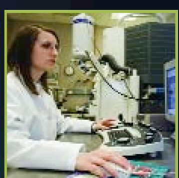
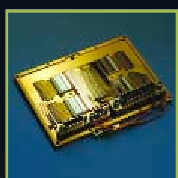
National Aeronautics and Space Administration

A Report on the FY 2007 Internal Research and Development Program

NASA Goddard Space Flight Center


R&D Achievements

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This crisp image, taken with the Hubble Space Telescope's Advanced Camera for Surveys, reveals arcs and bubbles formed when stellar winds — streams of charged particles ejected by the Trapezium stars — collide with material in the Orion Nebula.

The image uncovered thousands of stars never seen before in visible light. Some are merely one-hundredth the brightness of previously viewed Orion stars.

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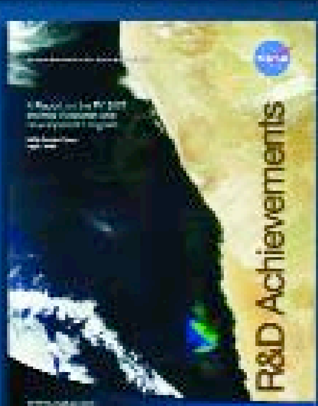


About the Cover

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this image of the waters off Namibia in early November 2007. The blue and green areas indicate a phytoplankton bloom that stretched from north to south along hundreds of miles, although it was brightest in the center of this image. Such blooms are common in the coastal waters off southwest Africa where cold, nutrient-rich currents sweep north from Antarctica and interact with the coastal shelf.

Message from the Chief Technologist

Stimulating Technological Innovation Through R&D

I am very pleased with the progress and accomplishments of the Goddard Space Flight Center's FY 2007 Internal Research and Development (IRAD) program.

Through our support of 83 research efforts last year, Goddard scientists and engineers secured follow-on funding from NASA Headquarters and others; validated promising new technologies in aircraft demonstrations; and created much-needed new facilities and testbeds important to our future.

They formulated concepts for future science and exploration missions. They filed patent applications. They published papers and participated in important decision-making panels. They created educational programs to nurture the Agency's future scientists and engineers. They formed collaborations with others to advance their technologies. In short, they took the steps necessary to ultimately realize success in areas vital to NASA's continued success.

R&D Magazine even recognized one IRAD-sponsored team for producing one of the year's most innovative and technologically significant new products — the Adaptive Sensor Fleet — while another was featured on the Science Channel's "Mars Rising" documentary due to their innovative dust-devil research in Arizona.

Despite these successes, the program still faced challenges.

Continued erosion in IRAD resources forced us to become more selective about the technologies we funded. In FY 2007, the vast majority of winning proposals responded to nearer-term mission opportunities, with clearly identifiable future funding streams. This came at the expense of longer-term, higher-risk technologies that sometimes contribute to significant leaps in capability and discovery. I took initial steps to address this by increasing the number and resources awarded to longer-term R&D efforts in our FY 2008 portfolio, but I'll be exploring additional avenues to strengthen our mid-to long-term investments in the near future.

All in all, however, I am pleased with the progress we made. After all, lavish budgets do not guarantee performance. The most reliable predictor, according to studies, is whether the R&D organization identifies priorities and actively manages the activities. Our diligence in making sure that the proposals we funded were well planned, managed, and aligned with the strategic direction of the Center and the Agency contributed to our success.

This report highlights some of the year's accomplishments and details plans for the future. I believe that those who read this report will come away with the conclusion I reached…2007 was a very good year.

Peter M. Hughes
Chief Technologist

The Purpose of Internal Research and Development

Internal R&D programs — whether a government agency or a private corporation manages them — all share a basic common principle: they are designed to provide a technological advantage. The Goddard Space Flight Center operates under the same principle. It, too, must win new work and compete with others also seeking new mission and instrument opportunities.

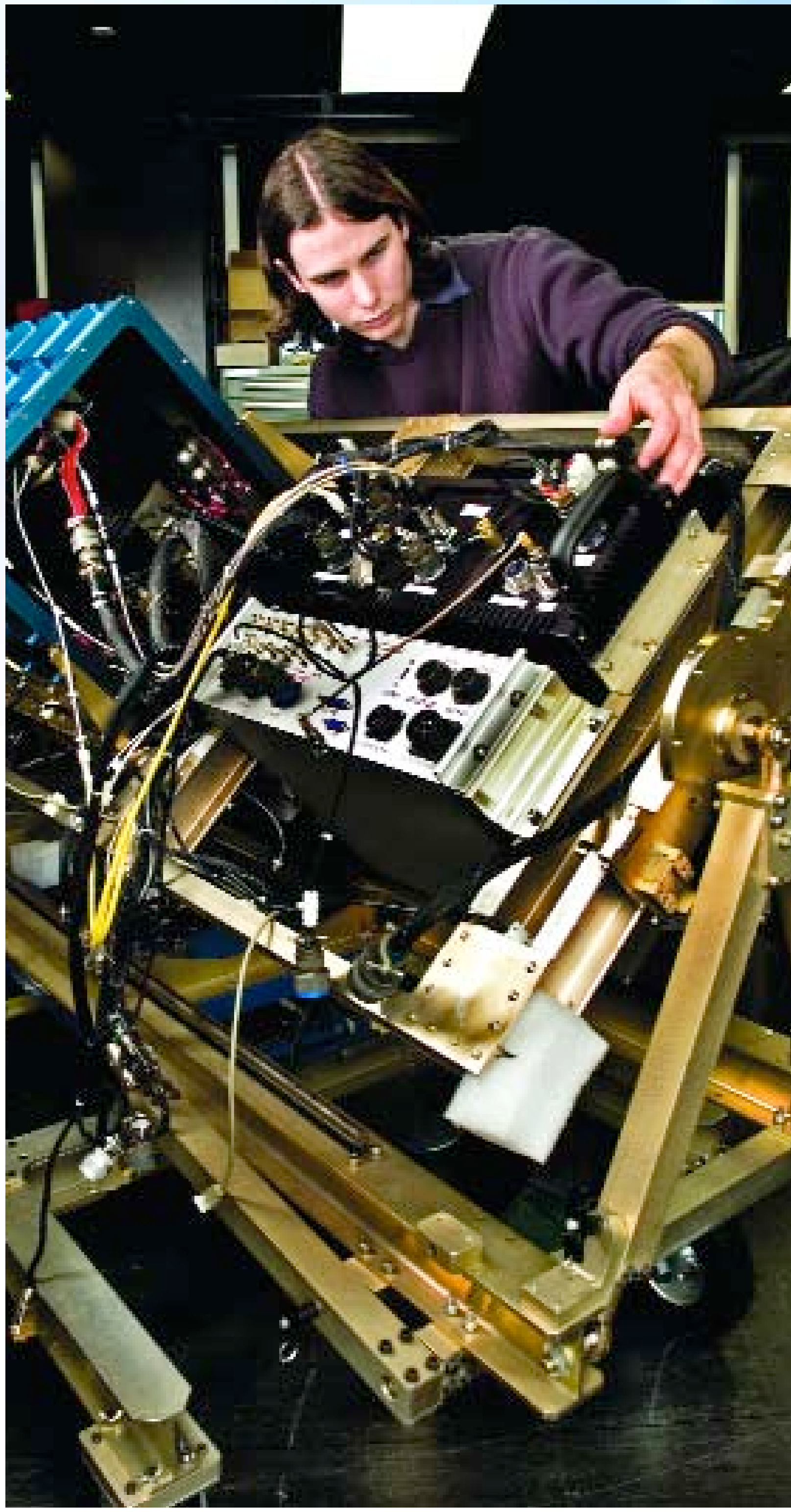
Assuring that the Center maintains its competitive edge is the primary purpose of the IRAD program. Formally established in 2000, the program has invested in new technologies that benefit astrophysics, communication and navigation, Earth science, exploration, heliophysics, and solar system exploration — areas that management has deemed important to the Center's overall vitality.

> *"One thing that Goddard has already done is to improve the management of our Internal Research and Development funds.…We've improved the quality of management's role in the evaluation process, which has led to a noticeable change in the quality of the projects and the alignment of those projects with the big goals."*
>
> *— Peter Hildebrand, Deputy Director, Sciences and Exploration Directorate*

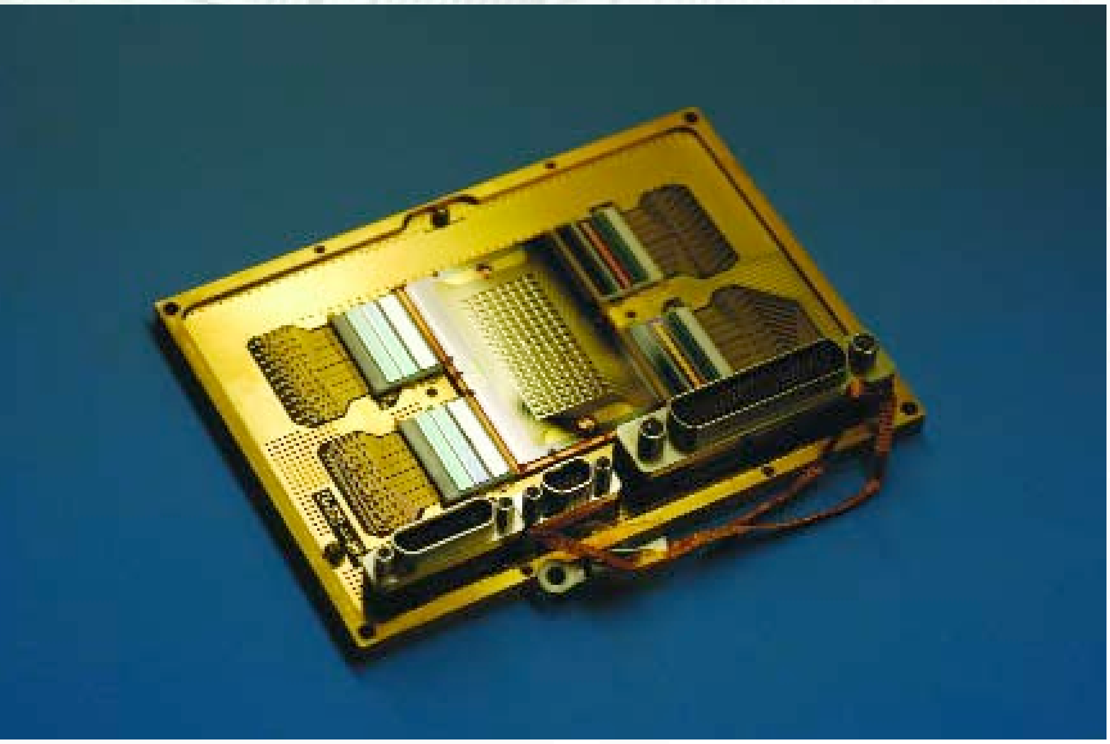
Measuring Success

A reliable measure of our success is in the number of proposals awarded to our people and the missions they join.

By this measure, the IRAD program is making noteworthy headway. This year, a number of IRAD-funded proposals — both past and present — resulted in principal investigators winning millions of dollars from various NASA research programs, including the Astronomy and Physics Research and Analysis (APRA) program and a number of other supplements in the NASA Research Opportunities in Space and Earth Sciences (ROSES) program.



The original ER-2 Cloud Physics Lidar instrument pictured here is being adapted for use on an unmanned aerial vehicle, thanks to past IRAD awards and current ROSES funding.



Principal Investigator Christine Allen used past IRAD funding to develop a large-format, faster, and more efficient detector-array system shown here. In 2007, she and her colleagues installed the technology in the Goddard-IRAM Superconducting 2-Millimeter Observer (GISMO), which obtained high-quality infrared data on nearby and very distant galaxies during a demonstration at a ground-based telescope in Spain.

NASA's Exploration Technology Development Program (ETDP) and other external technology-development programs further invested in several IRAD-funded efforts. Some of the winning tasks involved*:

- *Completing an instrument for emission-line astronomy (Principal Investigator: Bruce Woodgate)*
- *Integrating the highly successful Goddard-developed Cloud Physics Lidar into an unpiloted aerial vehicle (Principal Investigator: Matt McGill)*

Successful Demonstrations

In 2007, a former IRAD principal investigator also had matured her technology to the point where she could demonstrate it under real observing conditions. Christine Allen, who used a past IRAD award to develop a large-format, faster, and more efficient detector array system, installed the technology in the Goddard-IRAM Superconducting 2-Millimeter Observer. The observer obtained high-quality infrared data on nearby and very distant galaxies during a demonstration at a ground-based telescope in Spain. With the successful ground-based demonstration, she hopes to tailor the technology to operate at a wide range of wavelengths.

And Bernard Rauscher, another past IRAD awardee, announced a breakthrough in the development of a thick, fully depleted, photon-counting p-channel charge-coupled device (CCD) — a critical enabling technology for spectroscopic studies of exoplanets. The successful demonstration, also involving personnel from Lawrence Berkeley National Laboratory, brought the principal investigator's 2-year, IRAD-funded program to a successful conclusion, paving the way for a ROSES/APRA proposal this spring.

*** Other successful awards that resulted from the 2007 IRAD program are highlighted in the Significant Achievements section of this report.**

Strategic Investment Areas FY 2007

- Mission Concepts
- Next-Generation Instruments
- Lasers
- Advanced Climate Instruments
- Heliophysics
- Exploration Systems and Technologies
- Space Systems
- Education and Public Outreach

2007

Significant Achievements: New Missions and Funding

The IRAD program provides seed funding for promising new technologies. It is not meant to be a long-term funding solution. The goal is to ultimately transition successful technologies to other funding sources for further development or enhance them so that they contribute significantly to flight missions. Several IRAD-funded investigators, who received FY 2007 funding, successfully made that transition. Here we spotlight a few, along with the program's first-ever recipient of the "IRAD Innovator of the Year" award.

"The selection of our VAPoR proposal demonstrates the success of Goddard's investment in key technologies and underscores why Goddard needs to continue investing in R&D."

— Daniel Glavin, Goddard Technologist

Chief Technologist Peter Hughes presents the "IRAD Innovator of the Year Award" to Principal Investigator Daniel Glavin at the annual IRAD Poster Session in November. Also on hand for the presentation were Laurie Leshin and Nancy Abel.

IRAD's First Innovator of the Year: Daniel Glavin

Goddard technologist Daniel Glavin received word last summer that of the 77 proposals submitted under the Agency's Lunar Sortie Science Opportunity (LSSO) program, his to define and test a suitcase-size instrument measuring the high concentrations of hydrogen at the lunar poles was one of only seven to get funding. It was a testament to the quality of his proposal and the significance of the proposed work.

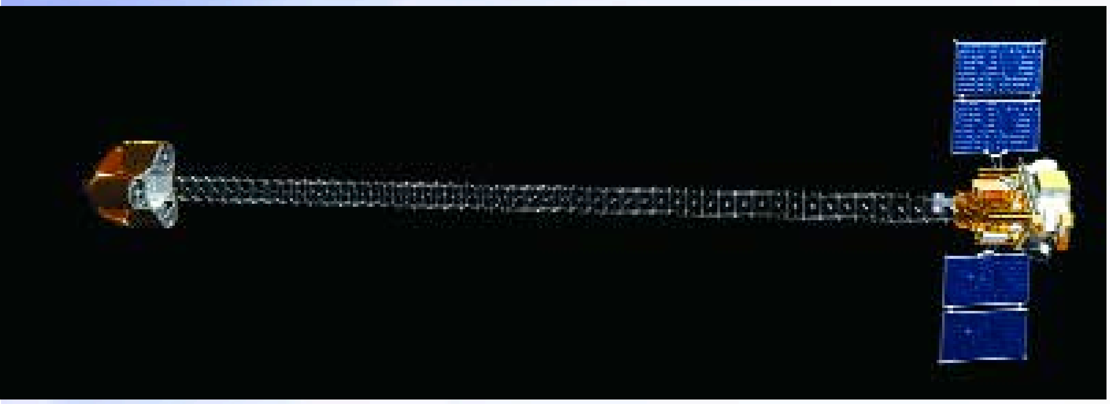
However, his capture of the LSSO award was only one of many reasons why he was chosen to receive the first-ever "IRAD Innovator of the Year" award — an honor created in 2007 to recognize the outstanding achievements of Goddard's top-performing technologists. He also was singled out because of his demonstrated technical innovation and management approach, as well as his ability to use resources effectively and pull together an excellent team.

"I am very fortunate for the opportunity to lead the VAPoR (Volatile Analysis by Pyrolysis of Regolith) team,"

Members of the winning VAPoR team include (from left to right): Paul Mahaffy, Patrick Roman, Ed Patrick, Inge ten Kate, Daniel Glavin, Jason Dworkin, Eric Cardiff, Tim Stephenson, and Steve Feng. Not pictured are Andrew Jones, Marla Moore, Dan Harpold, Dave Martin, and Robert Boyle.

Glavin said after receiving the award at the IRAD Annual Poster Session in November. "We really appreciate the Center support and recognition and are excited about the possibility of getting this instrument on the Moon to search for water and other volatiles."

If his miniaturized mass spectrometer finds a flight opportunity, it would help scientists determine whether the large concentrations of hydrogen are actually water-ice deposited by cometary bombardments or simply hydrogen implanted by the sun. It also could answer whether organic compounds exist on the Moon.



Goddard Principal Investigators Rob Petre and Jack Tueller will be providing formed or slumped-glass mirror segments and other support to the Nuclear Spectroscopic Telescope Array (NuSTAR) mission. This is an artist's rendition of the CalTech-led NuSTAR

NuSTAR

Goddard's investment in X-ray mirror development technologies already is paying off. Principal Investigators Rob Petre and Jack Tueller will be providing formed or slumped-glass mirror segments and other support to the Nuclear Spectroscopic Telescope Array (NuSTAR) mission — an award valued at around $6 million. Their involvement in the CalTech-led Small Explorer Program mission could be leveraged for future opportunities, including NASA's proposed Constellation-X mission. *(Investment Area: Instruments)*

Astrophysics on the Moon

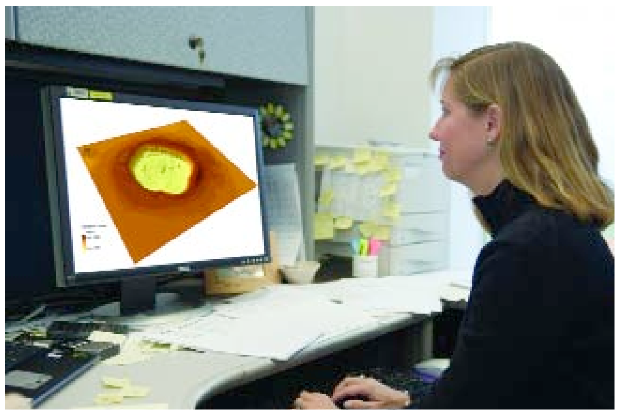
IRAD funding of dust characterization studies resulted in Principal Investigator Michael Collier winning one of four LSSO awards focusing on astrophysics. Collier's winning proposal involves the potential development of a Lunar X-Ray Observatory that would gather data on how the solar wind — a stream of charged particles ejected from the sun — interacts with the tenuous lunar atmosphere close to the Moon's surface. The observatory also would help improve measurements of low-energy X-ray emission from the galaxy. *(Investment Area: Exploration Systems and Technologies)*

Polarimeters

Efforts to build and demonstrate the first X-ray polarimeter using a time-projection chamber contributed to the win of two ROSES awards in 2007, one by Brian Dennis to develop a solar-flare polarimeter and the other by Keith Jahoda and Joe Hill to build a gamma-ray burst polarimeter for MidSTAR II, a Naval Academy satellite. The technology, developed in part by Principal Investigator Phil Deines-Jones, will provide the sensitivity needed for investigations of solar flares, gamma-ray bursts, and strong gravity. *(Investment Area: Instruments)*

Lunar Mapping

In 2007, the Lunar Precursor and Robotic Program identified Goddard as one of the principal developers of its Lunar Mapping and Modeling Project — a designation that positions Goddard to develop key components of this lunar information system. The recognition is a direct result of IRAD investments in the so-called Integrated Lunar Information Architecture for Decision Support project, which Principal Investigators Stephen Talabac and Julie Loftis developed to make lunar geographical and environmental data and tools accessible to mission planners. *(Investment Area: Instruments)*



Julie Loftis, a co-investigator on the IRAD-developed Integrated Lunar Information Architecture for Decision Support (ILIADS) project, shows the type of lunar geographic data that ILIADS would make available to NASA lunar mission planners.

2007

C/NOFS Upgrade

When the Defense Department launches its Communication/Navigation Outage Forecast Systems (C/NOFS) spacecraft later this year, it will be flying a greatly improved sensor package, thanks to Goddard Principal Investigator Robert Pfaff. Using IRAD funding, Pfaff upgraded a critical component of his Vector Electric Field Instrument, resulting in higher-resolution measurements that will help the prototype system forecast ionospheric irregularities that degrade signals from communication and navigation satellites.
(Investment Area: Instruments)

Dust Devils

Physicist Brent Bos received ETDP funding in 2007 to enhance an IRAD-funded, large Depth-of-Field Particle Image Velocimeter, which he successfully field tested in Arizona in early June while studying dust devils, mini-cyclones that form mostly in arid areas. Currently, scientists do not completely understand how they form or what sustains them. They are of particular interest to NASA because dust devils also form on Mars and appear electrical in nature. Bos's dust devil field research was recently featured on the Science Channel's "Mars Rising" documentary that dramatized the dangers that a human mission to Mars might face. *(Investment Area: Exploration Systems and Technologies)*

Simultaneous Read-Outs

Under his 2007 IRAD, Principal Investigator Thomas Stevenson designed the first prototype microwave multiplexer capable of simultaneously reading out thousands of large-format superconducting detectors, thereby maintaining the Center's prominence as the leading low-temperature detector-development institution in the world. He met his technical objectives, resulting in a ROSES award in 2007 to develop far-infrared microwave kinetic inductance detectors.
(Investment Area: Instruments)

Lightweight Mirror

Today, Principal Investigator David Content is collaborating with ITT Space Systems under the Innovative Partnerships Program's (IPP) Seed Fund program to develop an ultra-lightweight, diffraction-limited mirror that measures 0.5-meters in diameter and weighs a mere 4.5 kg (10 lbs.) — a partnership that Content believes could not have happened without his IRAD award in 2007. Through testing, the partners have advanced the mirror's technology readiness level. The partners hope to eventually use this technology for NASA science through Explorer, Discovery, or other science mission opportunities. *(Investment Area: Instruments)*

Eric Cardiff, who has used IRAD funding to advance his vacuum pyrolysis technology for converting lunar soil into breathable air, is now working with Pratt & Whitney/Rocketdyne under an IPP Innovation Fund award to further advance his work.

Vacuum Pyrolysis

Technologist Eric Cardiff also received an IPP Innovation Fund award for his IRAD-funded work in the area of vacuum pyrolysis, a technique that uses extreme heat to extract chemicals bound up in soil samples and rock. Under the IPP award, Cardiff is collaborating with Pratt & Whitney/Rocketdyne. The resulting technology could benefit future NASA missions demanding the analysis or use of in situ resources, such as creating breathable air from lunar regolith.
(Investment Area: Exploration Systems and Technologies)

Wanda Peters won NASA Headquarters funding to further refine a special coating that would prevent the Moon's highly abrasive dust from clinging to spacesuits and other equipment. She is shown here with one of her samples.

Mimicking Nature

In FY 2007, aerospace engineer Wanda Peters carried out a number of environmental tests on two special coatings that mimic the unusual self-cleaning properties of the lotus plant, finding that both maintained their particle-shedding properties even when exposed to harsh ultraviolet light and other space-like conditions. Her work led to ETDP funding to continue the research, which could lead to a lightweight method to prevent the Moon's highly abrasive and electrostatically charged dust from accumulating on lunar explorers and their gear. *(Investment Area: Exploration Systems and Technologies)*

Other Notable IRAD Achievements

R&D investment programs are high-risk endeavors, even if they are strictly aligned with clearly established priorities. In some cases, the research does not yield the expected outcome or result and is chalked up as a lessons learned, not to be repeated again. In other cases, quite the opposite occurs. Here we spotlight IRAD-funded efforts that could result in Goddard winning new work in the future and help NASA to carry out its science and exploration missions.

> *"Past and current IRADs and Instrument Incubator Program (IIP) awards have given me the experience to propose and build possible future satellite missions. At this point, I have an excellent new optical design based on the current IRAD award, which hopefully will transfer into the upcoming IIP and then a future satellite proposal."*
>
> *— Jay Herman, Goddard Technologist*

Advanced Climate Instruments

The National Academy of Sciences in its first-ever decadal survey on Earth science missions recommended that NASA develop 15 of 17 proposed new missions to replace and enhance its existing fleet of Earth-monitoring spacecraft. This investment area includes technologies needed for both Earth and planetary applications.

- Conceived a possible approach for the Academy's recommended *Aerosol-Cloud-Ecosystems* mission to answer the question of why the climate is changing. The mission, presented in a white paper to NASA Headquarters, calls for six instruments either flying on the same platform or in close formation in a 650-km orbit. (Principal Investigators: Bob Connerton and Mark Schoeberl)

To understand why the climate is changing, scientists need to understand the role of aerosols, such as desert dust, in precipitation and cloud formation. Goddard principal investigators conceived a mission approach for the proposed Aerosol-Cloud-Ecosystems spacecraft that would get to the heart of that issue.

• Redesigned a *Fabry-Perot sensor* operating near 1.6 microns to detect methane and water vapor in the Martian atmosphere. The team expects to prepare it for airborne testing by the summer of 2008. (Principal Investigator: William Heaps)

• Investigated methods to improve *next-generation laser altimeters*, building on an Instrument Incubator Program (IIP)-funded activity to advance those intended for use in Earth orbit.The goal is to develop instruments that are smaller, consume less power, and are capable of mapping, rather than profiling, topography at high-spatial resolutions. Investigations focused on single-photon ranging in the near infrared because this technique is more efficient. (Principal Investigator: Dave Harding)

Heliophysics

Heliophysics has long been one of Goddard's strategic areas of interest, and therefore an important IRAD investment area.

• Completed conceptual designs and mechanical drawings of *solar X-ray imagers* and worked with Mikro Systems to fabricate and characterize X-ray modulation test grids — efforts aimed at maintaining Goddard's involvement in solar X-ray astronomy. (Principal Investigator: Brian Dennis)

• Completed the enhanced *ion mass spectrometer* (IMS) for the Living With a Star instrument development program. The effort was aimed at developing plasma analyzers for Solar Sentinels and Solar Orbiter missions.

In a related IRAD, the principal investigator also made excellent progress developing *electronics support for plasma analyzers,* like the IMS. This included contributions to a discrete, wavelet transform, data-compression, application-specific integrated circuit, a 16-channel imaging anode for micro-channel electron multiplier detectors, a control-and-data handling board suitable for processing plasma data at unprecedented video-frame rates, and ultra-fast stepping, high-voltage power supplies. Prototypes of all these devices were tested extensively. (Principal Investigator: Thomas Moore)

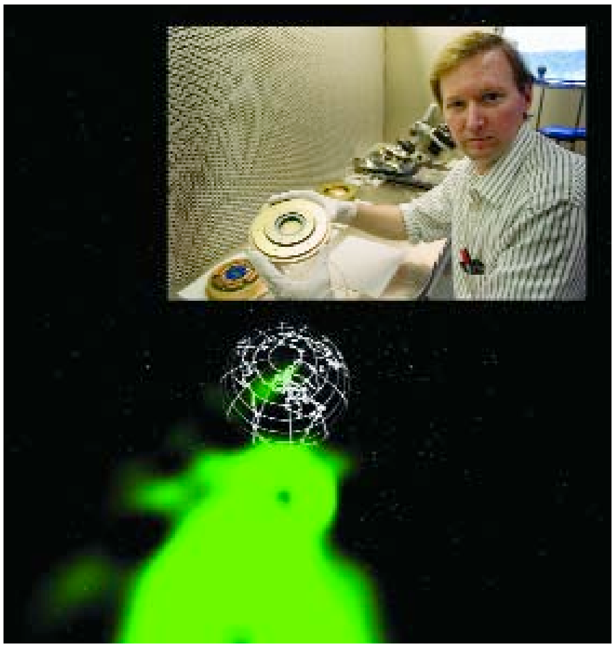
Instruments

In FY 2007, the IRAD program made a large investment in new instrument concepts and related technologies. The following describe some of the accomplishments.

• Demonstrated the first *carbon-nanotube electron gun*, a critical component of a time-of-flight mass spectrometer. The prototype measures just one centimeter in width, height, and depth and is constructed of patterned towers of carbon nanotubes — as opposed to films. The towers have proved to be more effective at operating at low voltages than other techniques. The ultimate goal in the effort is creating a mass spectrometer that is about as large as a CD case and consumes less power than a clock radio. (Principal Investigator: Stephanie Getty)

Principal Investigator Stephanie Getty explored the use of nantotechnology to miniaturize the next-generation mass spectrometer. With IRAD funding, she developed patterned towers of nanotubes (right) that could be used in the mass spectrometer's electron gun, a critical instrument component.

Meanwhile, Todd King, a co-investigator on Getty's FY 2007 IRAD won a small award from the Space Operations Mission Directorate for his proposal, *"A Miniature, Low-Power, Time-of-Flight Mass Spectrometer for In Situ Air Quality Monitoring and Lunar Science."*



The Goddard-developed Low-Energy Neutral Atom (LENA) imager captured the image above. It shows the low-energy ion outflow from the Earth's auroral region. Goddard technologist Michael Collier (inset) is building a flight instrument that takes LENA's capabilities to the next level.

• Revised the design of the *Miniature Imager for Neutral Ionospheric atoms and Magnetospheric Electrons (MINI-ME)*, which will be delivered to the U.S. Naval Academy next year for integration into MidSTAR-2, an experimental satellite. The modifications will make MINI-ME even more capable, thus assuring Goddard's continued leadership in neutral atom imaging. Also this year, the instrument passed the U.S. Navy's Space Experiment Review Board. (Principal Investigator: Michael Collier)

Another instrument slated to fly on MidSTAR-2 — the *Thermospheric Temperature Imager* — passed a major milestone, completing a Preliminary Design Review in early October. The revolutionary instrument will remotely sense the temperature of Earth's upper atmosphere, which is critical for understanding the effects of atmospheric drag on low-altitude spacecraft. (Principal Investigator: John Sigwarth)

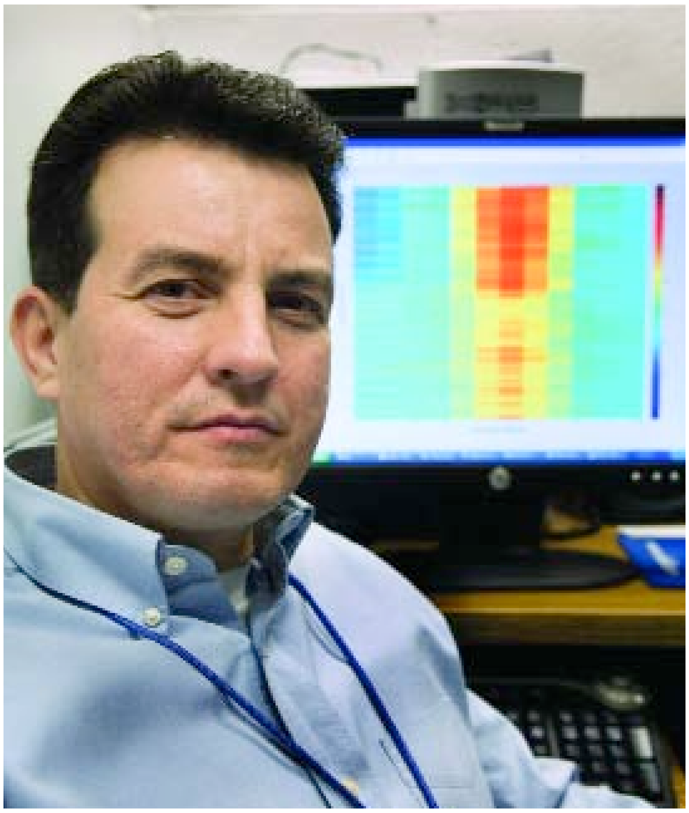
A third MidSTAR-2 instrument, the *Plasma Impedance Spectrum Analyzer (PISA)*, also made progress. Principal investigators developed a prototype of the instrument's front end and measurement circuitry and designed a mechanical sensor assembly. PISA will provide highly accurate measurements of the electron density and temperature in the ionosphere. (Principal Investigator: Douglas Rowland)

• Developed algorithms and codes to estimate how well the proposed *Laser Interferometer Space Antenna* (LISA) mission would measure binary black holes. The analytical work enabled by the IRAD helps to maintain Goddard's leadership in the field. (Principal Investigator: John Baker)

Atmospheric scientist David Starr used his 2007 IRAD award to successfully demonstrate a novel instrument concept to collect ice-cloud data.

- Proved the feasibility of the *Submillimeter and InfraRed Ice Cloud Experiment (SIRICE)* concept during a field campaign from Costa Rica. During the demonstration, the principal investigator collected the first observations of ice clouds in two frequency bands. A SIRICE-type instrument has been recommended to fly on the proposed Aerosol-Cloud-Ecosystems mission, one of 17 next-generation Earth-observing spacecraft advocated by the National Academy of Sciences. (Principal Investigator: David Starr)

- Advanced the *Digital Beamforming Synthetic Aperture Radar* technology to the point where it can be tested onboard a P-3 aircraft this spring. The technology offers significant advantages over conventional synthetic aperture radar because it simultaneously synthesizes and processes multiple radar beams and produces imagery in real time. (Principal Investigator: Rafael Rincon)



Principal Investigator Rafael Rincon plans to demonstrate his Digital Beamforming Synthetic Aperture Radar technology onboard a P-3 aircraft this spring.

• Designed, built, assembled, and tested cadmium *zinc telluride readout electronics and detector packaging* for the X-ray Imaging Survey Telescope, one of the candidate Black Hole Finder Probes. The principal investigator plans to demonstrate the technology in a balloon telescope, thereby solidifying its potential use on the mission. (Principal Investigator: Scott Barthelmy)

• Demonstrated photon counting with an indium gallium arsenide sensor head, which could lead to the development of a *photocathode-based, near-infrared photon-counting imager.* Such a capability is needed to detect chemicals that could indicate the presence of life on extra-solar planets. (Principal Investigator: Randy Kimble)

• From testing, learned that it is possible to vertically stack *mercuric iodide thin-film detectors* to enhance the detection of gamma rays — an application that would support resource mapping on planetary surfaces. The principal investigator submitted a proposal in response to Headquarters's Planetary Instrumentation Definition and Development program solicitation. (Principal Investigator: Min Namkung)

• Assembled an optical table and made initial tests in the development of a *high-resolution spectrometer* in the 6-16 mm wavelength regime, capable of probing the composition, temperature, and wind in planetary atmospheres both in situ and remotely from landed, aerial, or orbital platforms. The results allowed the principal investigator to submit proposals under the Agency's Planetary Instrument Definition and Development Program. (Principal Investigator: Theodor Kostiuk

• Nearly completed the design and fabrication of a *light-weight, low-cost X-band wind and rain radar* for unmanned aerial vehicles (UAVs), which will give Goddard a functional system when UAVs become available. The instrument is especially useful for future hurricane research and precipitation missions. (Principal Investigator: Shannon Rodriguez)

Lasers

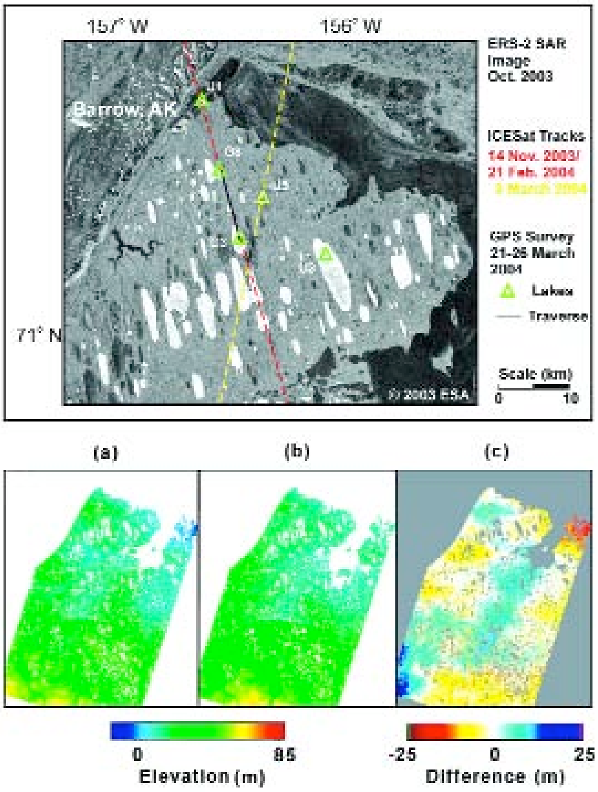
Laser technology can be used in everything from science to communication. These are just a few of the technologies that made progress during FY 2007.

• Constructed a new fiber laser system and integrated it into the existing *Laser Vegetation Imaging Sensor*. The updated instrument flew a successful airborne demonstration over Greenland, proving that it could measure ice sheets as well as vegetation, thereby making it a viable contender for other types of climate change missions. (Principal Investigator: Bryan Blair)

Also in 2007, Blair filed a patent application, *"Three-Dimensional Range Imaging Apparatus and Method"* — an approach that received IRAD and DDF funding in previous years.

This image of the rough and highly complex ice sheets at Jacobshavn Glacier in Greenland was taken from the window of a P-3 aircraft during an IRAD-funded campaign to gather precise data on whether the ice sheets were moving up or down.

• Investigated the use of *ICESat laser-altimetry data with interferometric synthetic aperture radar* to generate digital elevation models. The work resulted in a paper that a renowned technical journal, *Geoscience and Remote Sensing,* featured as a cover story in its November issue. (Principal Investigator: Jeanne Sauber)



Principal Investigator Jeanne Sauber investigated the use of ICESat laser-altimetry data with interferometric synthetic aperture radar to generate digital elevation models. Her research resulted in a cover story in the November issue of Geoscience and Remote Sensing.

• Developed algorithms and designs for an *asynchronous optical transponder* that can range to the Laser Geodynamics Satellite. The new capabilities also are being used for the Mercury Laser Altimeter-Earth Link experiments. (Principal Investigator: Phil Dabney)

• Completed fabrication and began assembling the *High-Output Maximum Efficiency Resonator (HOMER),* which offers two times the efficiency and an order of magnitude increase in repetition rate of previously developed Goddard lasers. The final step in FY 2008 is to test a protoflight unit that would allow HOMER to achieve a technology readiness level of six. In 2007, the HOMER team won the AETD Science and Technology Advancement Award. (Principal Investigator: Cheryl Salerno)

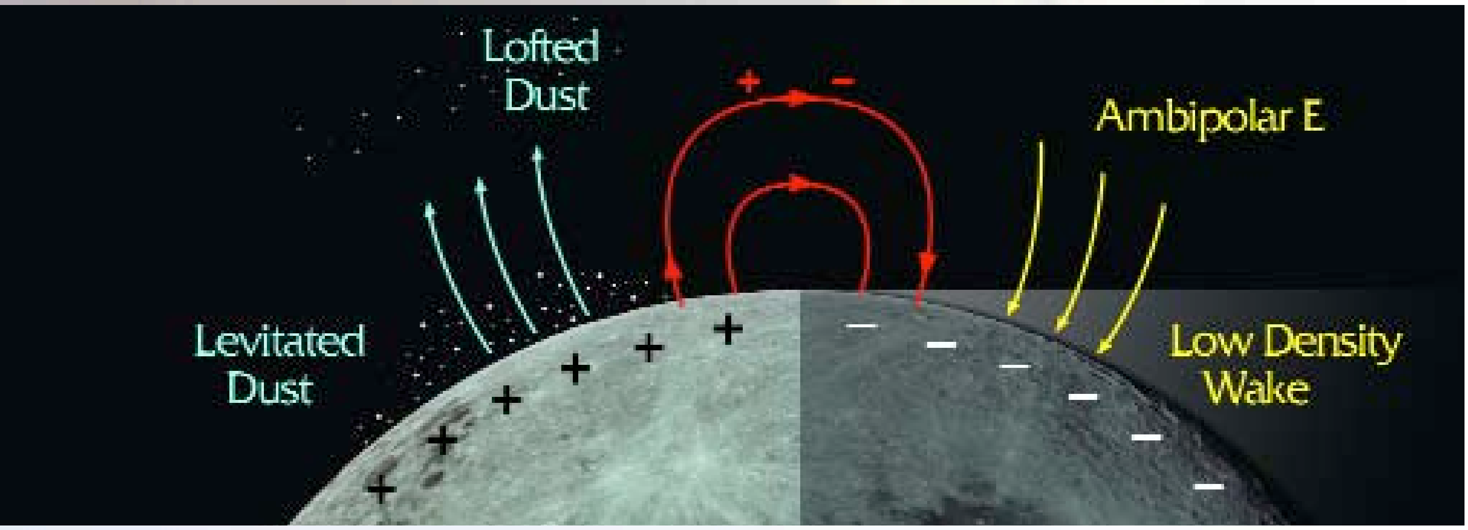
• Developed and tested a laboratory testbed for *simulating atmospheric turbulence* and designed a wavefront control algorithm based on the "centroid" tracking technique — efforts aimed at enhancing Goddard's expertise in laser communication. Compensating for atmospheric turbulence in real time is an important unsolved problem limiting the effectiveness of the technology. (Principal Investigator: Ron Shiri)

• Improved the technology readiness level of a *tunable, fiber-based lidar* for sensitive detection of trace gases — primarily carbon dioxide and methane — on Earth and Mars. Researchers demonstrated the technique in laboratory tests, resulting in numerous published papers. (Principal Investigator: James Abshire)

Exploration Systems and Technologies

Next decade, human explorers are expected to return to the Moon for extended stays. For the past couple years, the IRAD program has funded a variety of technologies that range from understanding the physics that create the Moon's dusty environment and ways to mitigate it to creating technologies needed to transport humans and carry out science investigations on the Moon and Mars.

• Developed a model of the *dusty plasma at the lunar terminator* — the moving line between lunar day and night — and demonstrated that solar storms greatly alter the plasma and its electrical surface potential, which could be a hazard to human explorers. The research resulted in seven papers relating to the Moon's dusty plasma as well as an LSSO award to co-Principal Investigator Michael Collier. (Principal Investigator: Bill Farrell)



Principal Investigator Bill Farrell developed a model of the dusty plasma at the lunar terminator — the moving line between lunar day and night — that could create more complex and stronger electric fields on the Moon. These electric fields cause the Moon's ultra-tiny dust grains to levitate and adhere to everything with which they come into contact.

• Built a prototype of a *Dust Mitigation Vehicle (DMV)* that NASA could use to control lunar dust around human habitats. Under the concept, a lens would focus sunlight onto the lunar surface and either melt or sinter the regolith, depending on the type of surface required. The DMV project is a spin-off of other IRAD-funded research aimed at developing a technique to create breathable oxygen by incinerating lunar dirt and rock to extract oxygen bound up in the materials. (Principal Investigator: Eric Cardiff)

This prototype of the so-called Dust Mitigation Vehicle, which would help control the lunar dust problem around lunar bases by melting or "paving" lunar regolith, was developed with IRAD funds.

• Designed a *Moon Portable Electrostatic Detector* that astronauts could affix to spacesuits and lunar equipment to determine their surface charging. With real-time readings, astronauts could dissipate their charge before handling equipment and creating a discharge hazard that could injure them and damage their equipment. (Principal Investigator: Bill Farrell and Telana Jackson)

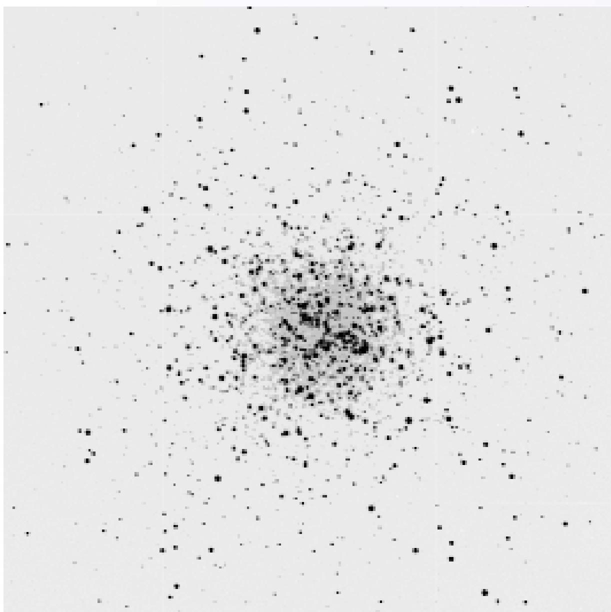
• Designed and bought components to build the *Dust Environmental Effects Particulate* chamber. The facility, to be located in Building 4 on Goddard's Greenbelt campus, will provide a much-needed tool for characterizing the effect of lunar and Martian dust on spacecraft surfaces. It also will give scientists a venue for testing their theories on how dust travels and levitates. (Principal Investigator: Sharon Straka)

• Developed a sub-scale *cyro-propellant tank system* and demonstrated that a liquid oxygen and liquid hydrogen propellant system would fit in the Crew Exploration Vehicle-Service Module. The work showed that that the use of cryogenic fuels is not only feasible, but also highly advantageous to NASA because of increased payload capacity. (Principal Investigator: Ed Canavan)

Space Systems

Communication and navigation technologies are important to Goddard's future missions and other mission and spacecraft technologies. The accomplishments chronicled here represent cross-cutting capabilities or multi-application technologies.

• Developed and tested the world's first large-format, *CMOS-based visible imager.* Principal investigators delivered the 16-million-pixel prototype camera to the U.S. Naval Observatory (USNO) and within a few weeks had received "first-light images" measuring highly precise locations of stars. The USNO is now planning a flight mission using the system and system developers are actively marketing the imager to the U.S. Army. In addition to its science applications, the system is ideal for rendezvous and docking. (Principal Investigator: Peter Shu)



This "first-light" image, taken with the world's first large-format, CMOS-based visible imager, shows highly precise positions of stars. The imager, developed in part with IRAD funds, was installed in the U.S. Naval Observatory's Flagstaff, Arizona, facility. The technology also is ideal for rendezvous and docking.

• Developed a *cylindrical, low-cost phased array* as well as a pointing-control system for sounding-rocket applications — technologies aimed at reducing the cost of high data-rate communication systems. A sounding rocket demonstration is planned for 2008. (Principal Investigator: Dan Mullinix)

• Designed a *time-of-flight, application-specific integrated circuit (ASIC)* that achieves its targeted resolution and range. The technology is especially useful for a range of applications, including three-dimensional imaging, autonomous landing and hazard avoidance, mass spectrometers, and advanced laser communications. (Principal Investigator: Gerry Quilligan)

• Defined and demonstrated a *new architecture for SpaceWire plug-and-play.* SpaceWire is currently the most widely used onboard local area network for spaceflight systems. By making it plug-and-play, mission planners can dramatically reduce integration time and costs. The principal investigators are now working with the Air Force Research Laboratory to further develop the software. (Principal Investigator: Glenn Rakow)

• Preserved the partnership with the U.S. Defense Department in the continued effort to advance *"plug and play" avionics* interfaces and supported the development of the GSFC Robotics for Exploration and Avionics Testing (GREAT). In a demonstration in Antarctica, GREAT, a mobile rover, successfully showed "hardware-in-a-loop" avionics within an end-to-end data-system architecture. (Principal Investigator: Jaime Esper)

• Implemented a *synthetic aperture radar (SAR) nadir altimetry technique* on SpaceCube's onboard processor. The technology will allow SAR missions to collect up to 20 times more data without filling up the onboard recorder. This capability will enable data-intensive missions previously thought unimaginable. (Principal Investigators: Tom Flatley and Jim Garvin)

• Advanced the functionality of an *orbit determination toolbox* to help solidify Goddard's current leading role in satellite navigation. (Principal Investigator: Kevin Berry)

• Developed a *Ku-band telemetry modulator* that will dramatically improve data transmission rates for suborbital platforms, including sounding rockets, balloons, unmanned aerial vehicles, and expendable launch vehicles. A demonstration onboard a Black Brant XI sounding rocket is scheduled for 2008. The possibility also exists to fly the modulator as part of the Orion Max Launch Abort System demonstration in September 2008. (Principal Investigator: Steve Bundick)

• Tested an algorithm and proved that it could work in acquiring *ultra-weak GPS signals* in lunar orbit. The technology could improve autonomous navigation and is useful to NASA's Constellation program and the U.S. military. (Principal Investigator: Ian Cohen)

• Developed software and other components for a ground system that would support missions using the *GPS Enhanced Onboard Navigation System,* which offers better navigational perfo rmance and reduced operations costs. (Principal Investigator: Bo Naasz)

• Implemented several technologies needed to develop an *automated rendezvous and docking capability,* one of the Exploration Systems Mission Directorate's highest-priority goals. (Principal Investigator: Charles Campbell)

• Carried out studies, analyzed formation flying, and developed partnerships with Princeton University, Case Western Reserve University, and Ball Aerospace in an effort to jumpstart serious research into a *Terrestrial Planet Finder-O mission.* (Principal Investigator: Sara Heap)

Education and Public Outreach

Education and public outreach formerly fell under the auspices of the Director's Discretionary Fund. In 2006, however, the Center consolidated all R&D into the IRAD program, including research efforts geared to education. Below are the results of FY 2007's investments.

• Collaborated with the University of Maryland-Eastem Shore under the *Airbome Science Training Initiative* to create a curriculum introducing the concepts of airborne remote sensing to college students. As a result of the collaboration, the university will offer a new class, Introduction to Aero/Space, in the spring of 2008. (Principal Investigator: Geoff Bland)

• Partnered with the Virginia Space Grant Consortium to provide university students with an understanding of the life cycle of a NASA mission, from concept to operations. Under the *Mission Management Initiative* program, Virginia Tech students designed, built, tested, and flew a GPS antenna and magnetometer balloon experiment aimed at obtaining measurements that would advance existing knowledge of the Moon's magnetic field. The instrument piggybacked on the High Altitude Student Payload flight led by Louisiana State University. (Principal Investigator: Jessica Thompson)

Principal Investigator Jessica Thompson participated in the High Altitude Student Payload balloon launch on September 2 in Ft. Sumner, New Mexico. The balloon flew for roughly 19 hours and carried 11 student experiments. One of those experiments, developed by Virginia Tech aerospace engineering students, was made possible through an IRAD-funded effort.

• Worked with Columbia University and the Goddard Institute for Space Studies (GISS) to make global climate models accessible to students in grades 5-12. Under the program, the team modified the *Educational Global Climate* (EdGCM) program for use in schools and offered EdGCM workshops for Goddard aerospace education specialists and GISS scientists. (Principal Investigator: Frank Scalzo)

The Office of the Chief Technologist sponsored a technology tour to coincide with the Exploration Systems Mission Directorate's (ESMD) Quarterly Planning Management Review hosted by the Goddard in October. During that event, principal investigators explained and demonstrated their IRAD-funded technologies to ESMD decisionmakers.

Looking Ahead in FY 2008

Although the IRAD program has made stellar progress aligning funded research to clearly identifiable goals and future opportunities, room always exists for improvement, particularly in the area of promoting Goddard technology and educating Goddard technologists about the work of their peers.

In 2007, the Office of the Chief Technologist took steps to rectify the former by sponsoring two technology tours for important NASA decisionmakers. Both events demonstrated the power of a good old-fashioned "show and tell." Many of those who attended were unaware of Goddard's capabilities and appreciated the one-on-one interaction with the Center's innovators.

To truly increase our competitiveness and impact, however, we need to foster greater interaction among our innovators. In addition to holding the annual IRAD Poster Session, the Office of the Chief Technologist instituted "Collaboration Workshops" for each line of business. The objective was to provide Goddard personnel an opportunity to hear directly from line-of-business leads on the direction and priorities of each area and stimulate collaboration among the current and prospective research efforts. We also are investigating other ways to promote more dialog and partnerships among Center engineers and scientists. Workshops and special speaking events are just two possibilities.

Principal Investigator Geoff Bland collaborated with the University of Maryland-Eastern Shore to create the Airborne Science Training Initiative that exposes university students to airborne remote sensing. He discusses his IRAD program at the Annual Poster Session in November.

In an era of budget uncertainty and continued erosion of R&D funding, collaboration is key. Sharing ideas and costs are vital for strengthening the IRAD program and nurturing revolutionary new technologies that will maintain Goddard's competitive edge and provide the Agency with technologies it needs to carry out world-class science and exploration missions that inspire the world.