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Cutting edge
Goddard's Emerging Technologies

One Man's Trash is Another Man's Treasure

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in this issue:

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STORM and its creators, Michael Collier, David Sibeck, and Scott Porter (Photo Credit: Chris Gunn)

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One Man's Trash is Another Man's Treasure

Three Science Divisions Team to Build First Wide-Field X-ray Imager

The old saying — "one man's trash is another man's treasure" — certainly applied when three Goddard scientists teamed to develop and demonstrate NASA's first wide-field soft X-ray camera for studying "charge exchange," a poorly understood phenomenon that occurs when the solar wind collides with Earth's exosphere and neutral gas in interplanetary space.

The unique collaboration involved Goddard's heliophysics, astrophysics, and planetary science divisions and resulted in the first successful demonstration of the Sheath Transport Observer for the Redistribution of Mass (STORM) instrument and a never-before-flown X-ray focusing technology called lobster-eye optics.

STORM and another NASA-funded experiment, the Diffuse X-ray emission from the Local Galaxy (DXL), flew aboard a two-stage Black Brant IX sounding rocket from the White Sands Missile Range in December 2012. DXL, developed by University of Miami professor Massimillano Galeazzi, also studied the same charge-exchange phenomenon but from a different perspective using a refurbished instrument developed by the University of Wisconsin. This instrument produced the first all-sky map of soft X-rays several years ago.

Though Goddard scientists served as co-principal investigators on DXL, STORM holds a special place in their hearts. Developed and assembled at Goddard with Internal Research and Development (IRAD) program funding, the instrument "is a wonderful example of cooperation across divisions to better understand a process that is of interest to us all, but for different reasons," said Michael Collier, a planetary scientist who collaborated with astrophysicist Scott Porter and heliophysicist David Sibeck. "Charge exchange is one of the few phenomena that brings together scientists from three of the science divisions at Goddard," Porter added.

Mysterious Charge Exchange

Scientists first discovered the charge-exchange effect in the mid-1990s while observing comet Hyakutake. "They got quite a surprise," Collier said. "They found an intense source of soft X-rays

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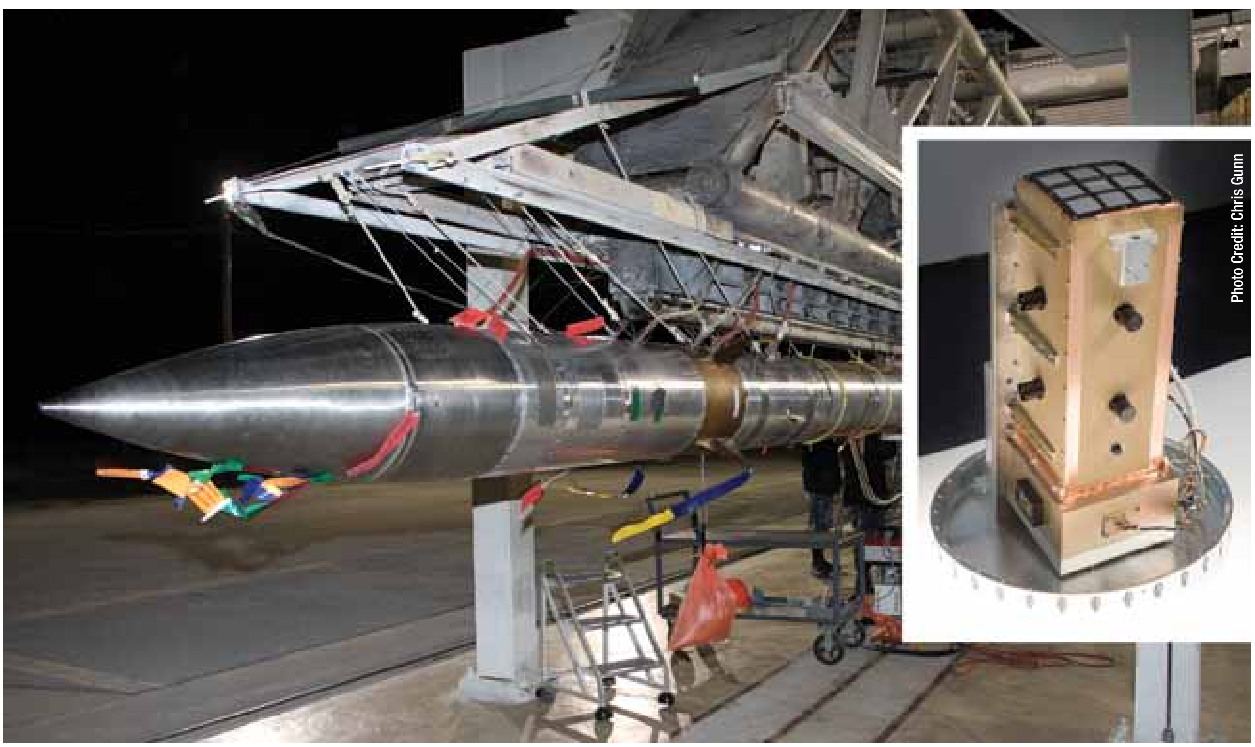

This Black Brant IX rocket carried two instruments designed to study a poorly understood phenomenon that occurs when the solar wind collides with Earth's exosphere and neutral gas in interplanetary space. STORM, shown in the inset, was one of those instruments. Funded by Goddard's R&D program, STORM is the first wide-field-of-view soft X-ray camera for studying "charge exchange."

at the comet's head, which was unusual because comets are cold objects and soft X-rays are associated with hot objects. How could balls of ice emit X-rays? No one could figure it out."

Scientists soon discovered that the X-ray emission was caused by the solar wind, a constantly flowing stream of charged particles that sweeps across the solar system at about a million miles per hour. When highly charged heavy ions in the solar wind collide with neutral atoms found in space, the heavy ions "steal" an electron from the neutrals — an exchange that puts the heavy ions in a short-lived excited state. As they relax, they emit soft X-rays.

Furthermore, the phenomenon is far from rare. Since its head-scratching discovery nearly 20 years ago, scientists have observed charge exchange and the resulting emission of soft X-rays in comets, interplanetary wind, possibly supernova remnants, and galactic halos. Planetary scientists have observed soft X-ray emissions in the atmospheres of Venus and Mars, leading some to question whether the charge-exchange phenomenon that produced the radiation has contributed to atmospheric loss on the red planet.

Heliophysicists, likewise, have observed them in Earth's exosphere, the uppermost atmospheric layer that encompasses Earth's protective magnetosphere, a region particularly sensitive to solar storms that can damage spacecraft electronics, cause spurious readings from global positioning satellites, and knock out satellite-based communications and terrestrial power grids.

Unwanted Noise

And astrophysicists have observed them, too — as unwanted noise in data collected by all X-ray observatories sensitive to soft X-rays.

"At first blush, STORM seems to have very little to do with astrophysics," Porter said. But "the emission of soft X-rays provides a very significant temporally, spatially, and spectrally varying foreground to all soft X-ray observations from every single X-ray observatory," he explained. "It's essential that we, as astrophysicists, understand and are able to model this foreground emission in detail. On all recent X-ray observatories, significant observing time has been lost and errors in scientific interpretation have happened due to our lack of understanding of this phenomenon."

In other words, planetary scientists and heliophysicists want to measure this emission as treasured data and astrophysicists want to remove it as noise.

STORM Holds Answer

STORM potentially holds the answer for obtaining a more complete understanding of the physical process, giving scientists insights currently impossible with existing instruments, the scientists said. During the sounding-rocket mission, for example, DXL studied the X-ray emission. However, it studied X-rays emitted when the solar wind interacted with gas entering our solar system from the Milky Way.

STORM gave scientists a global view. The wide-field-of-view camera imaged processes near Earth's magnetosphere, which until now was impossible. "These are extremely important, highly dynamic, and poorly understood regions that channel solar wind energy into the magnetosphere where it drives space weather," Porter said. If this process is important to determining space weather in and around Earth, it also affects other planetary bodies, to say nothing of its deleterious effect on data collected by multi-million-dollar X-ray observatories.

Making the imagery possible was an emerging technology called lobster-eye optics. As the technology's name implies, the optics mimic the structure of a lobster's eyes, which are made up of long, narrow cells that each captures a tiny amount of light, but from many different angles. Only then is the light focused into a single image.

Pioneered by researchers at the United Kingdom's University of Leicester, a partner in STORM's development, lobster X-ray optics work the same way. Its eyes are a microchannel plate, a thin curved slab of material dotted with tiny tubes across the surface. X-ray light enters these tubes from multiple angles and is focused through grazing-incident reflection, giving the technology a wide-field-of-view necessary for globally imaging the emission of soft X-rays in Earth's exosphere. "I'm unaware of any instrument that can do this," Collier said.

With the successful launch, the team said they are in good position to propose STORM for a possible mission. "We're happy it turned out so well," Sibeck said. "We all stand to gain from STORM's development." ❖

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The Last Frontier

Team to Test Carbon-Nanotube Sensors Measuring Earth's Radiation Budget

A Goddard scientist wants to explore one of NASA's last frontiers in climate studies by launching small, carbon nanotube-based instruments on dozens of satellites to determine with unprecedented accuracy the imbalance in Earth's energy budget and measure the extent to which fast-changing phenomena, like clouds, contribute to the imbalance.

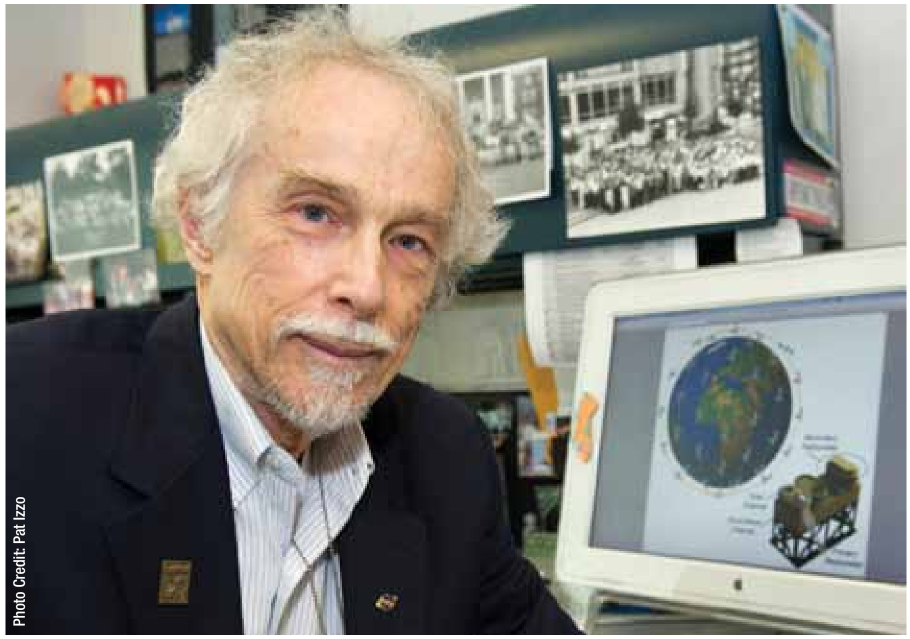

Photo Credit: Pat Izzo

Scientist Warren Wiscombe wants to explore one of NASA's last frontiers in climate studies. He wants to launch small, carbon nanotube-based instruments on dozens of satellites to determine the imbalance in Earth's energy budget.

Last year, scientist Warren Wiscombe and a "virtual" team of climate-studies experts used Goddard Internal Research and Development (IRAD) program funding to flesh out a concept to collect Earth radiation-budget measurements with scores of radiometers installed on massive satellite constellations, such as the one operated by the Virginia-based Iridium Communications, Inc. Although NASA found the science compelling, Agency reviewers ultimately did not select the concept under its Earth-Venture 2 (EV-2) mission solicitation, saying that the idea considerably exceeded EV-2's $150-million cost cap.

Wiscombe is not giving up, however. And to a certain degree, neither is NASA.

Now Wiscombe and his team, including Lars Dyrud, a scientist at the Johns Hopkins University Applied Physics Laboratory (APL) and principal investigator of the EV-2 proposal, plan to use NASA Space Technology Program funding this spring to test a next-generation detector that Wiscombe believes would be ideal for measuring the amount of solar energy reflected by the Earth and the amount of energy emitted to space as infrared radiation or heat. "I call this detector the roach motel for photons," Wiscombe joked. "Light goes in, but it doesn't come out."

The 'Holy Grail' of Climate Studies

Wiscombe believes the effort is paramount in importance. "Understanding this imbalance is the new Holy Grail. It's the single-most crucial measure of climate change — much more reliable than surface air temperatures, which occasionally flat-line — and can foretell climate change in the pipeline. The imbalance tells us how fast the Earth responds to greenhouse-gas forcing and the relative roles of the oceans and aerosols in modulating that forcing."

Widely cited papers by James Hansen, director of NASA's Goddard Institute for Space Studies, have concluded more energy is being absorbed from the Sun than is emitted back to space, throwing the Earth's energy "out of balance" and warming the globe. In one study released last year, Hansen's team calculated that, despite unusually low solar activity between 2005 and 2010, the planet continued to absorb more energy than it returned to space. In particular, the team concluded that Earth absorbed more than half a watt more solar energy per square meter than it released, bringing the finely tuned system into a state of imbalance.

He based his findings on ocean temperature measurements from 3,400 free-drifting Argo floats, which monitored temperature, pressure, and salinity of the upper ocean to a depth of 6,560 feet. His analysis, along with other ground-based

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and satellite data, showed the upper ocean absorbed 71 percent of the excess energy. The so-called abyssal zone of the ocean — between 9,800 and 20,000 feet below the surface — absorbed five percent, while ice and land absorbed eight and four percent, respectively.

"The fact that only eight percent of the extra energy caused the vast amount of ice melting that NASA satellites have measured gives perspective on the size of this extra energy," Wiscombe said.

Pinpointing the magnitude of Earth's energy imbalance and its causes are fundamental to climate science, Wiscombe added. "Instead of just warming the air, it mostly warms the ocean, and the rate of change in ocean heat correlates with the imbalance," he added. In fact, surface temperatures, considered the gold standard in detecting global climate change, have, in fact, flat-lined since the great El Nino of 1998, which caused an unprecedented spike in warming. "This has caused us to rethink our way of thinking about climate change. We need to focus on Earth's radiation budget, not surface air temperatures."

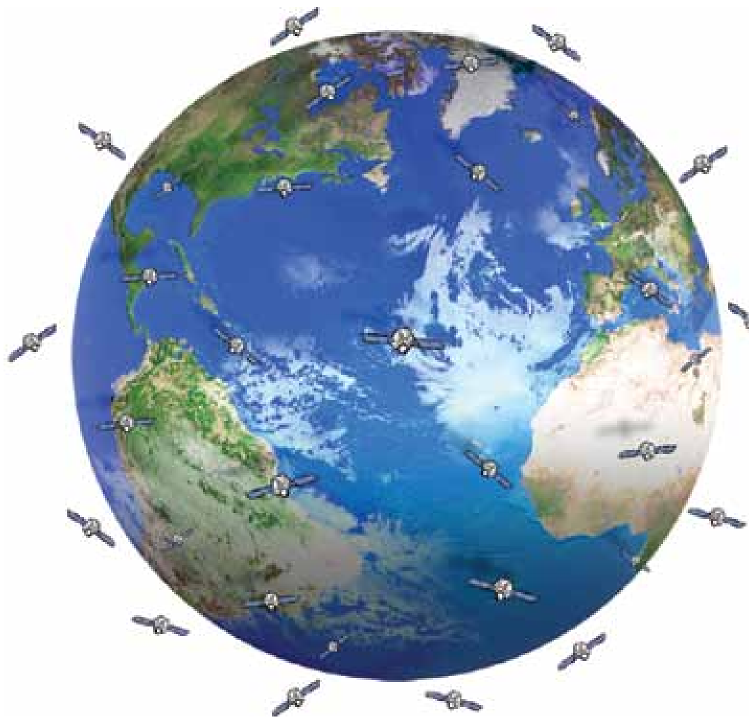
Photo Courtesy: JHU/APL

Radiometers may be flown on a constellation of satellites, like the one operated by Iridium shown here in this graphic. The goal would be to gather data about Earth's energy budget.

The Need: ERBE on Steroids

Although NASA launched the Earth Radiation Budget Experiment (ERBE) in the 1980s, only three Earth-orbiting satellites hosted the ERBE payload. While ERBE helped scientists better understand cloud forcing and provided Earth's average monthly energy budget, Wiscombe said the satellites provided limited temporal sampling. Today, the situation is even worse, he said. NASA's current Earth-sensing spacecraft sample a given location at best only four times a day. The rapid fluctuations during the diurnal cycle due to clouds, for example, remain largely unobserved, he added.

"Our satellites huddle together in near-noon, Sun-synchronous orbits, leaving vast stretches of each day unmeasured by any low-Earth-orbiting satellites," Wiscombe said. "Yet every Earth scientist knows that the diurnal cycle is extremely important and quite large. The only way to properly observe diurnal cycles is to have every place on Earth visible from one or more functionally identical and calibrated satellites 24/7, and the best way to do this right now is with a low-Earth-orbit constellation."

Though NASA did not select his EV-2 proposal, which called for the deployment of scores of identically equipped radiometers on a satellite constellation, Wiscombe and his partners are working to advance a critical radiometer component — the Vertically Aligned Carbon Nanotube (VACNT) detectors now being developed by APL in collaboration with Goddard technologist John Hagopian. Hagopian used IRAD resources to develop the technology, which is now being considered for a range of spaceflight applications (see related story, page 11).

Another Test of Carbon-Nanotube Technology

As their name implies, the VACNT detectors are made of a thin layer of vertically aligned, multi-walled carbon nanotubes 10,000 times thinner than a strand of human hair. Grown on silicon and other materials, these tiny hollow tubes are highly efficient at absorbing and trapping light across multiple wavelength bands, so efficient, in fact, that only a tiny fraction of the light actually escapes. Testing performed in 2011 revealed that the tech-

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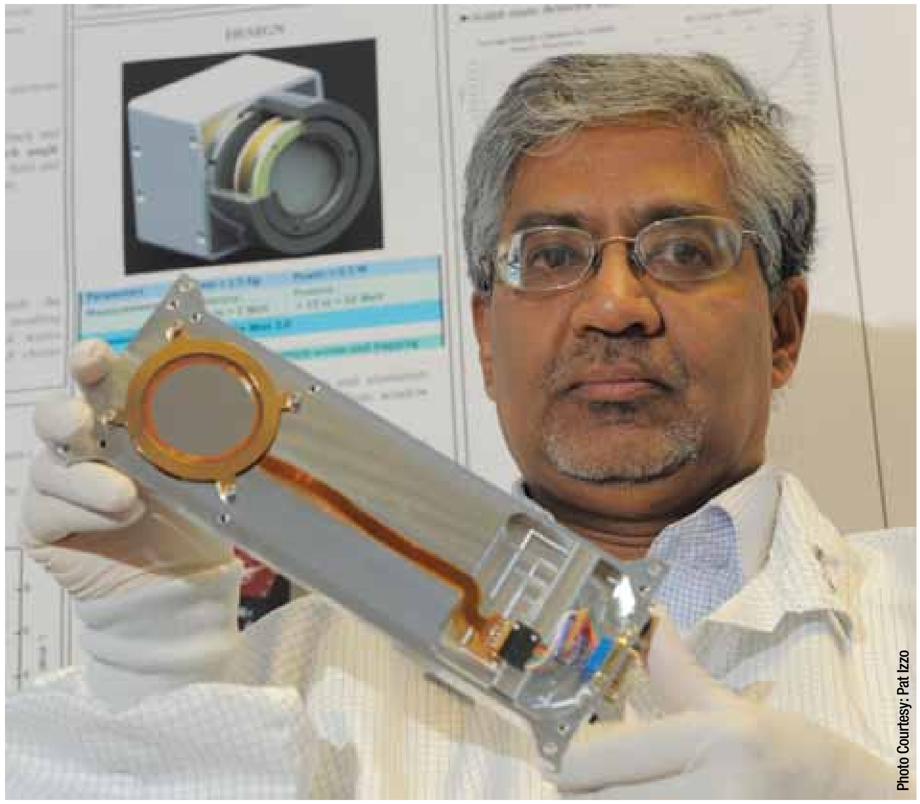
CREPT Wins Coveted Spot on NASA-Sponsored Cubesat Mission

A smaller version of an instrument now flying on NASA's Radiation Belt Storm Probes, now named the Van Allen Probes, has won a coveted spot aboard an upcoming NASA-sponsored Cubesat mission — the perfect platform for this pint-size, solid-state telescope.

Weighing just 3.3 pounds, the Compact Relativistic Electron and Proton Telescope (CREPT) will "augment the science of a major flagship mission" and demonstrate the effectiveness of two new technologies that make the instrument a factor-of-four faster than its 30-pound sibling at gathering and processing data, said CREPT Principal Investigator Shri Kanekal.



Scientist Shri Kanekal holds one of the solid-state detectors that will be used in the CREPT instrument. The picture to the left is a design diagram of the instrument.

LCAS-Funded Effort

The small solid-state telescope, which Kanekal and his team are developing under NASA's Low-Cost Access to Space (LCAS) program, will measure energetic electrons and protons in Earth's Van Allen radiation belts, the concentric bands of charged particles around Earth. CREPT measurements will give scientists a better understanding of the physics of electron microbursts and their role in the loss of electrons in Earth's Van Allen radiation belts.

Discovered in 1958 by NASA's Explorer 1 spacecraft, the Van Allen radiation belts have long intrigued scientists. The inner belt, stretching from about 1,000 to 8,000 miles above Earth's surface, is fairly stable. However, the outer ring, spanning 12,000 to 25,000 miles, can swell up to 100 times its usual size during solar storms, engulfing communications and research satellites, bathing them in harmful radiation.

Further complicating matters, the outer belt does not always respond in the same way to solar storms. Sometimes they swell; sometimes they shrink — an event caused when electrons in the outer loop either drop into the atmosphere or escape into space.

Object of Interest: Microbursts

Microbursts, CREPT's primary object of interest, are one mechanism by which the outer belt loses electrons.

"We don't know when a solar storm hits the Earth what the net effect will be," Kanekal said. "The Van Allen belts can swell, shrink, or in some cases remain unchanged. To understand what will happen when a solar storm impacts Earth, we need to know not only why the number of particles increases but also how they decrease or get lost. This is why studying microbursts is important. They tell us how particles are lost from the Van Allen belts," he said.

Kanekal, who also is the lead scientist on the Relativistic Electron and Proton Telescope (REPT)

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now flying on the Van Allen Probes mission, decided to develop a more compact version of the instrument last year — an effort initially funded by Goddard's Internal Research and Development (IRAD) program.

"To our delight, NASA selected our proposal," Kanekal said, adding that the unit Kanekal created under his IRAD to demonstrate the telescope's flight heritage is expected to fly on a Spanish Cubesat.

Cubesat Mini and New Algorithm Demonstrated

Under his $1.5-million LCAS award, Kanekal and his team will spend the next two years building CREPT. In year three, he plans to fly the telescope on a three-unit Cubesat, which more than likely will be launched by an Air Force Falcon 9 rocket. From its polar orbit, CREPT will be able to study electron growth and decay from a low-altitude polar orbit — an observing location that augments the science now being performed by REPT, which is flying in an equatorial orbit at high altitudes.

Although not quite as robust as the larger REPT, the new instrument offers enhanced processing capabilities. It will carry the Goddard-developed SpaceCube-Mini, one of three in a family of IRAD-funded processors developed by technologist Tom Flatley. Twenty-five times faster than the current state-of-the-art RAD750, the technology is a cross between SpaceCube 1.0 and 2.0 and includes commercial radiation-tolerant chips and specially developed algorithms that detect and correct radiation-induced upsets (*Goddard Tech Trends,* Spring 2010, Page 7).

IRAD-Leveraged Technologies

Another CREPT technology is an application-specific integrated circuit developed by Goddard scientist Nick Paschalidis. This analog-to-digital circuit helps analyze data, which then are directly fed into SpaceCube-Mini. Combined, the package provides a factor-of-four improvement in time resolution, meaning that the telescope can take measurements every five milliseconds.

"We made this instrument more compact and we improved how fast we can measure particles," Kanekal said. "Everything came together. We leveraged our technologies from the IRAD program, which really was crucial." ❖

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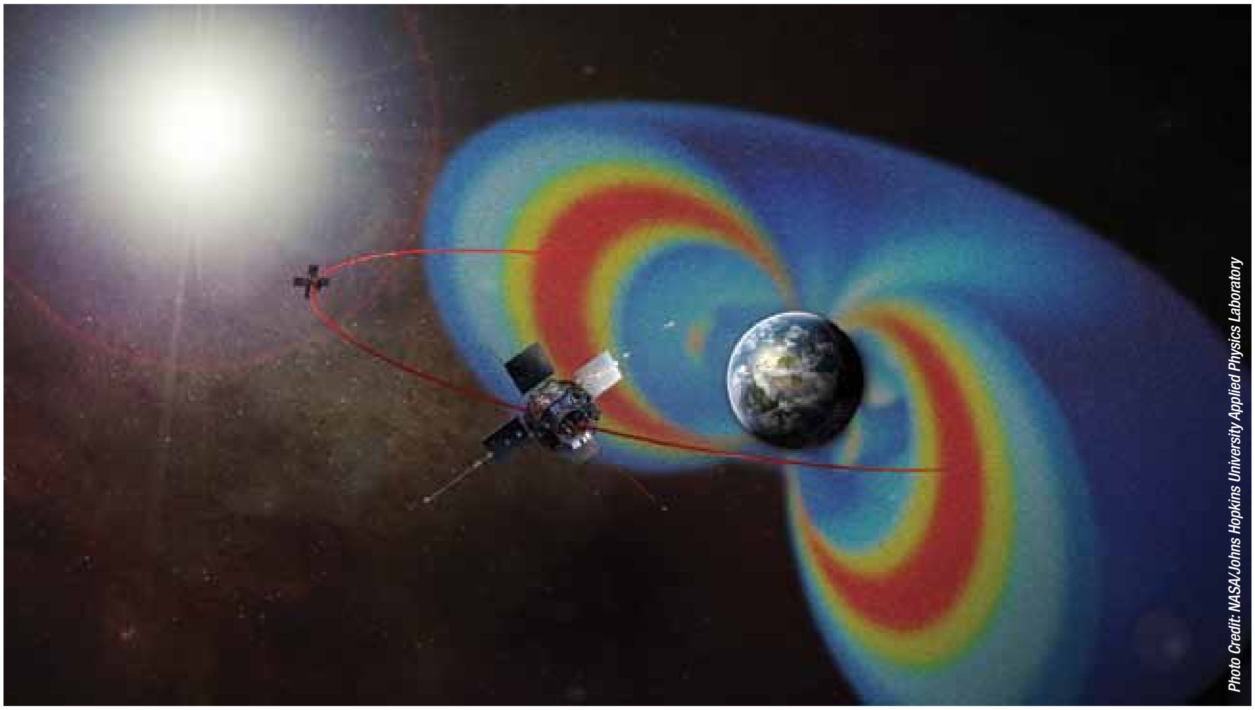

The tiny CREPT will augment the science of NASA's Van Allen Probes, formerly known as the Radiation Belt Storm Probes. This artist's rendering of the Van Allen Probes mission shows the path of its two spacecraft through the two radiation belts, which are made visible in false color.

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SPECIAL REPORT

R&D can be a high-risk endeavor sometimes requiring years to produce meaningful results. In this special report, CuttingEdge examines two Goddard-developed technologies that took years to develop and are now being applied to or considered for new missions and next-generation instruments — the quintessential definition of success. The report continues on pages 9,10, and 11.

BUG Technology Comes of Age

If technologist Christine Jhabvala learned anything during her years-long quest to build a super-sensitive infrared detector for sensing some of the oldest, most distant objects in the universe, it is this: all good things take time.

After nearly eight years in development, the new detector and more precisely its Backshort Under Grid (BUG) architecture "have finally come of age," said Ed Wollack, a Goddard scientist described as the "math genius" behind the technology. "This really is a story about how long it can take to mature a technology," Jhabvala agreed.

This year she and her team, including technologist Tim Miller, received $2.5 million in NASA funding to upgrade, integrate, and test larger-format BUG detector arrays for the agency's High-resolution Airborne Wideband Camera (HAWC+), which will fly on NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA). This heavily modified 747SP aircraft carries an eight-foot telescope to altitudes above 39,000 feet, above more than 99 percent of the water vapor in Earth's atmosphere that blocks most infrared radiation from celestial sources. HAWC+ upgrades an existing instrument, developed by the University of Wisconsin in collaboration with Goddard. But that's just the latest.

Before winning a place on SOFIA, Jhabvala's detector shop already had begun building BUG detector arrays for two balloon missions and a ground-based observatory, and is now working to further enlarge the size of the detector array to a whopping 40,000 pixels, a factor of 30 larger than currently possible. "Next generation science experiments studying the universe will require large-format, background-limited detector arrays containing tens of thousands of pixels," Jhabvala explained.

Her technology is leading the way, particularly in infrared astronomy, where astronomers gather data about the universe as it was a very long time ago.

Path to Success

The beauty of BUG is its ease of assembly. Jhabvala and her team devised a method to merge the array's three major components onto a single detector unit. This contrasted sharply with previous fabrication techniques requiring a significant

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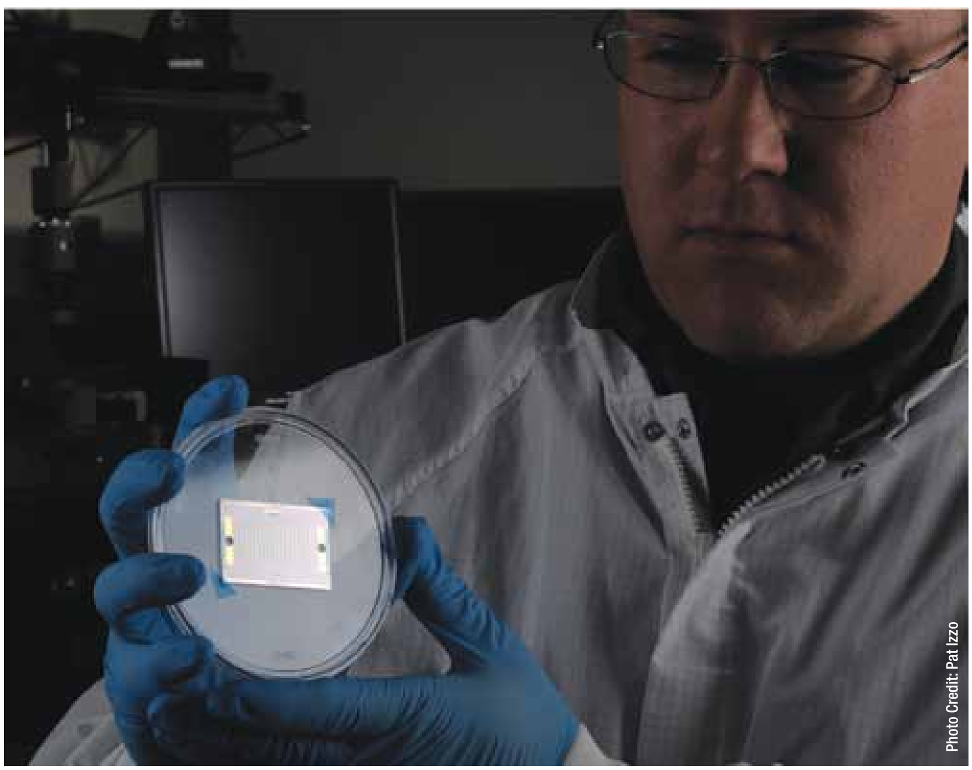
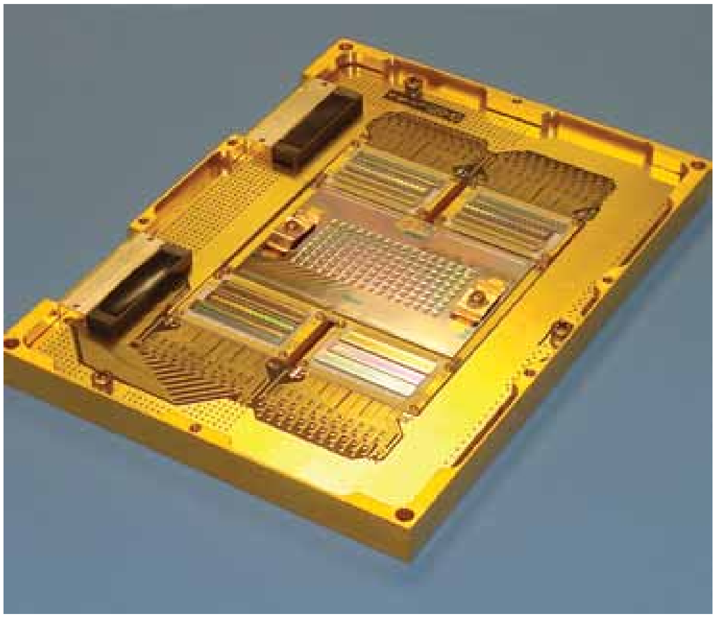


Photo Credit: Pat Izzo

Technologist Tim Miller holds the BUG detector array now being used in a number of space applications.

amount of handwork. As a result, Jhabvala can now produce larger, more sensitive arrays, which deliver higher-resolution data at a lower cost.

Her path to success began in 2005 when she and Goddard scientist Johannes Staguhn began building a BUG-based detector array for the Goddard-IRAM Superconducting 2-Millimeter Observer (GISMO), a prototype bolometer camera that the team installed two years later in a 30-meter ground observatory operated by the Institut de Radio Astronomie Millimétrique in Spain (*Goddard Tech Trends*, Spring 2008, Page 5).



This is a close-up of the full BUG focal-plane assembly.

Invented by Samuel P. Langley in 1878, bolometers are commonly used to measure infrared or heat radiation, and are, in essence, very sensitive thermometers. When radiation strikes an absorptive element, typically a material with a resistive coating, the element heats. A superconducting sensor then measures the resulting change in temperature, revealing insights into the physical properties of the distant object being studied.

"The technological breakthrough was that we were able to come up with a design that could be flexible," Jhabvala said. "We can adjust our detector arrays for different observing conditions."

Technological Breakthroughs

One of the adjustments is a new technique for gathering and ultimately reading the scientific data. Instead of being only partially absorbed by the resistive material, the incident radiation is reflected off the "backshort" — in other words, the backshort stops the light and reflects it back to the detector's absorber. This way, the detector absorbs the maximum amount of energy, Jhabvala said. "When properly tuned, the array can achieve an efficiency rate of 98 percent or more," she said.

Three detector projects, a ground-based instrument and two balloon payloads, will employ the new reflective design. However, the four 1,280-pixel arrays on HAWC+ will use the backshort to stop and then absorb the radiation.

GISMO-2, a follow-on to the successful GISMO-1, is one of the three new instruments using the reflective technique. It will be equipped with both a 256-pixel and a 1,280-pixel array. Considerably larger than the 128-pixel array installed inside its predecessor, GISMO-2 will more efficiently gather higher-resolution infrared light of very distant galaxies in the universe and will expand its capabilities to new wavelengths. Like GISMO-1, it will be installed on a ground-based telescope in Spain.

Principal Investigator Stephen Rinehart also has ordered four 81-pixel, reflective-type detector arrays for his Balloon Experimental Twin Telescope for Infrared Interferometry. This instrument, also developed in part with Goddard's Internal Research and Development program funding, will be NASA's first infrared interferometer, providing key data for studying star formation and paving the way for future space interferometry missions.

The other balloon mission, the Primordial Inflation Polarization Explorer, will require an even larger detector — a testament to the team's ability to easily scale up the size of the detector arrays. It will contain four separate 1,280-pixel arrays, which will help Principal Investigator Al Kogut search for the gravity-wave signal of cosmic inflation. This theory postulates that the early universe underwent an almost instantaneous period of expansion.

"Eight years ago, we knew the technology was important for infrared astronomy," Jhabvala said. "GISMO paved the way for us," Miller added. "Making the GISMO arrays and seeing the exciting science results that followed has motivated us to get these even larger arrays into the field. We know what science may come," he added. ❖

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Single-Crystal Silicon Mirror Technology Gains Traction

More than a decade ago, technologist Vince Bly began looking into how NASA might use thin silicon wafers — like those used in computer chips — to build ultra-lightweight mirrors for space telescopes. Although it soon became clear that the original idea wouldn't work, it did get him thinking about silicon as a mirror material. And as they say, the rest is history.

Photo Courtesy: Pat Izzo

Technologists Peter Hill (foreground) and Vince Bly pose with a single-crystal silicon mirror, which is mounted in the mandrel of the diamond-turning machine used in its fabrication.

Instrument developers now are evaluating the technology for use in next-generation instruments and efforts are afoot to use single-crystal silicon to create even larger telescope mirrors, featuring a range of non-spherical shapes. Even the Goddard team that built the Thermal Infrared Sensor (TIRS), one of two instruments on the Landsat Data Continuity Mission that NASA plans to launch in February, commissioned Bly to fabricate a spare mirror from single-crystal silicon.

"Even though the silicon mirror was superior to TIRS's aluminum mirror in every test, the new technology ultimately was not flown because it has no space flight heritage yet," Bly said.

Proponents of single-crystal silicon hope to change that.

"We've made incredible progress," said Peter Hill, a technologist now leading new research into the technology's maturation. "The relationship of my research to Vince's previous work was to evaluate the possibility of applying his idea to a broader class of classical optics."

What initially attracted Bly to the material — its high-thermal conductivity and low expansion, which make it less likely to distort when exposed to extreme swings in temperature — are the attributes now attracting scientists building next-generation instruments for a range of science disciplines. So are its purity, homogeneity, and highly crystalline composition, making the material more structurally uniform and stable.

These physical properties make the material easier to work with when fabricating mirrors. With more traditional optics, particularly those made of glass, technicians must first lightweight the material — a time-consuming, expensive process where technicians remove portions of the mirror blank before they polish the optical surface. The technique creates a honeycomb that maintains the mirror's strength while significantly reducing its weight.

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Because single-crystal silicon is so pure and homogenous, however, technicians can polish the reflecting surface first and then machine away the excess material without jeopardizing the mirror's integrity. Better yet, silicon is commercially available, which further reduces the price of mirror making.

Ideal for Multiple Science Disciplines

Will Zhang, an expert in X-ray optics, is just one of many scientists who has begun evaluating the nonconventional mirror-making material. He is now using NASA technology-development funding to construct super-thin X-ray mirrors from large blocks of single-crystal silicon (*CuttingEdge,* Winter 2012, Page 4).

Hill, meanwhile, is manufacturing mirrors for a prototype telescope that astrophysicist Jeff Livas plans to demonstrate for a potential gravitational-wave-detection mission now being spearheaded by the European Space Agency. The concept, now known as the New Gravitational Wave Observatory, would consist of three spacecraft placed in an equilateral triangle about three million miles apart. Minute changes in the position of free-floating cubes inside each satellite would be measured by high-precision

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CIRS-Lite: Chock-Full of New Technologies

Single-crystal silicon mirrors aren't the only new technology that Goddard scientist John Brasunas has installed inside the potential successor to the highly successful, 95-pound Composite Infrared Spectrometer (CIRS), one of 11 instruments aboard NASA's Cassin-Huygens mission.

The instrument prototype — known as CIRS-Lite — is literally chock-full of emerging, Goddard-developed technologies that Brasunas and his team believe will improve the instrument's performance and dramatically reduce its size to a mere 33 pounds — all important for winning a berth on a future planetary mission and maintaining Goddard's expertise in Fourier transform spectrometers. This spectrometer type uses the interference of light to determine the constituents in planetary atmospheres.

Leveraging Technologies

"We've made a fair amount of progress," said Brasunas, who used funding from NASA's Planetary Instrument Definition and Development Program and Goddard's Internal Research and Development (IRAD) program to design and build the prototype. "We're leveraging as many technologies as we can," added technologist John Hagopian, who has played a key role advancing the instrument's design and its alignment.

The team, which also includes Armando Morell, Bert Pasquale, and Billy Mamakos, will begin testing this year. Under one test, the team will place CIRS-Lite inside a cryostat that will plunge the instrument to a frosty 140 Kelvin. This test will demonstrate its ability to operate at very cold temperatures necessary for planetary science.

In addition to baselining a single-crystal silicon primary mirror, Brasunas's team, under an IRAD awarded to Hagopian, built the first-ever superconducting transition-edge detector array equipped with a carbon-nanotube material that is more efficient at absorbing infrared light — the wavelength band of interest to Brasunas. The carbon-nanotube coating is made of tiny tubes of pure carbon grown vertically on various substrates. Tiny gaps between the tubes collect and trap light, making the material appear black to the human eye.

Because the material is so black, the team also is evaluating its use as a radiator, which would remove heat from the instrument and radiate it away to deep space. The blacker the material, the more heat it radiates away. The carbon-nanotube technology would help cool the instrument to lower temperatures, making it more sensitive to faint infrared signals that otherwise might be swamped by instrument-generated heat.

In yet another application of the carbon-nanotube technology that Hagopian is developing, the team is considering using the material as a calibrator to assure the accuracy of the instrument's readings.

The challenge now, Brasunas said, is finding a flight opportunity, possibly as a balloon-borne payload, to demonstrate its efficacy at studying the atmospheres of extraterrestrial planetary bodies. When a flight opportunity arises, we'll be ready," he said. ❖

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New Filter Tidies Up the Messy

Preventing stray light or heat from contaminating the measurements of ultra-sensitive infrared detectors used to be a messy, cumbersome affair involving the application of a gooey, cement-like material around the electronic wiring that delivered this unwanted signature.

Photo Courtesy: Pat Izzo

Ari Brown devised a tidier, less weighty technique to block heat from contaminating measurements collected by ultra-sensitive infrared sensors.

A team of Goddard technologists and scientists has devised a tidier, less weighty technique to block this unwelcome heat and has proven in testing that it works. The challenge now is taking the concept to the next level and fabricating many more of these chip-like devices that can be tailored to a variety of instrumentation needs.

"We're trying to make the most sophisticated detectors even more sensitive," said Goddard technologist Ari Brown, who is working with Goddard scientist Ed Wollack to advance the new technology. "But heat generated by the electronics can travel down these wires and overwhelm the infrared signal that the instruments are supposed to gather. It's really important that we control this undesired source of infrared light."

The solution is a compact array of superconducting, lowpass filters on a silicon substrate. Each filter itself measures just 300 microns wide and six microns tall — dimensions best appreciated when comparing them to the width of a human hair, which is 200 microns wide. Embedded inside the chip are superconducting wires. They allow the electrical signals from an instrument's electronics to travel to the detectors, while blocking the heat that typically propagates along the electrical wiring.

Instrument developers have long known of the problem, which is particularly acute in infrared-sensing instruments that must be super cooled so that they can detect the faint infrared light emanating from the oldest objects in the universe. Typically, these sensors sit inside super-cold dewars. The operating electronics, meanwhile, sit outside the cryogenic flask. To absorb the heat that travels through the wiring connecting the electronics to the detectors, instrument builders embed the lines in an absorptive, highly viscous material, typically a mixture of metal and silica powders in an epoxy that binds them together.

Though the coating works well at blocking heat, Brown says the material is unwieldy and adds mass to the overall instrument. "It's like applying cement," Brown said. "It's cumbersome, especially when you're working with small instruments."

The idea of developing a multi-channel silicon chip that could filter out the heat while transmitting an electrical signal is the brainchild of Wollack and his Goddard colleague, Kongpop U-yen. In fact, Wollack won Goddard Internal Research and Development funding a few years ago to pursue the idea.

However, the original concept was not entirely successful, Wollack said. "We didn't give up on the idea, though," he added. "Once we understood why the device didn't work, we were able to figure how we could make one to work in an extremely compact space. I had no doubt about its prospects."

Under a three-year NASA instrument-development award, the team has since advanced the design and has proven in testing that the tiny device does its job and keeps out the heat. This year, the team wants to incorporate the lightweight filtering chip, which contains as many as 34 different channels, with the detector and begin testing to make sure the entire package performs as designed.

"As we originally devised this technology, it has evolved. It has grown up," Wollack said. ❖

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HOPE for HEROES

Joint Project Features Retrofit of Telescope

Why build a new telescope when you can retrofit an existing one?

That's the question two NASA scientists asked when they took an existing X-ray telescope built at the Marshall Space Flight Center and retrofitted it with new capabilities so that it could also carry out a Sun-gazing experiment conceived by a Goddard scientist.

Funded by NASA's Hands-On Project Experience (HOPE), a program specifically designed to give early-career scientists soup-to-nuts experience developing missions, Goddard's Steven Christe and Marshall's Jessica Gaskin joined forces to create the High-Energy Replicated Optics to Explore the Sun (HEROES) now slated to fly as a balloon-borne payload this fall.

The researchers found a way to modify the existing telescope designed for nighttime astrophysical observations so that it could study solar events during the day. "This kind of cross-center, dual-use project is something of a rarity at NASA," Christe said, adding that both centers provided research and development program funding to support the effort.

"The idea was to keep it simple. We would use a payload Marshall already has, add the ability to point it at the Sun, and make solar observations during the day in addition to the astrophysical observations at night. We needed to make sure the project was small enough in scope that we could do it in a year as required by HOPE," Christe said.

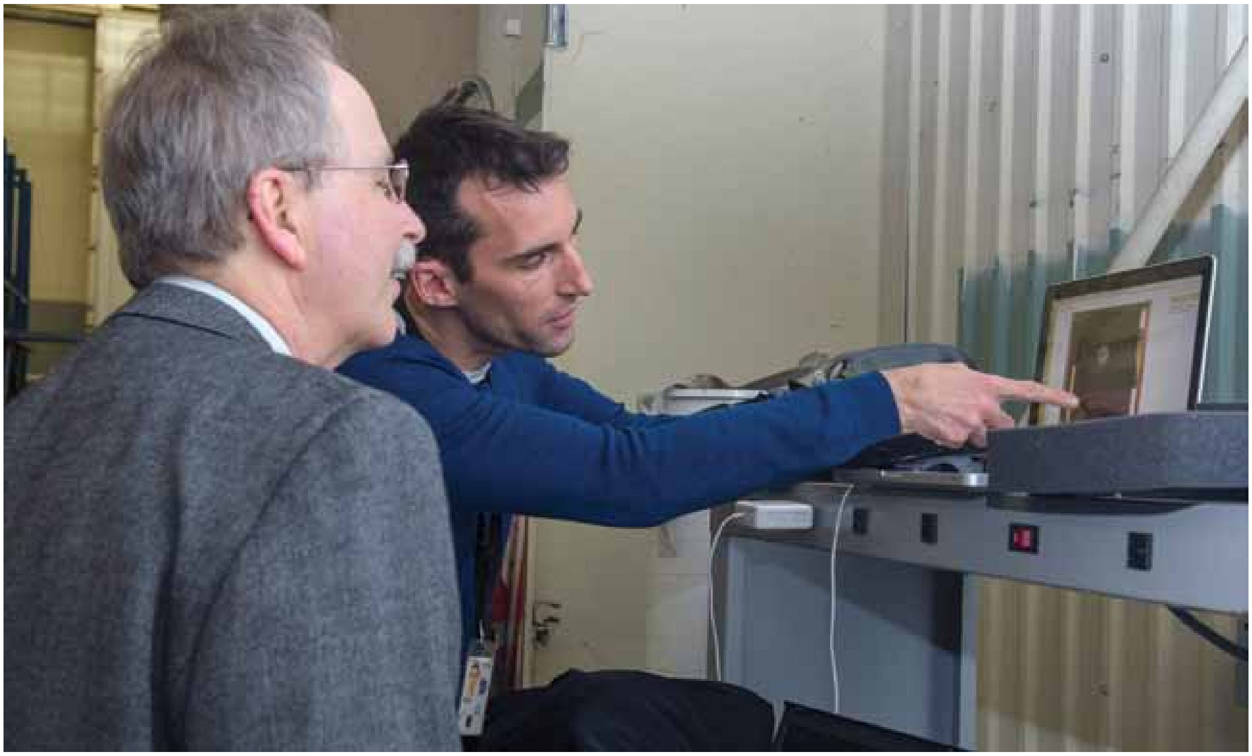
To accommodate the added capability, the Goddard team is building a new solar-aspect system for solar pointing and Marshall is adding a star camera that closes to protect the equipment when the telescope is pointed at the Sun.

X-ray Optics New for Solar Gazing

Using X-ray focusing optics to observe the Sun is new. Previous observations relied on indirect methods for imaging X-rays, Christe said. With the refurbished telescope, however, the direct observing method will provide higher sensitivity so that scientists can see fainter sources over a greater dynamic range. This will permit observations of fainter sources in the presence of brighter ones.

Christe's particular goal is investigating the energy-release mechanism of solar eruptive events, known as solar flares. While previous images only allowed partial views of particle acceleration and energy release, HEROES should be able to view

Continued on page 14



Co-Principal Investigator Steven Christe explains the HEROES balloon mission to Paul Hertz, Director of NASA's Astrophysics Division.

the entire particle-acceleration process and peer directly into the region where the particles are being accelerated.

"This acceleration process and energy release process is not well understood at all," Christe said. "These observations would help us understand what is happening not only on the Sun, but across the universe in different settings. This is thought to be a universal way that particles can get accelerated in magnetized plasmas, which exist across the universe."

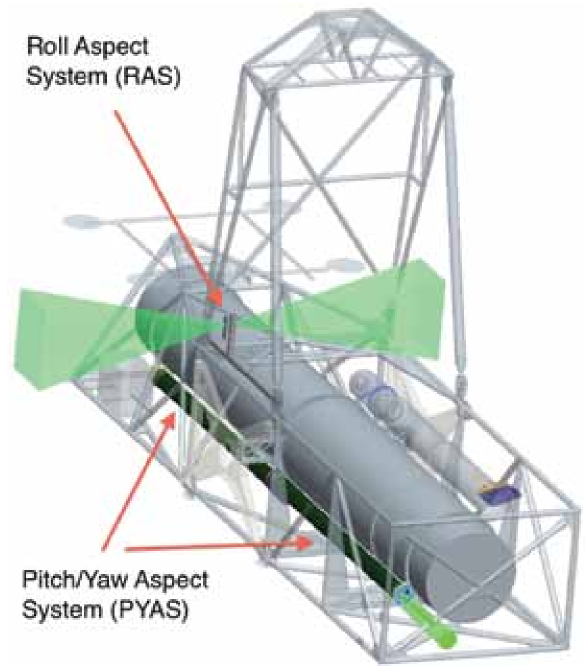
Overall, the project offers NASA a good platform to validate dual-use technology that could be applied to a later space mission," said Nick Paschalidis, senior project scientist for technology advancement at Goddard's Heliophysics Division. "Being able to see in real-time the acceleration regions in solar eruptions and then track the eruptions as they move is the new advancement with this project," he said.

"This kind of cross-center, dual-use project is something of a rarity at NASA. The idea was to keep it simple. We would use a payload Marshall has, add the ability to point it at the Sun, and make solar observations during the day in addition to the astrophysical observations at night. We needed to make sure the project was small enough in scope that we could do it in a year as required by HOPE." — Goddard Heliophysicist Steven Christe

As it happens, Christe's research is somewhat similar to Gaskin's. She is interested in studying the Crab Nebula, a supernova remnant. Like our own Sun, the Crab ejects energetic flares or jets of high-energy radiation. With HEROES, she believes she will be able to see the locations of these emissions and learn more about their acceleration processes. "There is a lot we still don't understand, because there aren't many high-resolution imaging telescopes in hard X-rays," she said.

More Observing Time

Although Christe employed similar hard X-ray fo-



Shown here in this artist's rendition is the gondola that will carry the HEROES payload during a balloon mission this fall. The fields-of-view of each system are shown in green.

cusing optics on a recent solar-observing mission, called the Focusing Optics X-ray Solar Imager, the payload was launched from a sounding rocket. His joint effort with Gaskins, on the other hand, will fly aboard a scientific balloon from the Fort Sumner test site in New Mexico.

While a sounding rocket can reach heights of about 217 miles above Earth's surface, it only can provide about six minutes of observing time, which is not well suited for observing flares that occur unpredictably. The balloon, on the other hand, can reach an altitude of 25 miles and stay aloft for about a day and a half, allowing for much longer observations. While the winds will carry the balloon on an uncharted path, the balloon flight will be tracked. At the mission's conclusion, the team then will retrieve the gondola containing the telescope after it's released from the balloon.

Next up for the dynamic research duo, Gaskin and Christe said, is "Super HEROES," the next version of HEROES that will continue the collaboration. The new mission will fly for two to four weeks over Antarctica and test a new set of cutting-edge detectors, Christe said. ❖

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3-D Printing Creates Complex Astro-H Component

Neil Armstrong was the first man on the Moon and Yuri Gagarin was the first in space. Though engineer David Robinson may not put himself in the same league as Armstrong or Gagarin, he, nonetheless, can say he was the first at Goddard to use 3-D laser printing to fabricate a complex instrument component for an upcoming astrophysics mission.

The additive manufacturing technology Robinson employed — a computer-operated device that literally prints a solid object from powdered metals — is called direct metal laser sintering (DMLS). With this technology, a part is built with a high-powered optic laser that melts and fuses metal powder in precise locations as indicated by a 3-D CAD model. Since the components are built layer by layer, it is possible to design internal features and passages that could not be cast or machined.

Working with Goddard technologist Steven Kenyon, who spent last year thoroughly evaluating the technology's practicality for spaceflight applications, Robinson helped develop with Goddard's Cryogenics Branch a titanium heat switch for the Adiabatic Demagnetization Refrigerator. The cooling system, advanced by Goddard technologist Peter Shirron, will keep the ultra-sensitive microcalorimeter detectors on Astro-H's Soft X-ray Spectrometer at a frosty -459.58 degrees Fahrenheit (.05 degrees above absolute zero).

Although the Marshall Space Flight Center has purchased an additive-manufacturing machine to create rocket nozzles, this is the first example of a printed part being made for a Goddard-managed flight project, Robinson said. He originally built the heat switch as a demonstration unit; however, he may use it in the actual flight instrument should the baseline design unit run into difficulties.

The part showcases the benefits of laser printing, said Kenyon, who last August put Robinson in touch with the part's manufacturer, GPI Prototype and Manufacturing Services in Lake Bluff, Illinois.

Consisting of five nested shells inside a tube, the DMLS-produced heat switch is difficult and time consuming to create with standard machining processes, Robinson said. "Fabricating this part using conventional methods requires making five different-sized tubes and welding them together," he added. "I'd estimate that it would take about three months to receive this part and I'd expect to pay between $10,000-$20,000. But with this new

Goddard engineer David Robinson used 3-D laser printing to create this component for Astro-H — the first time Goddard has used the technique to create a part for a flight instrument.

printing process, the part cost only $1,200 and took two weeks for the finished part to get into my hands," Robinson said.

Kenyon's role in the fabrication of Goddard's first DMLS-produced part was in large part due to a study that he and his team carried out last year to investigate the technique's appropriateness for spaceflight applications. Kenyon, himself, became intrigued by the possibilities when he used the method to create a Modulated X-ray Source for an instrument Goddard scientist Keith Gendreau is developing for a possible flight on the International Space Station.

His investigation, funded by Goddard's Internal Research and Development (IRAD) program, included tests of various DMLS-produced specimens — tests that revealed that most samples met or exceeded the mechanical properties advertised for each material. Kenyon's IRAD-funded study also included the development of a manual that includes design rules and project examples.

"There isn't a large demand for producing parts using this process right now, but I think it's because people don't understand the process and its potential benefits," Kenyon said. "I do think there will be a demand in the future, though. This technique is the real deal. You can use these parts." ❖

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Last Frontier, *continued from page 5*

nology absorbed more than 99 percent of the light in the infrared bands where Earth's energy is emitted into space (*CuttingEdge,* Winter 2012, Page 6).

With this application, infrared light would strike the VACNT detector, which, in turn, would absorb the heat and measure the change in temperature, providing scientists with a more comprehensive picture of Earth's radiation budget.

The test of the VACNT detectors this spring aboard a commercial suborbital vehicle that takes off and lands vertically is the second flight demonstration of the carbon-nanotube technology. Wiscombe believes this opportunity will raise the detectors' technology-readiness level from three to seven. Obtaining a berth on these tiny Cubesats to further advance the observing technique is precisely what Wiscombe hopes will happen in the near term. In addition to preparing for the demonstration flight, he and his team are working to secure other flight opportunities on NASA- or National Science Foundation-sponsored Cubesat missions.

"We're going to continue pushing this," Wiscombe said. "Understanding Earth's energy imbalance is the one of greatest remaining frontiers in climate studies." ❖

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Mirror Technology, *continued from page 11*

laser light transmitted and received by the mirrors.

"You can take a block of silicon, figure it and then lightweight it and it keeps its figure," Livas said, explaining his attraction to the new technology. "It's lightweight and it has a good optical quality." Better yet, "when it gets cold, it works even better due to its thermal conductivity," Livas said.

John Brasunas also is testing the technology for use on the next-generation Composite Infrared Spectrometer-Lite (CIRS-Lite), a successor to the instrument flying on NASA's Cassini-Huygens mission (see related story, page 11). "There are many reasons why you'd choose single-crystal silicon mirrors," he said. "Silicon is the purest, most perfect material we can make. Because our instrument won't be in a constant thermal environment, it's useful to us that the mirror be more tolerant of changes in temperature."

Not a Panacea — Yet

Despite these qualities, the technology is not a panacea — just yet.

"Single-crystal silicon optics have never flown before in space," Hill said. "This is due to the fact that the material is both hard and brittle, making it both difficult and expensive to machine."

With Goddard Internal Research and Development (IRAD) program funding, Hill and his team matured new manufacturing techniques that make it less likely the material will chip during fabrication. In particular, he used a diamond-turning machine operated by Goddard's optics branch to fashion boules of silicon into mirrors. The new preparation technique prevented chipping and placed less stress on the material, he said, adding that low-stress mirrors are less likely to distort when exposed to extreme swings in temperature.

The group also experimented with techniques to bond different pieces of silicon to form larger and more diversely shaped mirror segments. Testing has shown that the bonded mirrors are just as stable as those made from a single boule of silicon.

The IRAD-funded research, Hill believes, will pay off. "We're hoping our effort will open up the applications. Single-crystal silicon offers great mechanical properties. It really is a great spaceflight material." ❖

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Cutting edge Goddard's Emerging Technologies

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