National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

Two-in-One Instrument Wins Big

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NICER/SEXTANT team (clockwise, front left): Keith Gendreau, Zaven Arzoumanian, Luke Winternitz, and Jason Mitchell (Photo Credit: Pat Izzo)

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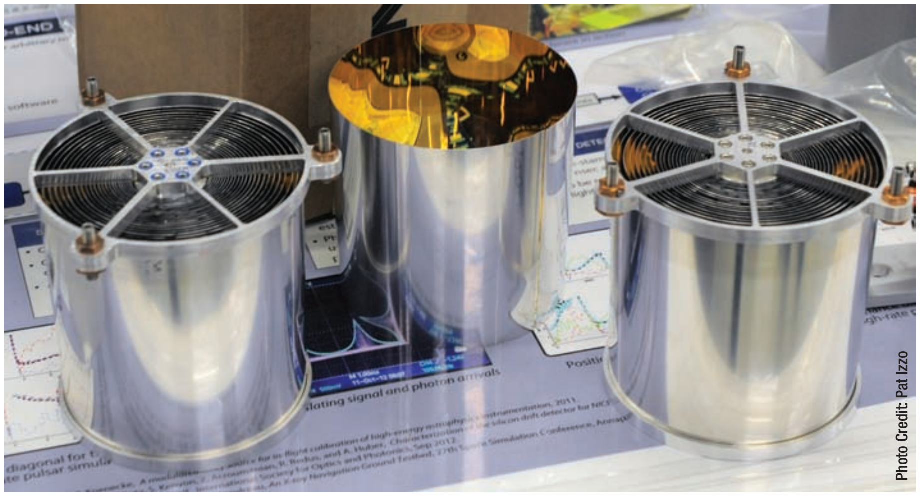
Inspired by a Black Hole

NICER/SEXTANT Team Wins Explorer Mission of Opportunity



These nested shells of X-ray mirrors will fly on a new two-in-one instrument that will study neutron stars and demonstrate X-ray navigation.

It all started because Goddard scientist Keith Gendreau wanted to directly image the event horizon of a supermassive black hole — the point of no return where absolutely nothing can escape its gravitational clutches.

Now, after years of work, Gendreau and his team are applying many of the advanced technologies conceived for imaging these as-yet unseen astrophysical boundaries to a dual-use instrument selected to fly on the International Space Station (ISS). Though Gendreau's team won't study black holes with the instrument's technologies — at least not yet — the group will gather observations of the next best thing: neutron stars and their rapidly rotating next-of-kin, pulsars.

The Neutron-star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT), which NASA's Science Mission Directorate recently selected as its next Explorer Mission of Opportunity, not only will reveal the physics that make neutron stars the densest objects in nature, but also demonstrate a groundbreaking navigation technology that could revolutionize the Agency's ability to navigate to the far reaches of the Solar System and beyond.

NASA's Space Technology Mission Directorate's Game Changing Development Program also is contributing to the mission's development.

In addition to Goddard scientists and engineers, the mission team includes the Massachusetts Institute of Technology and commercial partners, who are providing spaceflight hardware. The Naval Research Laboratory and universities across the U.S., as well as in Canada and Mexico, are providing science expertise. The experiment also may enable a future demonstration of a second technology — X-ray communication — that would allow space travelers in the future to transmit gigabytes of data per second over interplanetary distances.

"It's rare that you have an opportunity to fly a cross-cutting experiment," said Gendreau, the recipient of Goddard's "Innovator of the Year" award in 2012. "It's also rare that seemingly disjointed technologies originally conceived for one scientific application can now be applied to yet another. But that's what we've done with this mission."

Multi-Purpose Mission

The multi-purpose mission, whose technologies Gendreau advanced in part with seed funding from Goddard's Internal Research and Development program, consists of 56 X-ray telescopes in a compact bundle, their associated silicon detectors, and a number of other advanced technologies. Roughly the size of a college dormitory-size refrigerator, NICER/SEXTANT will fly in 2017 as an external attached payload on one of the ISS ExPRESS Logistics Carriers, unpressurized platforms used for experiments and storage.

The X-ray instrument's primary objective is to learn more about the interior composition of neutron stars and pulsars, the remnants of massive stars that, after exhausting their nuclear fuel, exploded and collapsed into super-dense spheres about the size of New York City. Their intense gravity crushes an astonishing amount of matter — often more than 1.4 times the content of the Sun or at least 460,000 Earths — into these city-size balls, creating the densest objects known in

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the universe. Just one teaspoonful of neutron star matter would weigh a billion tons on Earth.

"These objects are right at the threshold of matter as it can exist — if they were compressed any further, they would collapse completely and become black holes," says Zaven Arzoumanian, a Goddard scientist serving as the deputy principal investigator on the mission.

X-Ray Band Holds Key

Although neutron stars and pulsars emit radiation across the spectrum, observing in the X-ray band offers the greatest insights into their structure and the high-energy, dynamic phenomena that they host, including starquakes, thermonuclear explosions, and the most powerful magnetic fields known in the universe.

In particular, the payload's 56 telescopes will collect X-rays generated from the stars' tremendously strong magnetic fields and from hotspots located at their two magnetic poles. At these locations, the intense magnetic field emerges from the surface. Particles trapped in the magnetic field rain down and generate X-rays when they strike the surface.

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Pulsar-on-a-Table: An Unusual Testbed

Pulsars have a number of unusual qualities. Like zombies, they shine even though they're technically dead and they rotate rapidly, emitting powerful and regular beams of radiation that are seen as flashes of light, blinking on and off at intervals from seconds to milliseconds.

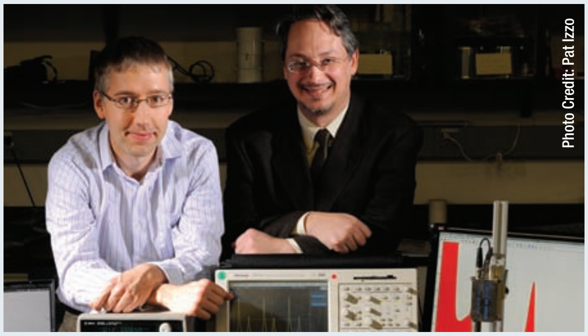
A Goddard team has built a first-of-a-kind testbed that simulates these distinctive pulsations.

The pulsar-on-a-table, known as the Goddard X-ray Navigation Laboratory Testbed (GXNLT), was built to test and validate a next-generation X-ray navigation technology to be demonstrated on a dual-use instrument recently selected as a NASA Explorer Mission of Opportunity (see related story, page 2).

"This is a unique capability," said Jason Mitchell, a Goddard engineer who helped develop the table-top-size facility that simulates the rapid-fire pulsations that distinguish this unusual class of stars, considered the densest objects in the universe. "We needed a capability that would let us retire technological risks early and test as many of the technology's components as possible," he said.

The facility is validating advanced technologies for the Neutron-star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT). Slated to fly on the International Space Station in 2017, the instrument will study the interior compositions of neutron stars largely through observations of their pulsating variants, pulsars.

Because of their predictable pulsations, pulsars can provide high-precision timing just like the



Goddard technologists Luke Winternitz and Jason Mitchell created what they believe is the world's first "pulsar-on-a-table," a laboratory system for testing X-ray navigation.

atomic-clock signals supplied through the Global Positioning System (GPS). However, unlike GPS signals that are geared to Earth-based applications, pulsars are distributed throughout the galaxy, making the X-ray navigation (XNAV) technology ideal for travel throughout the Solar System and beyond.

From its berth on the International Space Station, NICER/SEXTANT will use its telescopes to detect X-ray photons in the pulsars' powerful beams of radiation to measure their arrival times. With these measurements, the system will stitch together an onboard, autonomous navigational solution using specially developed algorithms.

With the Explorer win, the NICER/SEXTANT team will begin building and integrating the telescope package and associated hardware and software. But as with all spacecraft missions, end-to-end testing presents another set of challenges.

"We had to have a way to test the technology," said co-developer Luke Winternitz. "We have GPS

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Flatley Wins Prestigious AAS Award

Goddard engineer Tom Flatley has joined the pantheon of NASA greats.

The winner of Goddard's Innovator of the Year Award in 2009, Flatley received the American Astronautical Society's (AAS) 2012 William Randolph Lovelace II Award at the 51st Robert H. Goddard Memorial Symposium in late March, joining such NASA notables as astronaut Buzz Aldrin, world-renowned gamma-ray researcher Neil Gehrels, and former Goddard Director Noel Hinners, who also served as NASA's associate deputy administrator and chief scientist.

The AAS award was created to honor the lifetime achievements of Lovelace, a flight surgeon who received the Distinguished Flying Cross for an experimental parachute descent from more than 40,000 feet. He was appointed chairman of the NASA Special Advisory Committee on Life Sciences in 1958 and played a key role in the selection of Mercury program astronauts.

Flatley, who currently heads Goddard's Applied Engineering and Technology Directorate's Science Data-Processing Branch, received the award due to his pioneering contributions to space science and technology, primarily through his work with a reconfigurable, hybrid-computing platform called SpaceCube.

Ten to 100 times faster than the current radiation-hardened flight processors — such as the RAD750 — SpaceCube is offering science missions a much-needed alternative, particularly those requiring more robust computing power to handle significantly higher data rates, said Goddard Chief Technologist Peter Hughes, who manages the center's Internal Research and Development (IRAD) program that provided seed funding to the SpaceCube-development effort.

"Having first-hand knowledge of Tom's accomplishments and his vigorous pursuit of new SpaceCube products and applications, I can't think of a better recipient for this prestigious award," Hughes added. "SpaceCube provides high-performance computing from a smaller, more energy-efficient platform largely because of his efforts."

The Marriage of FPGAs and Algorithms

SpaceCube achieves its data-crunching prowess because Flatley and his team have married commercial radiation-tolerant Xilinx Virtex field

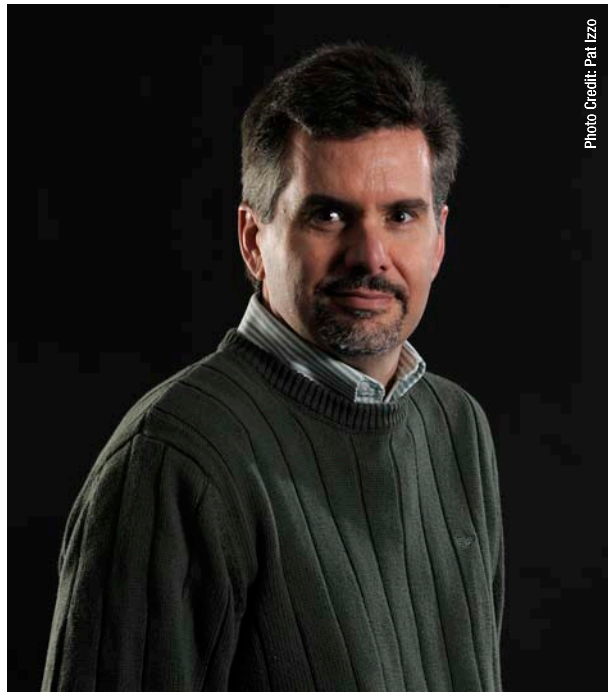

Photo Credit: Pat Izzo

Tom Flatley recently won the American Astronautical Society's 2012 William Randolph Lovelace II award for advancing SpaceCube, a more capable, hybrid flight processor.

programmable gate array (FPGA) technology to Goddard-developed algorithms that detect and correct radiation-induced upsets. As a result, SpaceCube is nearly as reliable on orbit as the fully radiation-hardened RAD750, while providing "order-of-magnitude" improvements in onboard computing power.

"Next-generation instruments are capable of producing data at rates of billions to trillions of bits per second, and both their instrument designs and mission-operations concepts are severely constrained by current data rates and volumes," Flatley said. "SpaceCube is an enabling technology for these missions."

First demonstrated in 2009 on Hubble Servicing Mission-4 as part of the Relative Navigation Sensor experiment, the first-generation processor — SpaceCube 1.0 — has since evolved into a family of products that can meet nearly any spaceflight need (*Goddard Tech Trends*, Spring 2010, Page 7). All members of the product line-up — SpaceCube 1.0, 1.5, 2.0, and the SpaceCube-Mini — were developed with support from IRAD, the Satellite Servicing Capabilities Office, and Defense Department funding.

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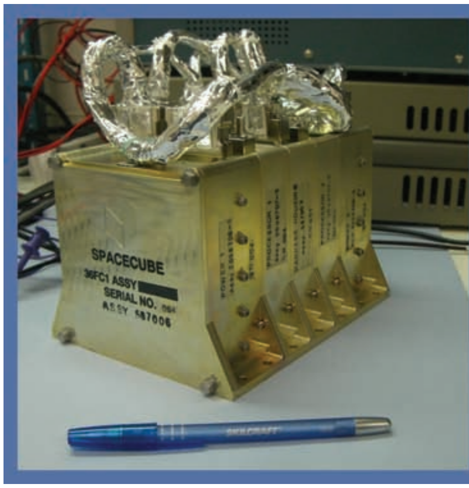

Left: The SpaceCube family of products began with the 1.0 shown in this photo.

Right: This image shows circuitry inside SpaceCube 2.0, which is flying on a military-sponsored instrument pallet expected to fly on the International Space Station later this year.

And all have flown or have been selected to fly on a variety of spaceflight missions.

In addition to flying on the Hubble Servicing Mission, SpaceCube 1.0 flew on a Naval Research Laboratory-sponsored experiment pallet deployed on the International Space Station (ISS) in 2009. A couple years later, Flatley and his team flew the SpaceCube 1.5 as part of a sounding-rocket mission demonstrating the Goddard-developed Small Rocket/Spacecraft Technology mini satellite.

This summer, SpaceCube 2.0, which weighs less than 10 pounds and is about the size of a half-gallon container of ice cream, will fly on the Defense Department's Space Test Program (STP)-H4 mission, an experiment pallet to be deployed on ISS. For this mission, the flight processor will be paired with a set of four Earth-viewing high-definition cameras and a heliophysics experiment called Firestation, a miniaturized instrument that will detect and measure terrestrial gamma-ray flashes from lightning.

Flatley and his team now are busy developing SpaceCube-Mini, which measures only 4 inches on each side and weighs less than two pounds, for use on sounding rockets, Smallsats, and rovers. And, in fact, the diminutive processor will be used on the Compact Relativistic Electron and Proton Telescope, a Cubesat mission that Goddard heliophysicist Shri Kanekal is now developing to measure energetic electrons and protons in Earth's Van Allen radiation belts.

The Future

The future remains bright for the technology.

Flatley said the cameras used on STP-H4, along with the real-time "situational awareness" data that SpaceCube 2.0 can process onboard, could in the future provide critical information about the direction of rapidly spreading fires or other natural disasters. In addition, he is planning to pair SpaceCube-processed data and images with other data gathered by satellites and ocean buoys to simulate next-generation "sensor-web" systems.

Also on the horizon, SpaceCube is being baselined, studied, or proposed for near-term robotic-servicing missions and additional Cubesats and Defense Department-sponsored attached ISS payload experiments. As a next step, Flatley also wants to place the technology on polar and geosynchronous (GEO)-orbiting spacecraft to test its performance in those orbits.

One example is the "SpaceCube At GEO Experiment." Under this proposed mission, two SpaceCube processors, one populated with a commercial Virtex 5 FPGA and the other with a radiation-hardened Virtex 5 QV FPGA, would execute identical processing algorithms from GEO or geostationary-transfer orbits. With the data, Flatley would compare the actual on-orbit performance of the radiation-hardened system against the one employing radiation-tolerant techniques. The findings could help quantify the types of applications and missions that would benefit from SpaceCube.

"SpaceCube's small size and low cost can enable other cutting-edge technology developed by research institutions, commercial companies, and the U.S. military," Flatley said.

"And If anyone can find the application, it's Tom," Hughes added. ❖

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Goddard to Deliver the Most Sophisticated Earth-Observing L-Band Radiometer Ever Built

A Goddard-led team plans to deliver in May a "smart" microwave radiometer specifically designed to overcome the pitfalls that have plagued similar-type Earth-observing instruments in the past.

Mark Wong (front left), Damon Bradley (rear left), Lynn Miles (rear right), and Rafael A. Garcia (front right) created the signal-processing system for a new radiometer to debut on NASA's Soil Moisture Active Passive mission.

Literally years in the making, the new-fangled radiometer that its developers equipped with one of the most sophisticated signal-processing systems ever developed for an Earth-science mission now will be integrated into NASA's Soil Moisture Active Passive (SMAP) spacecraft, along with a synthetic aperture radar system developed by the Jet Propulsion Laboratory (JPL).

With the two instruments, the JPL-led mission will globally map soil-moisture levels — data largely missing in climate models today — when it begins operations shortly after its launch in late 2014. In particular, the data will give scientists the ability to discern global moisture levels, a crucial gauge for drought monitoring and prediction, and fill gaps in scientists' understanding of the water cycle. Just as important, it could help crack an as-yet unsolved climate mystery: the location of the sinks that take up carbon emissions.

Years in the Making

Building the new radiometer took years to accomplish and involved the development of advanced algorithms and an onboard computing system capable of crunching a deluge of data estimated at 192 million samples per second. Despite the challenges, team members believe they've created a state-of-the-art instrument that is expected to triumph over the troubles encountered by other Earth-observing instruments designed to study moisture levels.

The instrument will penetrate vegetation and other barriers to gather the thermal-microwave signal that indicates the presence of moisture. The wetter the soil, the colder it will look in the thermal data. At the same time, the instrument also will mitigate the "noise" caused by radio interference — the very same noise that has contaminated measurements gathered by the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite and, to a certain extent, NASA's Aquarius satellite.

"This is the first system in the world to do all this," said Instrument Scientist Jeff Piepmeier, who initially used Goddard Internal Research and Development program funding to advance his concept.

Tuning into Earth's Noise

Like all radiometers, the new instrument listens to the noises emanating from a very noisy planet. Like a radio, it's specifically tuned to a particular frequency band — 1.4 GHz or "L-Band" — that the International Telecommunication Union (ITU) in Geneva, Switzerland, has set aside for radio astronomy and passive Earth remote-sensing applications. In other words, users only may listen to the "static" from which they can derive the moisture data.

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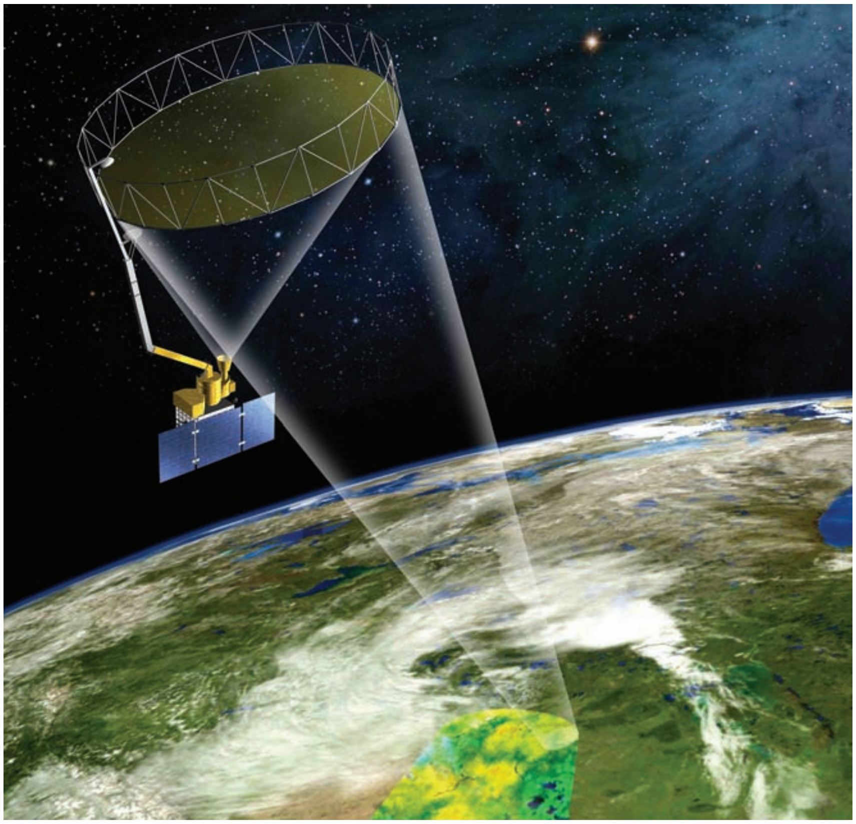
Despite the prohibitions, however, the band is far from pristine. "Radiometers listen to the desired signal in the spectrum band, as well as undesired signals that end up in the same band," said Damon Bradley, a Goddard digital signal-processing engineer who worked with Piepmeier and others to create the radiometer's advanced signal-processing capabilities. As operators of SMOS quickly discovered shortly after the spacecraft's launch in 2009, unwanted noise certainly exists in the data.



This artist's rendition shows the SMAP spacecraft and its data swath.

Signal-spillover from neighboring spectrum users, particularly air-traffic control radars, interfere with the microwave signal users want to gather. Just as troublesome is the illegal interference caused by radar systems and TV and radio transmitters who violate ITU regulations.

As a result, the global soil-moisture maps generated by SMOS data contain blank, data-less patches. "Radio-frequency interference is intermittent, random, and unpredictable," Bradley added. "There's not a lot you can do about it."

That's why he and his team turned to technology.

New Algorithms Implemented on FPGAs

In 2005, Bradley, Piepmeier, and other Goddard engineers teamed with researchers at the University of Michigan and Ohio State University, who already had created algorithms or step-by-step computational procedures for mitigating radio interference. Together, they designed and tested a smart digital-electronics radiometer that could use these recipes to find and remove unwanted radio signals.

Conventional radiometers deal with fluctuations in microwave emissions by measuring signal power across a wide bandwidth and integrating it over a long time interval to get an average. The SMAP radiometer, however, will take those time intervals and slice them up into much shorter time intervals, making it easier to detect the rogue, man-made signals. "By chopping the signal in time, you can throw away the bad and give scientists the good," Piepmeier said.

One of the first steps was in the design of the processor itself. Because the current state-of-the-art flight processor — the RAD750 — is incapable of handling the radiometer's expected data torrent (see related story, page 8), the team had to develop a custom-designed processing system featuring more powerful, radiation-hardened field programmable gate arrays, which are specialized application-specific integrated circuits.

The team then programmed these circuits to implement the university-developed algorithms as flight signal-processing hardware. The team also replaced the detector with an analog digital converter and bolstered the overall system by creating ground-based signal-processing software to remove interference not eliminated by the onboard system.

"SMAP has the most advanced digital processing-based radiometer ever built," Piepmeier said. "It took 12 years to develop the algorithms, the ground software, and the hardware. What we produced is the best L-band radiometer for Earth science."❖

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NASA Seeks High-Performance Spaceflight Computing Capabilities

Compared with the computer technology used in today's electronic gadgets, including the now ubiquitous smart phone, NASA's state-of-the-art general-use flight processor lags woefully behind.

As a result, NASA and the Air Force Research Laboratory (AFRL) are now partnering to share in the development of a high-performance space processor that would offer orders-of-magnitude increases in computing capacity. The two-agency team has released a Broad Agency Announcement under AFRL's Next-Generation Space Processor Analysis Program seeking two to four companies to perform a year-long study evaluating needs and then developing a set of solutions. The program plans to award contracts by August.

Based on the results of the study, the chosen industry team would develop a spaceflight processor capable of providing high-performance capabilities needed through 2030.

Four-Month Study Contributes to Decision

NASA's decision to partner with the AFRL and issue a joint solicitation was influenced by a four-month formulation study funded by NASA's Space Technology Mission Directorate's Game Changing Development Program. During that investigation, engineers from Goddard, the Jet Propulsion Laboratory (JPL), the Johnson Space Center, and the Ames Research Center evaluated 19 real-life mission scenarios involving the use of flight processors.

"We surveyed NASA's needs and it became more than obvious that we could take advantage of an advanced processor," said Richard Doyle, the

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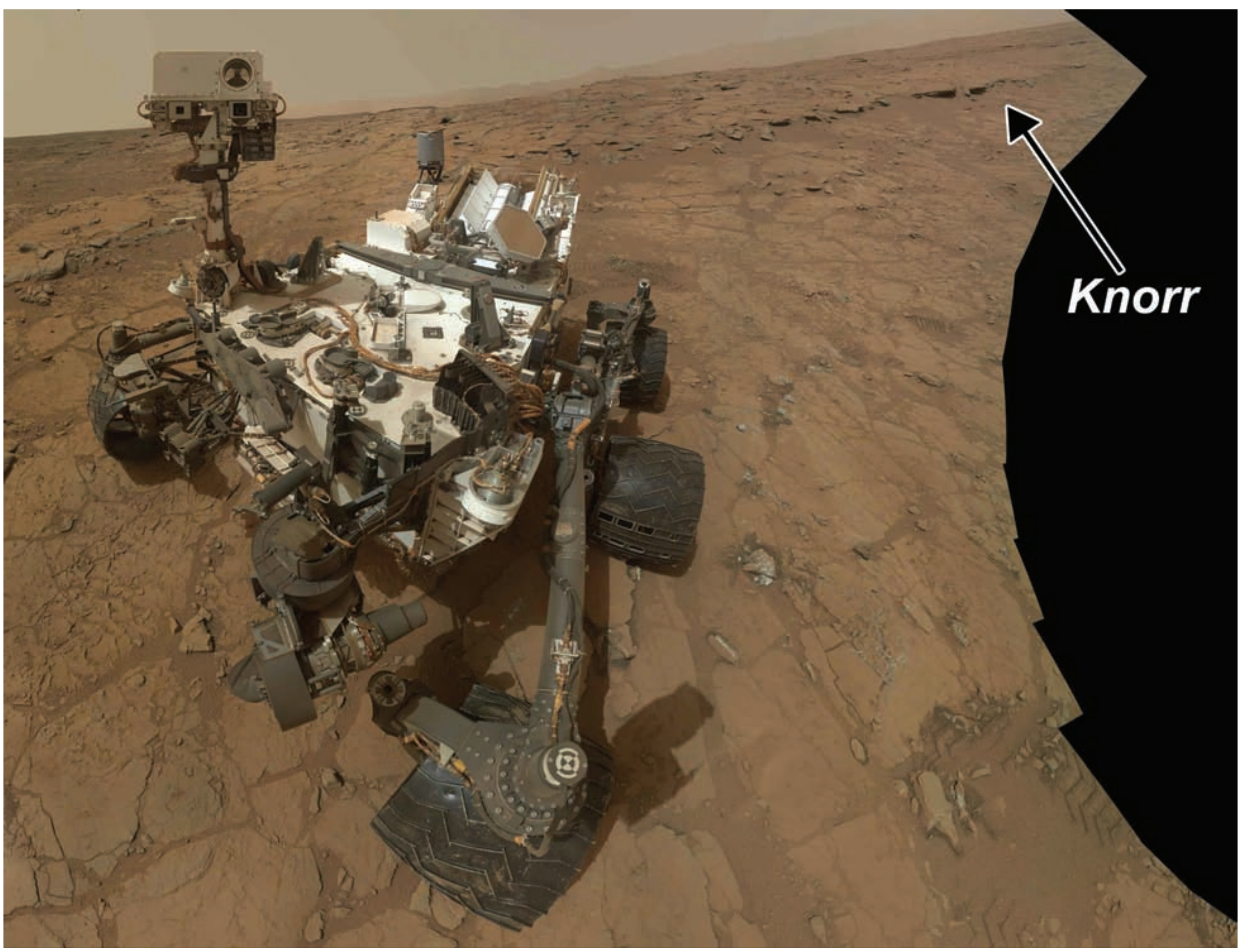
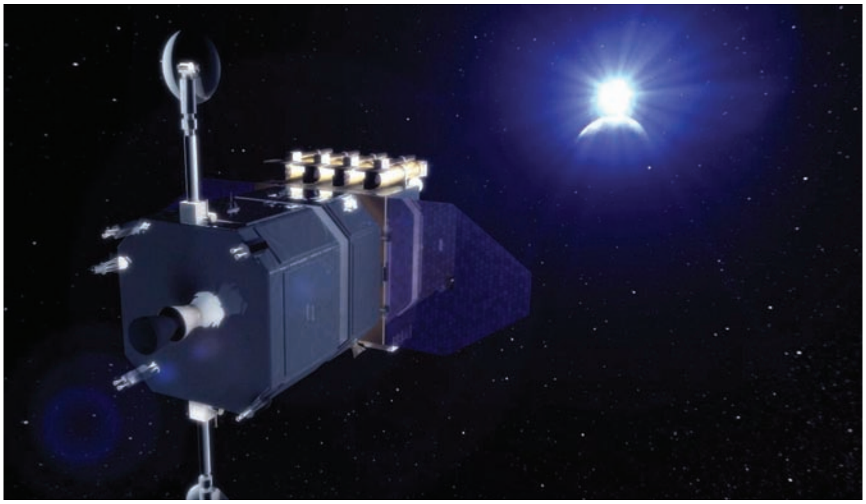


Curiosity, which uses the RAD750 flight processor, took this self-portrait while gathering spectral data of "Knorr," a rock in the background.

program manager for JPL's Information and Data Science Program and study leader.

By any standard, NASA's state-of-the-art is significantly less capable than what is available in most consumer products, added Wes Powell, a Goddard engineer who participated in the study and was instrumental in convincing the Agency to fund a technology-development effort.

"We have special requirements. Our flight needs are more extreme and our processors must be able to perform robustly in a radiation environment, using low power," Doyle said. As a result, both military and civilian mission planners must use specialized, vastly more expensive processors that have been hardened against radiation-induced upsets and generally have a higher degree of fault tolerance.



The Solar Dynamics Observatory, one of many NASA missions using the current state-of-the-art flight processor, studies solar atmospheric structures and magnetic fields from their emergence at the corona's surface.

Limits in the Current State-of-the-Art

The current state-of-the-art — the RAD750 — is a single-board computer manufactured by BAE Systems Electronic Solutions. Specifically designed to operate in high-radiation environments like those encountered in space, BAE released the technology in 2001 as the successor to the RAD6000. As of 2010, the RAD750 had become de rigueur for a broad range of space missions, including the Curiosity rover, the Solar Dynamics Observatory, and the Fermi Gamma-Ray Telescope, among others.

Though it's hardened against radiation-induced upsets and uses only five watts of power — another important performance requirement in energy-constrained spaceflight missions — the RAD750 computes only 200 million operations per second.

To get around these computational limitations, mission designers are implementing highly customized processors featuring more powerful, radiation-hardened field programmable gate arrays (FPGAs), which are capable of implementing application-specific processing circuitry (see related story, page 6). While these custom-designed processing solutions handle heavier data loads, they can be difficult and time consuming to program, and aren't as power efficient for general- purpose processing, Powell said.

What NASA needs is an energy-efficient general-purpose processor capable of billions of operations per second, thereby making it applicable to most missions, he added. "The bottom line is that while the RAD750 has been very successful, it is generations behind the current state-of-the-art."

Baselines Multi-Core Technology

In addition to establishing the rationale for a technology investment, the team surveyed six different architectures and decided that multi-core processing satisfied NASA's objectives. With multi-core technology, a single physical processor contains the core logic of several processors, which are packaged into a single integrated circuit. Multi-core technology is used in desktops, mobile PCs, servers and workstations, and allows the system to perform more tasks and scale its energy consumption, depending on what is needed at the time.

This isn't to say that the effort won't face challenges, Powell said. "The key challenges are processing throughput, radiation and fault tolerance, power efficiency, and the ability to broadly scale power and performance, using no more than seven watts."

The time for change, however, is now, he added. "We need a significant increase in performance and power efficiency. A small incremental improvement won't justify the investment. The development of a spaceflight multi-core processor will provide transformational improvements in onboard processing for NASA's future missions." ❖

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Mission Breaks Records; Scientists Go Back for More

Super-TIGER Team Begins Planning Next Antarctic Balloon Mission

Just a few weeks after a leviathan-size scientific balloon spent a record 55 days, one hour, and 34 minutes floating over the South Pole, scientists who developed the balloon's payload have begun planning a new series of flights that could reveal even greater insights into where heavy elements are produced and how they are accelerated to cosmic-ray energies at velocities approaching the speed of light.

And if they're lucky, they may even break more flight records.

Before tackling the next challenge, however, they must first recover the hefty 4,000-pound, SUV-size Super-TIGER instrument that landed about 1,000 miles away from the McMurdo Station when the launch team ended the mission February 1. The payload, which stands for Super Trans-Iron Galactic Element Recorder, gathered more than 50 million cosmic rays during its nearly two-month sojourn 127,000 feet above Antarctica.

Data Analysis Begins

"We have begun analyzing the data and the resolution of individual elements is excellent," said John Mitchell, a Goddard scientist who is participating in the mission led by Bob Binns, a professor at the Washington University in St. Louis, Missouri.

Super-TIGER is four times larger than its predecessor, which first flew in 2001 and 2003. It, too, measured heavy elements — those heavier than iron — among the flux of high-energy cosmic rays that bombard Earth. However, Super-TIGER extended those measurements to even heavier elements.

As confirmed by NASA's Fermi mission recently, the expanding debris of exploded stars produces high-energy cosmic rays, which are subatomic particles that move through space at nearly the speed of light. About 90 percent are protons, with

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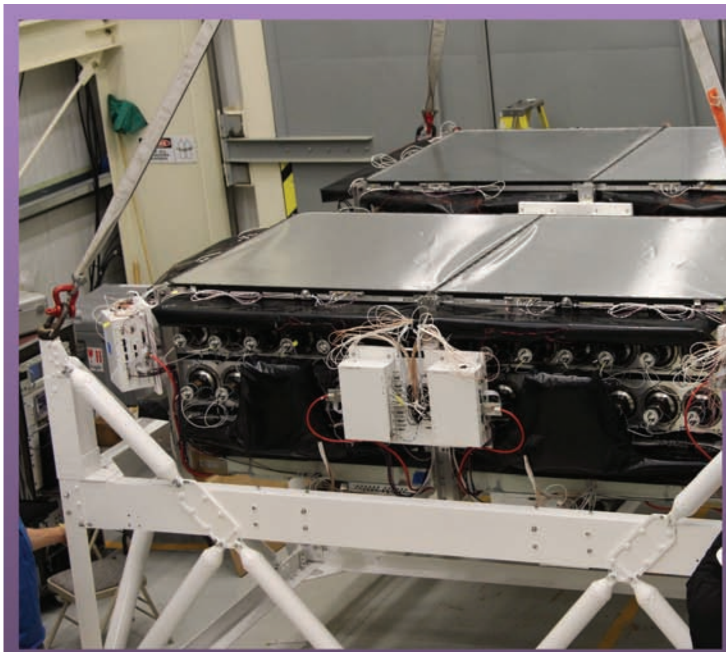
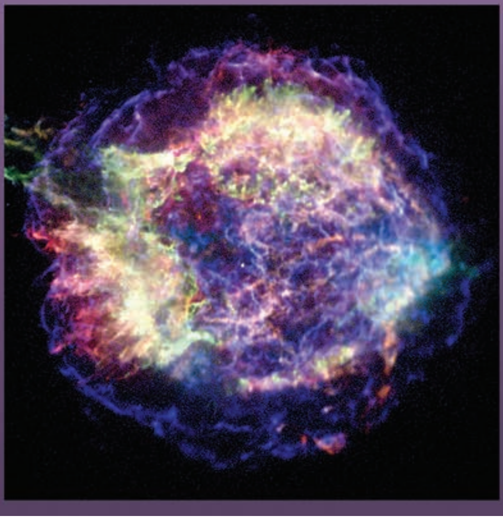
This photo was taken before scientists launched the Super-TIGER balloon payload that observed more than 50 million cosmic rays during its nearly two-month sojourn 127,000 feet above Antarctica.





Above: Super-TIGER is four times larger than its predecessor, which first flew in 2001 and 2003. It, too, measured heavy elements — those heavier than iron — among the flux of high-energy cosmic rays that bombard Earth. Super-TIGER, however, extended those measurements to even heavier elements.

Right: This Chandra image shows Cassiopeia A, the youngest known supernova remnant in the Milky Way. As confirmed by NASA's Fermi mission recently, the expanding debris disks of exploded stars produce high-energy cosmic rays — an object of interest to Goddard's Super-TIGER team.

the remainder consisting of heavier atomic nuclei, along with a much smaller percentage of electrons and antiparticles, antiprotons, and positrons. It is the nuclei — particularly heavy nuclei — that interest the Super-TIGER team.

Knowing their abundances will help scientists determine the type of star that produced them and where those stars were located, Mitchell explained. "Everything in the periodic table was produced in stars or by interactions of the nuclei made in stars with the interstellar gas," he said. As a result of Super-TIGER, "we expect to have very good statistics for all elements from neon up to molybdenum and to have some elements up to barium or even into the rare-Earth range of atomic number charge of 57 and above," he added.

The data, he said, also will reveal whether interstellar gas or dust grains pick up the particles and accelerate them to a near speed-of-light pace across the cosmos.

In addition to analyzing the data, the team is planning a follow-on flight in 2015. This time, however, the payload will carry more advanced instrumentation that will be able to precisely measure even heavier elements. "The goal of understanding where heavy elements are synthesized remains the same, but we intend to extend our reach."

Whether the next mission shatters flight records remains to be seen. "We had planned for two 30-day missions and we nearly got that in just one flight" — a happy occurrence made possible by the stratospheric, anti-cyclonic wind pattern circulating from east to west around the South Pole, Mitchell said.

The team cut down the massive 40-million-cubic foot balloon because the winds that kept it aloft had become more chaotic. Because NASA's balloon program had planned for a shorter-duration flight, it had equipped the system used to cut open the balloon at the end of the mission with a battery rated for only 60 days. As a result, the mission team terminated the mission over a part of Antarctica where it could reliably recover the payload.

Next time, however, Mitchell said he's preparing for a longer flight. "We'll set our sights higher." ❖

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Next-Generation Navigator Gets Smaller and Stronger

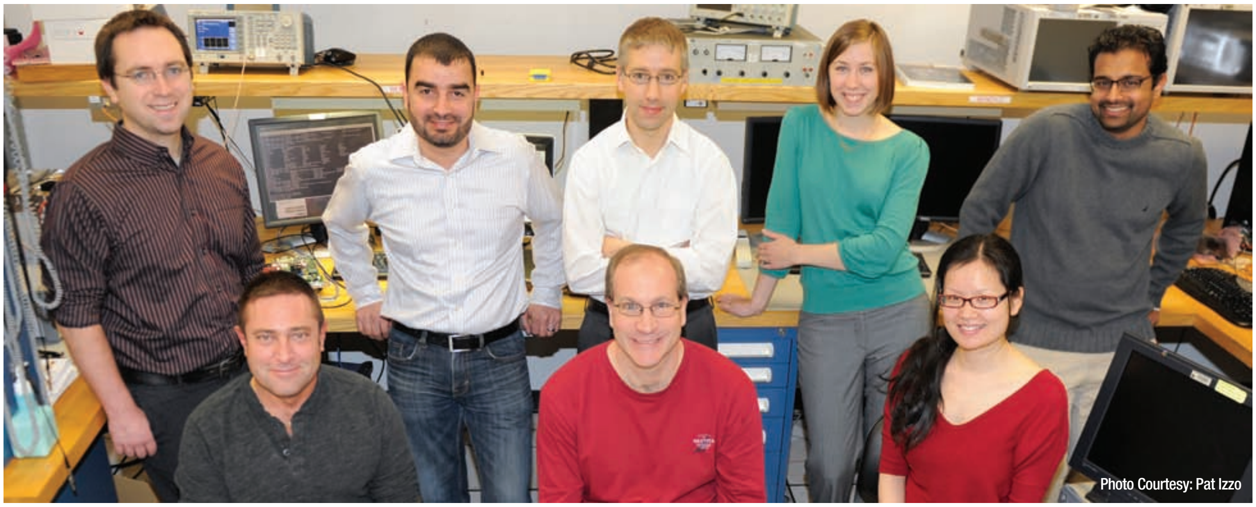

Photo Courtesy: Pat Izzo

A Goddard team is making the Navigator GPS receiver smaller and more capable. Team members include (back row, left to right): Sam Price, Monther Hasouneh, Luke Winternitz, Jennifer Valdez, Luke Thomas; (front row, left to right): Tony Marzullo, Harry Stello, Annie Chen.

Goddard's homegrown Navigator GPS receiver already has proven its mettle at detecting, acquiring, and tracking faint GPS signals, earning berths on major NASA science missions and on the product list of a commercial aerospace company. Now, Navigator is getting smaller and more capable.

The first-generation Navigator receiver, which an Arizona-based aerospace company has licensed for commercial development, was comparably large and easily accommodated on such flagship missions as NASA's Global Precipitation Measurement and Magnetospheric Multiscale missions.

However, with the trend toward smaller-size missions and demand for more capabilities, the Navigator team received Goddard Internal Research and Development program funding to modernize Navigator by adding new GPS signal capabilities, reducing its size, and enhancing its sensitivity to improve overall performance.

"We want to have Navigator available for other missions, so we needed to make it highly capable, smaller in size, and more affordable," said Monther Hasouneh, a senior navigation engineer for Goddard's Component and Hardware Systems Branch.

The current-generation Navigator is not easily expanded. That's why the development team wanted to enhance the technology and make it available to a broader range of missions, including smaller satellites, he added.

To that end, the Navigator team is testing the marriage of Navigator to another Goddard-developed technology, the SpaceCube flight processor. SpaceCube is 10 to 100 times faster than the current state-of-the-art flight processor, providing this data-processing prowess in a small package.

The potential addition of a GPS capability to SpaceCube would significantly expand its range of applications, said Tom Flatley, SpaceCube principal investigator and the recipient of this year's American Astroanautical Society's William Randolph Lovelace II Award (see related story, page 4).

"The SpaceCube's ample processing resources also will enable work we have been doing on an advanced GPS receiver antenna array that would provide sensitivity and better performance against interference," said Luke Winternitz, a lead engineer for the Navigator research program. The added signal capability would allow for more accurate measurements, he said.

In addition, the team is expanding Navigator's scope. Ongoing GPS system-modernization efforts are making new GPS signals available. Navigator currently receives only the legacy civilian signal, but the team is planning to include all modernized civilian signals, including those at new broadcast frequencies. ❖

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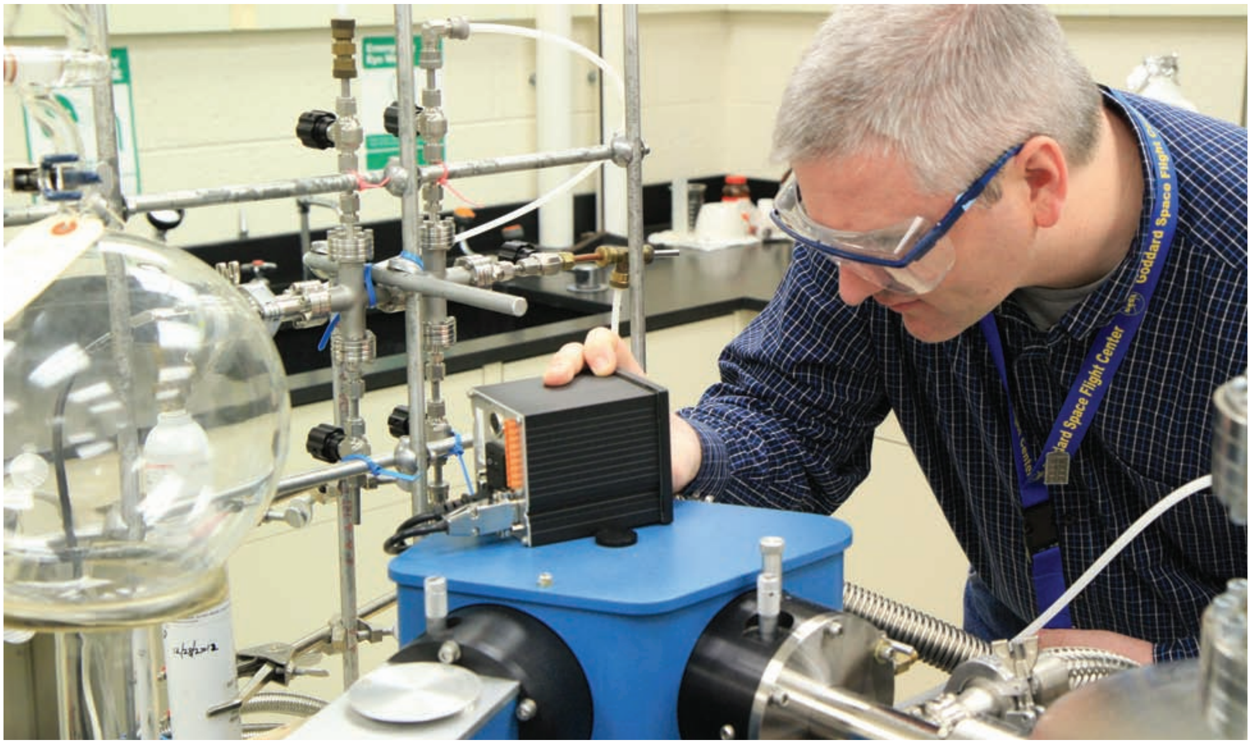
Goddard Lab Works at Extreme Edge of Cosmic Ice



Perry Gerakines uses a spectrometer to measure how much far-ultraviolet light an ice sample absorbs.

Behind locked doors, in a lab built like a bomb shelter, Perry Gerakines makes something ordinary yet truly alien: ice.

This isn't the ice of snowflakes or ice cubes, either. This particular ice needs intense cold and low pressure to form — conditions that rarely, if ever, occur naturally on Earth. And when Gerakines makes the ice, he must keep the layer so microscopically thin it's dwarfed by a grain of pollen.

These ultra-thin layers turn out to be perfect for recreating some of the key chemistry that takes place in space — and a valuable material for testing next-generation space instruments designed to analyze complex organic material with a level of specificity available only with a well-equipped Earth-bound laboratory.

Goddard's Cosmic Ice Laboratory, supported in part by the Goddard Center for Astrobiology and the NASA Astrobiology Institute, is one of a few laboratories worldwide where researchers can recreate and study cosmic ice. With its powerful particle accelerator, the facility mimics all manner of solar or cosmic radiation, which drives reactions in ice, allowing researchers to study the chemistry of ice below the surface of planets and moons as well as ice in space.

Where it All Begins

Recreating this extraterrestrial product of nature begins in a vacuum chamber about the size of a lunchbox. Gerakines pumps out air until the pressure inside drops to a level a billion times lower than normal for Earth. He chills the chamber to minus 433 degrees Fahrenheit and then opens a valve to let in water vapor.

The instant vapor molecules enter the chamber they literally freeze in their tracks. Still pointing in every direction, the molecules transform immediately from their gaseous state into the disorderly solid called amorphous ice — the exact opposite of terrestrial ice, which forms perfect crystals. Left over from the age when the solar system was born, amorphous ice is so widespread in interstellar space that it could be the most common form of water in the universe. It is scattered across vast distances, often as particles no bigger than grains of dust. It's also been spotted in comets and icy moons.

Continued on page 15

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In pulsars, this phenomenon becomes especially interesting. Due to their rapid pulsations that range from seconds to milliseconds, the powerful beams of radiation emanating from the pulsars' magnetic poles sweep around much like a lighthouse. Therefore, they are seen as flashes of light on Earth.

Because of their predictable pulsations, pulsars can provide high-precision timing just like the atomic-clock signals supplied through the Global Positioning System (GPS), an Earth-centric system that weakens the farther one travels out beyond Earth orbit and into the Solar System, Arzoumanian said. "Pulsars, on the other hand, are accessible in virtually every conceivable flight regime, from low-Earth orbit to deepest space," Gendreau added.

X-Ray Navigation Demonstrated

As a result, NICER/SEXTANT also will demonstrate the viability of pulsar-based navigation. "The hardware needed for neutron-star science is identical to that needed for pulsar-based navigation," Gendreau said. "In fact, the mission's two goals share many of the same targets and the same operational concept. The differences are on the back end in terms of how the data will be used."

To demonstrate the viability of X-ray navigation, also known as XNAV, the NICER/SEXTANT payload will use its telescopes to detect X-ray photons within these powerful beams of light to estimate the arrival times of the pulses. With these measurements, the system will use specially developed algorithms to stitch together an on-board navigational solution.

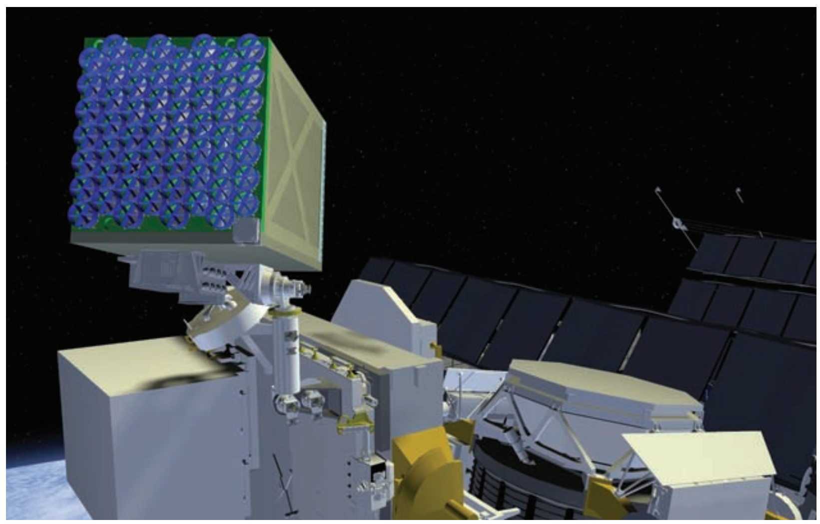
If an interplanetary mission were equipped with such a navigational device, it would be able to calculate its location autonomously, independent of NASA's Deep Space Network (DSN), Gendreau said. DSN, considered the most sensitive telecommunications system in the world, allows NASA to continuously observe and communicate with interplanetary spacecraft. However, DSN-supplied navigational solutions also degrade the farther one travels out into the Solar System. Furthermore, missions must share time on the network, Gendreau said.

X-ray Communications Possible

The second potentially revolutionary technology application NICER/SEXTANT could enable is the world's first X-ray communication system in space, with the potential to provide high data rates at low power over vast distances.

At the heart of this demonstration would be Goddard's Modulated X-ray Source (MXS), which turns on and off many times per second to encode digital bits for transmitting data. The technology currently is installed in a laboratory system designed to test the XNAV application (see related story, page 3).

However, MXS also could fly on an ISS supply spacecraft to demonstrate X-ray communications. As the craft approached the orbital outpost, MXS could transmit data via the modulated X-rays, which the NICER/SEXTANT hardware would then receive.



This artist's rendition shows the NICER/SEXTANT payload that NASA recently selected as its next Explorer Mission of Opportunity. The 56-telescope payload will fly on the International Space Station.

Gendreau said he plans to pursue additional funding to create flight-qualified hardware to demonstrate the next-generation communications technology, but for now funding only covers science and navigation.

"We're excited about NICER/SEXTANT's possibilities," Gendreau added. "The experiment meets critical science objectives and is a stepping-stone for technology applications that meet a variety of NASA needs." ❖

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Pulsar, *continued from page 3*

constellation simulators that make our GPS receivers think they are in orbit; we needed something analogous for an XNAV receiver."

In essence, the pulsar-on-a-table does just that.

It leverages several Goddard-developed navigation and orbit-determination software tools and specialized hardware to mimic a pulsar's spin rates, its location in the sky, the station's orbital parameters, and other considerations needed to simulate the environment and conditions that NICER/SEXTANT will encounter when formulating a navigational solution. "You can change a lot of the parameters in the testbed and add hardware in the loop, to perform a full suite of tests," Winternitz said. "We now have a way to take our mission concept and test it fully."

A central component of GXNLT is Goddard's Modulated X-ray Source, which produces X-ray photons with rapidly varying intensity, turning on and off many times per second to simulate the target star's pulsations. Each MXS-produced photon travels through a short channel and impinges on a silicon-drift detector, where it receives a time stamp. The photon events are grouped into batches and processed by algorithms to extract pulse-arrival time and Doppler measurements. A set of tools then uses these measurements to estimate the orbital outpost's position — all needed to ultimately formulate a navigational solution.

To ground-truth the calculations, the team will run comparisons with an onboard GPS receiver based on the Goddard-developed Navigator receiver (see related story, page 12). Experiments with the testbed have shown that NICER/SEXTANT, once deployed, will demonstrate real-time calculations with sub-kilometer accuracy, Winternitz said.

"The whole point is to test as you fly," Mitchell added. "This enables that." ❖

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Cosmic Ice, *continued from page 13*

The super-thin ice also can be spiked with chemicals found in space, including amino acids, which are key players in the chemistry of life on Earth. "Because water is the dominant form of frozen material in the interstellar medium and outer solar system, any amino acids out there are probably in contact with water at some point," Gerakines said.

But the real action begins when Gerakines hits the ice with radiation.

Although other researchers use ultraviolet light, Gerakines zaps his samples with cosmic radiation, which can reach ice hidden below the surface of a planet or moon. To mimic this radiation, he uses a proton beam from the high-voltage particle accelerator that resides in an underground room.

With the proton beam, a million years' worth of damage can be reproduced in just half an hour. By adjusting the radiation dose, Gerakines can treat the ice as if it were lying exposed or buried on comets or icy moons and planets.

"We find that some amino acids could survive tens to hundreds of millions of years in ice near the surface of Pluto or Mars and buried at least a centimeter (less than half an inch) deep in places like the comets of the outer solar system," Gerakines said. "For a place that gets heavy radiation, like Europa, they would need to be buried a few feet."

His findings are good news to Principal Investigator Stephanie Getty. She has used the laboratory's amorphous ice to expand the capabilities of a prototype two-step tandem mass spectrometer. The next-generation instrument is designed to detect non-volatile organics in complex mixtures, like those found in meteorites, and then determine the structure of selected molecules found in the sample (*CuttingEdge,* Summer 2012, Page 5).

She also thinks that the compounds made in Gerakines's experiments could be useful in future testing of the Organics Analyzer for Sampling Icy Surfaces, an evolving miniaturized liquid chromatograph-mass spectrometer that would hunt for organic molecules, including amino acids, on the icy moons of the outer planets, asteroids, and Kuiper Belt Objects (*CuttingEdge,* Fall 2012, Page 3).

"A lot of our focus has been on analyzing samples that you might find on Mars, but we also need an analogue for icy surface materials since our instruments are applicable to those studies," she explained. "This material fits the bill." ❖

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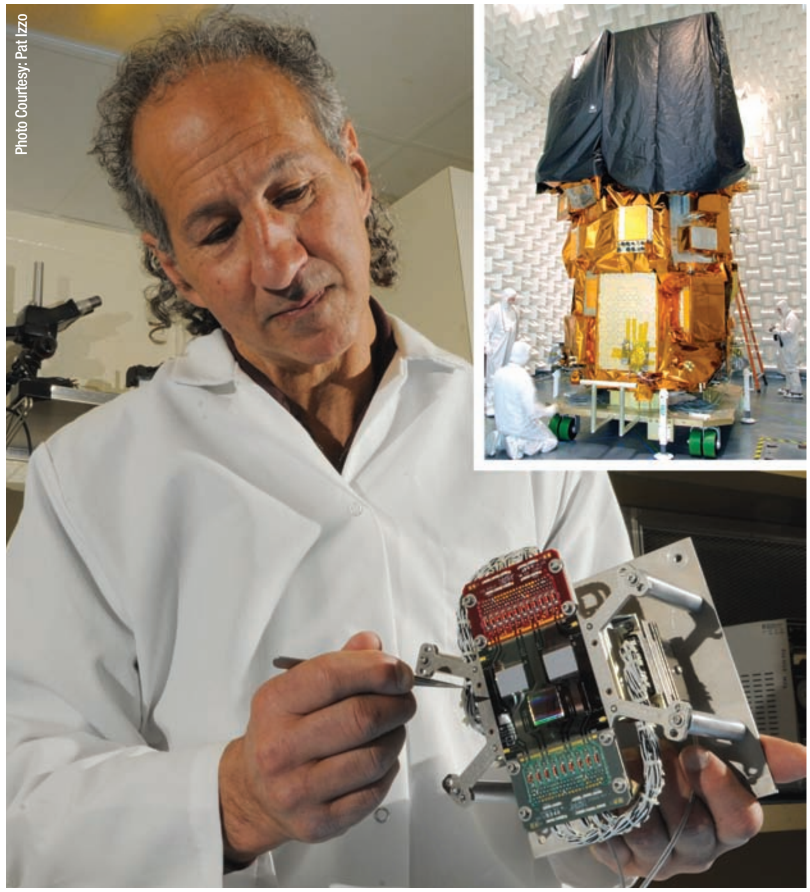
The Heat is On: QWIP Arrays Make Debut

Charting vegetation and environmental impacts from the sky is a tall order, but a years-in-the-making Goddard-developed focal-plane detector technology has shown it's up to the challenge.



Murzy Jhabvala is shown here with the backup QWIP focal-plane assembly, which he created for an instrument flying on the Landsat Data Continuity Mission (inset).

The Quantum Well Infrared Photodetector (QWIP), which made its spaceflight debut on the Landsat Data Continuity Mission's (LDCM) Thermal Infrared Sensor (TIRS), is detecting infrared wavelengths in two thermal bands to monitor the ebb and flow of land-surface moisture levels and the health of vegetation, among other tasks. NASA and the U.S. Geological Survey jointly manage LDCM, which the space agency launched in February.

First images indicate that the results are spot on, said TIRS Instrument Scientist Dennis Reuter. "With TIRS, every spot on the ground has its own detector. Because the QWIP arrays are very uniform, our task is so much easier," he said.

The QWIP-development effort, which began more than 20 years ago with support from Goddard and NASA research and development funding, has come a long way. "Back in 1989, we had just one single element. Since then, our arrays have grown from a few hundred to a few thousand elements, and now we're up to four million," said Murzy Jhabvala, QWIP principal investigator.

The model flying on TIRS is outfitted with three precisely aligned detector arrays containing more than 900,000 pixels. Each individual pixel covers 328 feet by 328 feet of the Earth's surface from a view 435 miles above the planet's surface. Each image covers a swath measuring about 115 miles wide.

Now that the QWIP technology is flight-proven, Earth scientists are eyeing next-generation QWIP arrays for advanced instrumentation, Jhabvala said. "Right now we are looking at 100 meters (328 feet) of Earth per pixel. We would like to look at 60 meters (197 feet) or fewer per pixel, providing better resolution and revealing more detail. We also would like to cover a much wider ground swath per image. Our next generation of QWIPs will allow new instruments to address both these issues." ❖

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Cutting edge Goddard's Emerging Technologies

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