the Sun, either. It has broad application to other space science missions, including a possible mission to Europa, one of Jupiter's smallest moons. **(Investment Area: Heliophysics)**



Goddard principal investigators are playing important roles on missions investigating why storms intensify — currently a poorly understood phenomenon. This image shows Hurricane Fran, a powerful hurricane that made landfall near Cape Fear in North Carolina.

Goddard Instruments Study How Hurricanes Intensify

While forecasters have made great progress accurately tracking hurricanes, they have made only small improvements in their ability to predict intensity. In FY10, NASA flew the Genesis and Rapid Intensification Processes (GRIP) experiment, a multi-platform effort that carried a dual-frequency radar developed by Principal Investigator Gerald Heymsfield in part with IRAD funds.

Heymsfield specifically developed the solid-state instrument, called the High-Altitude Imaging Wind and Rain Profiler, for use on unpiloted high-altitude aircraft. It will fly again in 2011 as one of seven instruments flying on the NASA's new Earth Venture-1 mission, the $30 million Hurricane and Severe Storm Sentinel (HS3) planned for 2011-2014.

Described as GRIP on "steroids," the Goddard-managed HS3 will carry two other IRAD-funded instruments aboard NASA's new Global Hawk unmanned aircraft (see below) — the Cloud Physics Lidar and the Tropospheric Wind Lidar Technology Experiment developed by scientists Matt McGill and Bruce Gentry, respectively. While GRIP laid the foundation, HS3 will give scientists something they have never had before — a sustained look at storms as they evolve over an extended period of time. **(Investment Area: Earth Science)**

The Global Hawk unmanned vehicle made its maiden scientific flight in April, proving it was a viable platform for high-altitude, long-duration missions. Goddard scientist Paul Newman co-managed the flight.

Instrument Helps to Establish Global Hawk Protocols

Global Hawk, which is playing an important role in NASA's hurricane studies, was first demonstrated in FY10, with help from a team led by Goddard scientist Paul Newman. On that maiden flight, flown in April 2010, the unmanned aircraft carried the Goddard-developed Cloud Physics Lidar and a handful of other instruments that showed these missions were possible and could yield valuable data. Just as important, Goddard scientists helped establish protocols and procedures for integrating science instruments and flying an unpiloted vehicle remotely from an operations center at Dryden Flight Research Center, reducing risk for future missions. **(Investment Area: Earth Science)**

LVIS to Fly on IceBridge

Operation IceBridge, the largest-ever airborne survey of Earth's polar ice, will get an assist from an IRAD-funded instrument that proved it could do what no one ever expected it to do — measure ice sheets over the poles. Originally designed to gather topographical and vegetation data, the Goddard-developed Laser Vegetation Imaging Sensor (LVIS) in FY10 earned a coveted spot on NASA's IceBridge project. The six-year mission will bridge the gap between NASA's Ice, Cloud, and Land Elevation (ICESat) and its predecessor, ICESat-2, planned for late 2015.

Principal Investigator Bryan Blair received a three-year, $4 million ROSES award to carry out the observations. LVIS's selection was in large part due to a demonstration over Greenland in late 2007, proving that the instrument was just as effective at measuring ice sheets as it was at gathering vegetation and topographical information. **(Investment Area: Earth Science)**

BETTII to Complement Herschel and James Webb Space Telescope

"I wouldn't say that any single IRAD effort led to the BETTII win, but that the group of them formed the landscape that made the win possible. Each IRAD that contributed helped make this challenging project possible, and as such, something that the reviewers could support."

— BETTII Principal Investigator Stephen Rinehart

Astronomical studies at infrared wavelengths have revolutionized scientists' understanding of galaxies, stars, and planets, as well as their origins. But further progress on major questions has been stymied because the spatial resolution of single-aperture telescopes degrades at long wavelengths. The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) project is expected to overcome those deficiencies.

In FY10, Principal Investigator Stephen Rinehart received a $5.5 million ROSES award to develop BETTII's 8-meter boom, which will operate in the far infrared on a high-altitude balloon — wavelengths currently inaccessible from the ground. The collaborative effort involves Goddard and the University of Maryland, with assistance from the Far-Infrared Telescope Experiment team in Japan. BETTII, which Rinehart said was made possible by previous IRAD investments in associated technologies, including modulators, detectors, and interferometers, will complement observations by Herschel and the James Webb Space Telescope. **(Investment Area: Astrophysics)**

QWIP Technology Finds a Home on LDCM

Goddard technology Murzy Jhabvala (seated), who spent nearly two decades developing his QWIP technology, tests the detector system in the Mojave Desert.

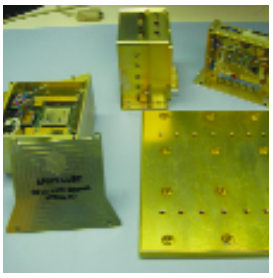
Principal Investigator Murzy Jhabvala, who received various Goddard and NASA R&D funding over the years to advance an infrared-detector technology, is debuting it on a Goddard-developed instrument that will help states monitor water consumption — an important capability in the American West where water rights are allocated.

The Quantum Well Infrared Photodetector (QWIP) is being integrated onto Goddard's Thermal Infrared Sensor (TIRS) — a late addition to the Landsat Data Continuity Mission that NASA plans to launch in 2012. Using R&D funds, Jhabvala matured the technology over roughly 20 years, finally qualifying it for actual spaceflight in FY10. In addition to already having the technology at hand, QWIP offered the TIRS development team two other significant advantages: As technology goes, it is relatively easy to build. Furthermore, it easily met the instrument's performance requirement. **(Investment Area: Earth Science and Planetary and Lunar Science)**

Goddard Scientists Tapped to Collaborate on CLASS

Goddard scientists and detector developers are collaborating with the Johns Hopkins University to build a new ground-based instrument, the $5 million Cosmology Large Angular Surveyor (CLASS). Goddard is providing most of the sophisticated bolometer detectors and other state-of-the-art technologies that will help the National Science Foundation-funded team test the "inflation theory" of the universe's origin. The experiment, which the team expects to ship to the Atacama Desert in northern Chile in 2014, will observe large swaths of the microwave sky in search of evidence that the infant universe expanded from the microscopic to the astronomical in a fraction of a second after its birth.

The bolometer detectors — an IRAD-funded technology developed by Principal Investigator Christine Jhabvala — also are being used in the Primordial Inflation Polarization Explorer (PIPER), a related balloon-based experiment also looking for evidence of cosmological inflation, but at a different frequency. Goddard hopes to use experiences gained from both to ultimately win a space mission devoted exclusively to cosmological inflation. **(Investment Area: Astrophysics)**



Several missions recommended by the National Research Council's Earth Science Decadal Survey are now baselining SpaceCube, a powerful flight processor developed by Goddard.

"In the recent ESA-led trade studies for IXO as part of the Cosmic Vision review, the Goddard/NIST approach to the XMS detector system was chosen for the IXO baseline, and tentative national responsibilities are already being assigned based on the baselined technologies. This illustrates how investment in the technology roadmap leads to direct benefit to NASA."

— TES Detector Principal Investigator Caroline Kilbourne

ESA completed its "Cosmic Vision" study in 2010 and chose the five-stage Continuous Adiabatic Demagnetization Refrigerator (CADR) now being developed by Principal Investigator Peter Shirron as the observatory's baseline detector cooling system. The decision was influenced in part by the three-stage CADR now flying on the Astro-H mission.

Baselined for Use in Future Missions

When planning complex space missions, panels of scientists evaluate technologies against science objectives and baseline a possible approach in their initial plans. Having a technology baselined into these architectures obviously bodes well for the technologist and the future of his or her technology.

SpaceCube Packs More than a Processing Punch

Goddard's SpaceCube, an experimental, next-generation flight processor that provides an order-of-magnitude increase in onboard computing power, has been baselined for at least six new missions, said Principal Investigator Tom Flatley.

The technology, first demonstrated on the Hubble Servicing Mission in 2009, is now being demonstrated on the International Space Station. In September, it flew on a sounding rocket mission testing a new automated range-safety technology. And next year, it will play a pivotal role on another sounding rocket mission testing X-band communications and a reconfigurable microsatellite — the Small Rocket/Spacecraft Technology (SMART) — also developed with IRAD funds by technologist Jaime Esper.

Buoyed by the success, SpaceCube developers are creating other products to meet the varying needs of new customers. In fact, several missions recommended by National Research Council's Earth Science Decadal Survey are baselining either SpaceCube 2.0 or a much smaller version, called the SpaceCube Mini, in their mission architectures. **(Investment Area: Communications and Navigation)**

Two Technologies Baselined for Proposed X-Ray Observatory

In FY10, the European Space Agency (ESA), NASA's partner in the proposed International X-ray Observatory (IXO), baselined two Goddard-developed technologies for use on the next-generation observatory should the space agencies decide to pursue it.

ESA completed its "Cosmic Vision" study — the agency's long-term plan for space science missions — and chose the five-stage Continuous Adiabatic Demagnetization Refrigerator (CADR) now being developed by Principal Investigator Peter Shirron as the observatory's detector cooling system. The decision was influenced in part by the three-stage CADR now flying on the Astro-H mission.

The plan also recommended that ESA baseline IRAD-funded transition-edge sensors for IXO's X-ray Microcalorimeter Spectrometer (XMS). Goddard Principal Investigator Caroline Kilbourne, who is partnering with the National Institute of Standards and Technology to advance the technology, also received a $2.4 million ROSES award in FY10 to develop microcalorimeter arrays that would benefit IXO and other missions.

Whether the IXO is built remains to be seen; however, the fact that the technologies are baselined puts Goddard in good position to play a significant role in the mission's development should NASA proceed with it, principal investigators said. **(Investment Area: Astrophysics)**

Follow-On Funding to Advance Technology-Readiness Levels

The IRAD program is not meant to provide cradle-to-grave support. Therefore, a key IRAD success metric is whether principal investigators succeed in securing follow-on funding to further advance their technologies. This follow-on funding does not necessarily result in the award of a mission, but the advances technologists make frequently can be applied to other opportunities that lead to scientific discovery.

Harvey Moseley holds the detector that Goddard technologists developed for a revolutionary far-infrared spectrometer called MicroSpec. Kongpop U-Yen and Wen-Ting Hsieh (pictured in the background) are assisting in the effort.

On the Road to Creating a Revolutionary Far-Infrared Spectrometer

With IRAD and $150,000 in ROSES funding, Scientist Harvey Moseley demonstrated key components of MicroSpec — a groundbreaking, far-infrared spectrometer that promises to be 10,000 times more sensitive than competing instruments. Infinitely smaller than existing instruments, MicroSpec would be so tiny that its components could fit onto a silicon chip measuring four inches in diameter.

In FY10, the technology underwent cryogenic testing to gauge its functionality. The team finished the design and fabricated initial components. Ultimately, Moseley's team hopes to build a flight-like system that it would test at a ground-based observatory in preparation for a possible berth on a future far-infrared mission. **(Investment Area: Astrophysics)**

Principal Investigator Emily Wilson received a two-year, $485,000 NASA award to advance a new radiometer for Mars research.

Radiometer Advanced to Identify Active Regions on Mars

One of Goddard's early-stage innovations — the Hollow-Fiber Gas Correlation Radiometer — garnered a two-year, $485,000 Planetary Instrument Definition and Development Program award in FY10. Under the award, Principal Investigator Emily Wilson will develop a reduced-size gas correlation radiometer that simultaneously will measure and localize the sources of methane, water vapor, and deuterated water important for identifying active regions on Mars — sites that might be ideal for landing a mission. Her award continues work begun under her FY10 IRAD.
(Investment Area: Planetary and Lunar Science)

CATS Readied for Demonstration Flights

Scientist Matt McGill, whose Cloud Physics Lidar collected data during the maiden flight of NASA's Global Hawk unmanned aircraft in FY10 (see page 5), also received $760,000 from the Airborne Instrument Technology Transition program to advance a new airborne instrument that is both a Doppler lidar and, by its nature, a high-spectral resolution lidar. Specifically, McGill will use the funding to prepare for demonstration flights.

The instrument, called the Cloud-Aerosol-Transport System (CATS) lidar, will profile clouds and aerosols, their internal structure, and optical properties. It is a strong contender for the proposed Aerosol-Cloud-Ecosystems mission — particularly if it is successfully demonstrated on airborne platforms. **(Investment Area: Earth Science)**

A new thermal-control technology developed by Principal Investigator Jeff Didion will be demonstrated on a reconfigurable microsatellite called the Small Rocket/Spacecraft Technology (SMART) platform pictured here.

A Wallops technician puts the finishing touches on a payload carrier that will be used in 2011 to test SMART and other technologies.

"This FY10 IRAD investment has also helped to increase GSFC's profile in the arena of space-flight cryocoolers."

— Shuvo Mustafi, Subcooling Cryogenic Propellants Principal Investigator

Thermal Control Technology Draws Military Support

A new technology that uses electric fields to pump coolant through tiny ducts inside a thermal cold plate has attracted the attention of the Air Force Office of Space Research. The organization has awarded Principal Investigator Jeff Didion $50,000 for three years to advance the electrohydrodynamic-based thermal-control unit that requires no moving parts, just electrodes to apply voltage to move the coolant.

The technology, which will fly on a sounding rocket mission in 2011 as a key component of a new reconfigurable microsatellite called the Small Rocket/Spacecraft Technology platform (see page 7), currently enjoys in-kind support from the Space Vehicles Directorate at Kirkland Air Force Base. Didion also reported in FY10 that he is in the process of securing a second collaboration with the Materials Engineering Directorate at Wright-Patterson Air Force Base — a development he said was made possible because of IRAD funding. Didion plans to further miniaturize the unit to the chip level. **(Investment Area: Strategic Crosscutting)**

Subcooling Technology Promises New NASA Capability

Goddard Principal Investigator Shuvo Mustafi is leveraging Goddard's unique experience with long-life cryogenic cooling systems to develop a Thermodynamic Cryogen Subcooler critical for the exploration of space. In FY10, Mustafi and his team received $500,000 from the Enabling Technology Development and Demonstration program to further advance a technique that would subcool cryogenic fuels below their boiling point, thereby eliminating the need for venting and substantially extending their "hold times."

Subcooling technology would significantly expand NASA's ability to store cryogenic propellants on upper stages and in space-based propellant depots. It also would enhance NASA's ability to fly missions to far-flung planets and asteroids, such as Chiron, a planetoid discovered in the outer solar system in 1977. Mustafi sees 2011 as a transition year. In addition to advancing the subcooler technology, he plans to find additional external support to develop a subscale model that could lead to a flight demonstration. **(Investment Area: Exploration)**

Decade Survey Motivates Principal Investigator to Pursue a Balloon Mission

Since discovering the first gas giant in 1995, scientists have found more than 506 extrasolar planets. The hunt has yet to abate, and in fact, scientists are now developing technologies that would allow them to actually image these alien worlds. Goddard scientist Mark Clampin is one.

In FY10, he received a two-year, $714,000 award from the ROSES Technology Development for Exoplanet Missions (TDEM) program to advance a planet-finding technology called the Visible Nulling Coronagraph, a hybrid interferometer that could be coupled to a single telescope to suppress starlight and increase the contrast of the circumstellar regions surrounding a Jovian-size planet.

Because the National Research Council did not specifically recommend a planet-finding mission in its Decadal Survey for Astrophysics, Clampin is focusing efforts now on flying the technology on a balloon mission and is optimistic that opportunities will be available — albeit on a much smaller scale. He also plans to compete for additional TDEM funds to continue advancing his concept. **(Investment Area: Astrophysics)**

Scientist Rick Lyon is pictured in the lab where he and other team members currently are developing new technologies that would allow scientists to image Jovian-size planets beyond our solar system.

CZT Detector Technology Applied to Homeland Security

Goddard is a world-renowned leader in large-array cadmium-zinc-telluride (CZT) detector arrays — an enabling technology on Swift's Burst Alert Telescope (BAT). Scientist Scott Barthelmy, in collaboration with Harvard University Professor Josh Grindlay, is receiving follow-on NASA funding to further advance the technology for the proposed Energetic X-ray Imaging Survey Telescope or a balloon-based experiment.

Barthelmy also is applying his know-how to helping the Department of Homeland Security (DHS) develop a system to detect radioactive material. In FY10, Barthelmy received an additional $2.3 million in DHS funding and believes the relationship will continue for at least a couple more years.
(Investment Area: Astrophysics)

Improvements in the Quantum Efficiency of UV Photocathodes Continue

Principal Investigator Bruce Woodgate attributed his $1.8 million ROSES award to continue improving the quantum efficiency of ultraviolet photocathodes to an IRAD he received in FY05. With his NASA funding, Woodgate hopes to mature the technology to the point where he can develop an advanced detector system for such proposed missions as the Joint Dark Energy Mission.
(Investment Area: Astrophysics)

New Capabilities

Some technologies are not meant to provide scientific data; their sole purpose is to provide technologists with components or services that assist them in their quest to develop instruments and develop low-cost, efficient missions.

NASA Orders a New Radar System for ER-2

Principal Investigator La Vida Cooper successfully produced three 16-bit analog-to-digital application-specific circuit boards for Goddard's Heliophyics Science Division in FY10.

Past IRAD awards contributed to a $640,000, two-year Airborne Instrument Technology Transition award to Principal Investigators Lihua Li and Gerry Heymsfield, who NASA tapped to integrate their more robust X-band radar onto the Agency's ER-2 high-altitude research aircraft. The ER-2 X-band Radar (EXRAD) will replace the aircraft's current Doppler radar system, which it has flown since 1993. EXRAD will gather cloud, precipitation, and wind measurement data for Earth scientists researching hurricanes and other severe weather events. It also offers the advantage of operating in conjunction with other ER-2 lidars, radars, and radiometers, similar to what has flown previously on ER-2.
(Investment Area: Earth Science)

New Analog-to-Digital Converter Ready for Infusion Testing

Principal Investigator La Vida Cooper and her team successfully designed three 16-bit analog-to-digital application-specific circuit boards for Goddard's Heliophysics Science Division. The three boards "are ripe for infusion and insertion" into the electronics systems of instrument prototyping efforts and "proof-of-concept testing," Cooper said. As a result of her success, Cooper said R&D seed funding no longer is needed. Future funding, if needed, will come directly from division scientists working on imaging instruments or Heliophysics-related instrument proposal efforts.
(Investment Area: Heliophysics)

Gas-Charged Heat Pipe Simplifies Design of Thermal Control System

Principal Investigator Jentung Ku developed a gas-charged heat pipe that would sustain repeated freeze/thaw cycles, thereby giving projects more choices on the thermal subsystems they fly on their spacecraft. Ku announced that the technology was successfully tested and is now ready for infusion into space missions.

Engineers traditionally have used conductance heat pipes to transport heat from a radiator to a spacecraft instrument. These devices, however, are prone to forming ice plugs at the condenser end. Until the ice melts and the pipe resumes its primary job of delivering heat, ground operators cannot safely turn on instruments. The solution is to heat the radiator above the freezing point of the working fluid — an especially unattractive solution for power- and mass-constrained missions.

Ku's new pipe overcomes these drawbacks and dramatically simplifies the design of spacecraft thermal, mechanical, and electrical subsystems. **(Investment Area: Strategic Crosscutting)**

New Capability Assists Scientists in Design of Hyperspectral Imaging Instruments

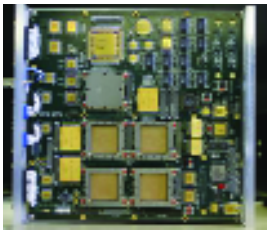
Principal Investigator Matthew Bolcar had one objective in mind when he began constructing a calibrated hyperspectral image projector (CHIP) that operated in the visible spectrum. He wanted to develop an instrument that scientists could use to characterize the performance of imaging spectrometers, such as those currently being developed for all areas of space science.

By the end of his FY10 IRAD, Bolcar had achieved his goal. CHIP will be made available to customers to test and calibrate their hyperspectral imaging instruments. The first customer to take advantage of this new capability is the Wide-field Imaging Interferometry Testbed. Bolcar also reports that he is collaborating with the National Institute of Standards and Technology to develop a near-infrared CHIP. **(Investment Area: Strategic Crosscutting)**

Technologists Develop System to Slash Flight Software Costs

In FY10, Goddard's Flight Software Systems Branch completed and rolled out the last remaining component of its Core Flight Software (CFS) system, a mission-independent, reusable flight-software environment that the branch began creating more than five years ago in part with the center's IRAD funding. CFS provides an automated system that offers proven software for such routine tasks as telemetry processing, health and safety monitoring, commanding, and data storage, with the obvious benefit that missions do not have to dedicate valuable resources to creating commonly used software.

Since the rollout of the initial Core Flight Executive — the cornerstone upon which all CFS components sit — the system has attracted a growing number of users, including the Magnetospheric Multiscale and the Global Precipitation Measurement missions. **(Investment Area: Communications and Navigation)**



BroadReach Engineering has licensed the IRAD-funded Navigator receiver that can quickly find, acquire, and track GPS signals in weak-signal areas.

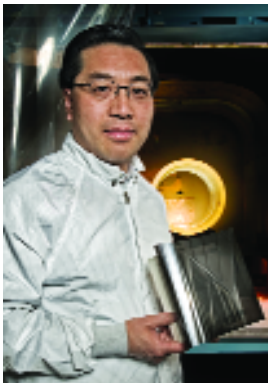
Infusion into Commercial Products

Navigator Licensed to BroadReach Engineering

Navigator, a Goddard-developed receiver that can quickly find, acquire, and track GPS signals in weak-signal areas, was licensed to BroadReach Engineering — just one of the many successes the technology enjoyed in FY10. BroadReach is using Navigator to design a compact, high-performance device for a classified Air Force mission.

The Navigator team is using FY11 IRAD funds to fine-tune the Navigator antenna and investigate its integration with other sensors, such as an emerging X-ray pulsar-based navigation system (see page 13). The technology's growing list of users also includes the Goddard-developed Global Precipitation Measurement and Magnetospheric MultiScale missions.

(Investment Area: Communications and Navigation)



Principal Investigator William Zhang is perfecting a method for manufacturing and assembling super-thin, curved mirror segments for the International X-ray Observatory.

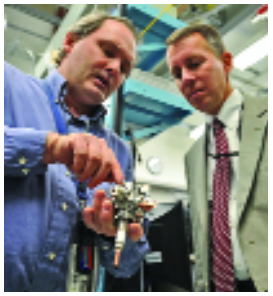
Chapter Four

Notable Achievements: Technologies to Watch

R&D investment programs are high-risk endeavors. In some cases, the research does not yield the expected outcome or result. In other cases, the principal investigator achieves precisely what he or she set out to accomplish. Here we spotlight a few IRAD-funded efforts that are making significant headway and could one day result in Goddard creating new opportunities and helping NASA carry out its science and exploration missions.

IXO Optics to Achieve TRL-4

The International X-ray Observatory (IXO), which the National Research Council ranked as one of its highest priorities in its Decadal Survey for Astrophysics, requires high-angular resolution and large collection-area X-ray optics. Principal Investigator William Zhang has perfected a technique for manufacturing and assembling the large number of super-thin, curved mirror segments needed for the mission's optics. In FY10, he and his team successfully tested his precision glass-forming techniques. Zhang now expects to reach a technology readiness level of four — an important step in eventually enabling IXO and other intermediary X-ray missions. **(Investment Area: Astrophysics)**

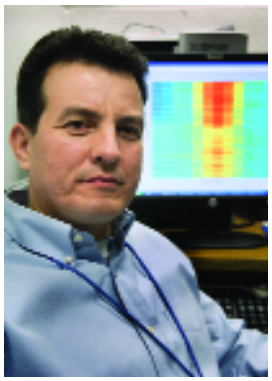


Scientist Keith Gendreau shows NASA Chief Technologist Bobby Braun a "modulated X-ray source," a key component in an X-ray communication system and other instruments he is developing.

Emerging Technology Navigates by the Stars

One of the barriers to sending humans beyond the Moon and into deep space is navigation technology. Physicist Keith Gendreau, however, is working on a revolutionary navigation technology that uses pulsars — stellar lighthouses — as a time and navigation standard just like the atomic clocks used by the Global Positioning System (GPS). Unlike the clocks on GPS satellites, however, pulsars are distributed across the galaxy, providing an infrastructure of precise timing beacons that are accessible in virtually every conceivable flight orbit across the solar system.

Using a variety of funding sources, including IRAD, Gendreau has developed the X-ray Navigation Demonstrator, which is designed to measure the arrival times of pulses through the detection of X-ray photons. The demonstrator then stitches together the measurements into an autonomous onboard navigation solution. To advance the system's technology-readiness level, Gendreau has proposed flying the technology on the International Space Station. A decision is expected shortly. **(Investment Area: Communications and Navigation)**



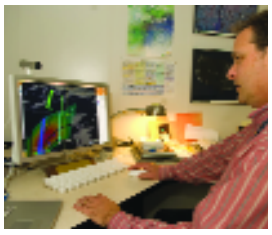
Principal Investigator Rafael Rincon has matured a new-generation airborne L-Band radar system to a level that makes it attractive to Earth science missions. The Carbon Monitoring System, for example, is now considering using the technology.

DBSAR Technology Enhances Goddard's Reputation in Radar Technology

Goddard's investment in a new-generation airborne L-Band radar system known as the Digital Beamforming Synthetic Radar (DBSAR) has paid off. Principal Investigator Rafael Rincon says the technology, which combines state-of-the-art technologies, onboard processing, and advances in signal-processing techniques, has reached a level where the center can compete and succeed in future remote-sensing missions. In fact, the Goddard-led Carbon Monitoring System program now is considering using the system in its mission. **(Investment Area: Earth Science)**

Climate@Home Makes Headway

Plans are coalescing to eventually launch the largest climate experiment NASA has ever attempted. With IRAD funds, Principal Investigator Michael Seablom built the infrastructure and user interface for "Climate@Home, a multi-directorate activity that will enlist volunteers worldwide to run complex climate simulations on their computers and other computing devices. Participants will be able to obtain the necessary software and instructions from a NASA Web site and run the models automatically as a background process whenever computers are on, but not being used to their full capacity. The goal is to use the findings to uncover gaps in data collection.
(Investment Area: Earth Science)



In FY10, Principal Michael Seablom built the infrastructure and user interface for "Climate@Home," which will enlist volunteers worldwide to run complex climate simulations on their computers.

Field Test Provides Insights into the Ecosystem

Under her FY10 IRAD, Principal Investigator Elizabeth Middleton designed, integrated, and demonstrated a fully integrated scanning system comprised of a full-waveform lidar, imaging spectrometer, and thermal imager for ecosystem studies. Her team then used the first-of-its-kind system to capture agricultural and forest data during the 2010 growing season — data that is giving the scientific community new insights into how Earth's ecosystem works.
(Investment Area: Earth Science)

Polarimeter to Maintain Competitive Edge in Cloud and Aerosol Remote Sensing

To maintain Goddard's leading role in aerosol and cloud remote sensing, Principal Investigator Lorraine Remer is developing a multi-angle imaging polarimeter, targeted for the proposed Aerosol-Cloud-Ecosystems mission. Because of its relatively small size, the polarimeter also might be suitable for a Venture Class mission or even as an experiment on the International Space Station. After three years of development, Remer believes the instrument is on the verge of demonstrating a technological breakthrough that assures Goddard's continued leadership in aerosol and cloud remote sensing.
(Investment Area: Earth Science)

"The outlook of future non-IRAD funding is positive. Every dollar invested by the IRAD program has genrated $2.5 from other sources. To date, more than $1 million has been invested in the PACS imaging polarimeter from non-IRAD sources."

— Principal Investigator Lorraine Remer, Multi-Angle Imaging Polarimeter

Principal Investigator Daniel Glavin field-tested the Volatile Analysis by Pyrolysis of Regolith instrument in Hawaii, demonstrating its efficacy at analyzing gases in the atmosphere and vapors produced when soil and rock samples were heated to scorching temperatures.

Goddard Begins Developing 'Wet Chemistry' Lotus Coating

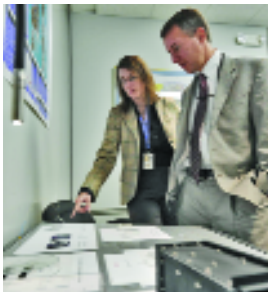
Using IRAD and NASA research funds, Principal Investigator Wanda Peters began developing an alternative Lotus coating using a wet-chemistry application process that promises to be suitable for all flight materials and a host of non-aerospace commercial applications. The special coating prevents dirt and even bacteria from sticking to and contaminating the surfaces of spaceflight gear, making it especially useful for planetary and lunar exploration. Since starting her work, several commercial companies have expressed interest in forming partnerships and marketing the coating as a repellant applicable to all types of textile, automotive, electronics, and medical products. In FY10, Peters tested the material during a field demonstration in Arizona. **(Investment Area: Exploration)**

VAPoR Field-Tested in Hawaii and the Arctic

A miniaturized version of the Goddard-developed Sample Analysis at Mars instrument suite flying on a car-size rover in 2012 underwent field-testing in Hawaii and the Arctic in FY10. The first field demonstrations showed VAPoR's (Volatile Analysis by Pyrolysis of Regolith) efficacy at analyzing gases in the atmosphere and vapors that are produced when its onboard oven heated soil and rock samples to at least 1,200°C (2,192°F). Principal Investigator Daniel Glavin, meanwhile, started building a second-generation oven capable of heating samples to much higher temperatures.
(Investment Area: Planetary and Lunar Science)

Principal Investigator Retires Risks on Nanotechnology

Working in collaboration with the VAPoR team (see above), Principal Investigator Stephanie Getty retired a number of risks associated with a field-emission electron gun that is being developed for a miniaturized time-of-flight mass spectrometer that could be used on VAPoR and other instruments. The electron gun — the heart of the spectrometer — produces and focuses an electron beam that ionizes gas molecules so that the spectrometer can analyze them. In addition to VAPoR, the technology could play a central role in the Europa-Jupiter System Mission, baselined to sample the chemistry of the planet's icy moon. **(Investment Area: Planetary and Lunar Science)**



Technologist Stephanie Getty shows Chief Technologist Bobby Braun samples of a new nanotechnology-based material that is 10 times more effective at suppressing stray light than current technologies.

Goddard Engineer Develops Promising New Alloy

For spacecraft requiring high pointing accuracy, Invar 36 is the material of choice because of its low thermal expansion. It has enabled the stunning images collected by the Hubble Space Telescope, Kepler, and NOAA's weather satellites. Despite the material's advantages, the alloy is relatively weak. Under IRAD funding, Principal Investigator Timothy Stephenson mixed an inert, nanoscale disperant with high-purity iron and nickel powder to form a stronger, stiffer low-thermal-expansion alloy for which a patent is being sought. The International X-ray Observatory, which would benefit from such a material, is supporting the effort and other funding sources appear likely.
(Investment Area: Strategic Crosscutting)

John Hagopian (left) and his 12-member "Nanostructures for Stray Light and Diffraction Suppression" team received this year's "IRAD Innovator of the Year" award for groundbreaking work in a new light-suppression technology. Goddard Deputy Director Rick Obenschain (center) and NASA Chief Technologist Bobby Braun were on hand to present the award.

The "Nanostructures for Stray Light and Diffraction Suppression" team, led by Principal Investigator John Hagopian, received this year's "IRAD Innovator of the Year" award. From left to right: Patrick Roman, Alex Maldonado, Jim Butler, Stephanie Getty, Cleophus Hunt, Mary Li, John Hagopian, and Georgi Georgiev. Not pictured are Greg Hidobro, Manuel Quijada, June Tveerem, Edward Wollack, and Ron Shiri

Chapter Five

Recognizing Goddard's Top Performers

John Hagopian and the Nanostructures for Stray Light and Diffraction Suppression Team Win "Innovator of the Year" Award

Light has a funny way of ricocheting off instrument components and contaminating measurements, but a team of Goddard technologists has created a blacker-than-pitch material that absorbs stray light, providing an order-of-magnitude improvement over current technology.

Given its potential to benefit future missions, especially those plagued by errant light, John Hagopian and the "Nanostructures for Stray Light and Diffraction Suppression" team were awarded the Office of the Chief Technologist's FY10 "IRAD Innovator of the Year" prize.

In testing this year, the team proved that the carbon nanotube-based coating was 10 times more effective than the black paint NASA now uses to suppress stray light — a development that potentially could improve the performance of future planet-finding and ocean-monitoring missions where errant light can obscure the faint signals scientists are trying to gather.

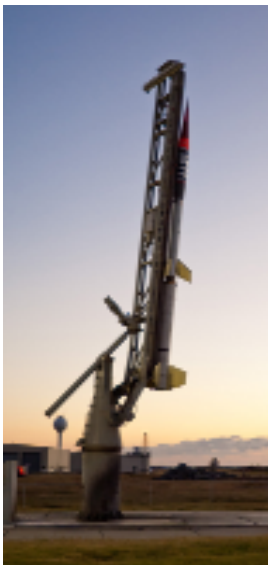
"Goddard has a well-deserved reputation for creating technologies that enhance instrument performance because we are adept at quickly infusing emerging technology for specific spaceflight applications. John's team demonstrated that key strength. And in doing so, he's leading the way in NASA's quest to bring about a new level of scientific discovery."

— Goddard Chief Technologist Peter Hughes

Achieving a Competitive Edge

The nanotech-based material promises to give Goddard a competitive edge over others vying for these types of missions. But more importantly, the technology could result in more precise scientific measurements, which are necessary for bringing about a new level of scientific discovery.

Team members receiving the award included: Patrick Roman, Alex Maldonado, Jim Butler, Stephanie Getty, Cleophus Hunt, Mary Li, Georgi Georgiev, Greg Hidobro, Manuel Quijada, June Tveerem, Edward Wollack, and Ron Shiri.



In FY10, Goddard added a new line of business — suborbital platforms and range services. Designating a specific line of business for this area officially recognized a capability Goddard has long offered to the scientific research community. It also assures continued investments in sounding rocket technology.

On Dec. 2, 2010, the Office of the Chief Technologist held its annual "Poster Session" to celebrate and acknowledge the year's R&D achievements. Earlier in the day, NASA Chief Technologist Bobby Braun headlined an "Open Session" with employees where he discussed NASA's plans to advance emerging technologies and the need for NASA leadership to take greater risks infusing new technology into spaceflight programs.

Chapter Six

Future: Maturing Technologies Faster

Just a few weeks into FY11, Goddard's R&D program already was off to a good start.

Three miniaturized instruments — each weighing only 3 kg and funded in part by the IRAD program to advance space technologies faster and at a dramatically reduced cost — had been launched on the new Fast, Affordable, Science, and Technology Satellite (FASTSAT). The microsatellite had reached its designated orbit and the instruments had passed their on-orbit checkout in preparation for their studies of the effects of solar activity in Earth's upper atmosphere.

The launch epitomized the value of Goddard's premier R&D program. The FASTSAT mission will give instrument developers insights into how to improve their instruments for a future NASA heliophysics mission, while returning valuable scientific data. Just as important, the instruments came in on time and on budget and gave students a chance to work on a spaceflight mission. This was a win-win situation by any measure.

FASTSAT Becomes the Norm

With NASA's refocus on advancing emerging technologies faster, we hope opportunities like FASTSAT become the norm. In the meantime, we will continue our strategy of dedicating a greater share of our resource-limited R&D program to early-stage innovations. Of the proposals we selected under our FY11 IRAD program, 43 percent are considered early-stage innovations. Twenty-three percent of our portfolio went to early-career innovators, defined as those who have no more than seven years of professional experience.

We also have created a new line of business that encompasses a capability Goddard has always enjoyed — suborbital platforms and range services. With NASA's focus on maturing emerging technologies faster, we need to assure technological advances in the very platforms needed to test new instruments, components, and concepts.

As the last 12 months showed, we are making progress in multiple areas of technology R&D. In short, we have mapped our course and we plan to leave a trail.

John takes a moment with his two young children, James and Darcy. An older son, Karl, is serving with the Marines in Afghanistan.

Chapter Seven

In Memoriam

Dr. John B. Sigwarth • 1960-2010

The Goddard technology community suffered a profound loss on Dec. 13, 2010, with the passing of Dr. John B. Sigwarth, a world-renowned expert in the physics of Earth's Aurora Borealis and esteemed member of our team.

John wore many hats. He was the project scientist for the Polar mission and the principal investigator for one of the miniaturized instruments flying on the recently launched FASTSAT mission. At the time of his unexpected death, he was developing new instrumentation to image the Earth's thermosphere and leading one of the center's Explorer mission proposals.

In spite of this incredibly busy schedule, John still found time to help Goddard's Heliophysics Line of Business Management Team formulate the center's strategies for investing in technologies assuring NASA's leadership in scientific discovery well into the future. Without his persistence and enthusiastic support, it is almost certain that the three R&D-funded heliophysics instruments flying on FASTSAT would not be in orbit today. As one of his colleagues said: "John was so critical to seeing that our participation on FASTSAT occurred."

To say John will be missed is an understatement. In fact, words do not convey the sense of loss our community bears now and in the future. His dedication, compassion, commitment, and expertise cannot be replaced.