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Cutting edge

Goddard's Emerging Technologies

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Innovating at Home

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Innovating at Home

Goddard Technologists Break Ground Despite Quarantine

Life can throw curveballs, but many Goddard scientists and engineers didn't let a worldwide pandemic and quarantine impede their progress advancing technologies NASA would need once the threat passed.

"I think I had a greater sense of urgency than most of my colleagues," said physicist Anne-Marie Novo-Gradac. "I started to think hard about what work I could do at home." She realized that Covid-19 could create challenges in her work developing and testing a relative position sensor for formation-flying satellites — work that normally would have required a large optical testbed and Goddard's integration and testing facilities. "I knew we were likely to be stuck teleworking a long time."

"Her story, like many others playing out in Goddard engineers' and technologists' garages, home offices, basements and family rooms, is one of innovation under pressure," said Goddard Chief Technologist Peter Hughes. "Goddard innovators have had to re-engineer their work-life balance, adapting to limited bench space in improvised labs, while testing the flexibility of the IRAD (Internal Research and Development) and other programs that fund their efforts. Their efforts have been heroic."

Novo-Gradac's IRAD-funded project involves measuring millimeter and micrometer-scale variations in a 100-meter-long laser light path. It would support two SmallSat-sized spacecraft flying in a precise formation. One would carry a lens and the other an optical receiver, thereby allowing a much longer focal length than what could be achieved with a single spacecraft. However, the two could not drift out of alignment by more than a millimeter in the 100-meter focal length or 10 to 20 microns – a fraction of the width of a human hair – side-to-side.

To carry out her work, she and her team developed a large and complex optical bench using multiple reflectors to achieve the desired range.

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About the Cover

Anne-Marie Novo-Gradac transformed her family room into an optics lab bench. During NASA's work-from-home order, she and other Goddard innovators sought and created silver linings, re-engineering their work and home lives, conscripting family to take pictures, and demonstrating the spark of ingenuity that can shine through adversity. This summer edition of *CutttingEdge* looks at a few of their efforts.

(Photo Credit: Kevin J. Novo-Gradac)

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Flexibility is Crucial

"Even though the funding hadn't been approved at the time, there was another concept I could work on at home," Novo-Gradac said. It involved designing and validating a wedge-shaped, 3D optical target for measuring precise drift of the other spacecraft flying in formation. "I don't need 100 meters of range to validate that technology. I can do it on a small bench at home."

While she continues to make purchases and design parts on a computer for the original project, the IRAD program agreed to shift most of her funding and labor to the second, mid-year IRAD request for now.

"I had to bring home about 10 different instruments," Novo-Gradac said. "My family room had a perfect countertop with an upper deck. Other than having to haul home all that equipment, the experiment was a very manageable thing to bring home."

Turning on a Penny

Like Novo-Gradac, Ian Adams is accustomed to working outside the box. His main IRAD project involves developing "off-road" uses of radar systems that enable self-driving automobiles. Integrated into a chip the size of a penny in a two- to three-inch platform, these radars will likely need bigger antennas to achieve the sensitivity his team needs to measure raindrops.

His first-year IRAD provides resources to characterize and to adapt the system to not only measure precipitation on Earth, but also methane precipitation on Saturn's moon Titan — an application that interests his co-principal investigator, planetary scientist Carrie Anderson. It could also be fine-tuned for use in self-driving rovers on the Moon, Mars, and beyond.

"There's obviously a bit of desk work that goes along with this," Adams said, but working at a home office is not the same. "Having to take care of kids and such is a challenge that goes along with this. Hardware and space are also a challenge when setting up a home lab. You need space to work with these things."

His six-person team also adapted to video conference calls while dividing tasks between desk work and his colleague's home workshop.

Also like Novo-Gradac, Adams asked for flexibility on a second-year IRAD: building a large airborne sensor — CoSSIR, which stands for Configurable Scanning Submillimeter Instrument/Radiometer — to measure clouds in 3D.

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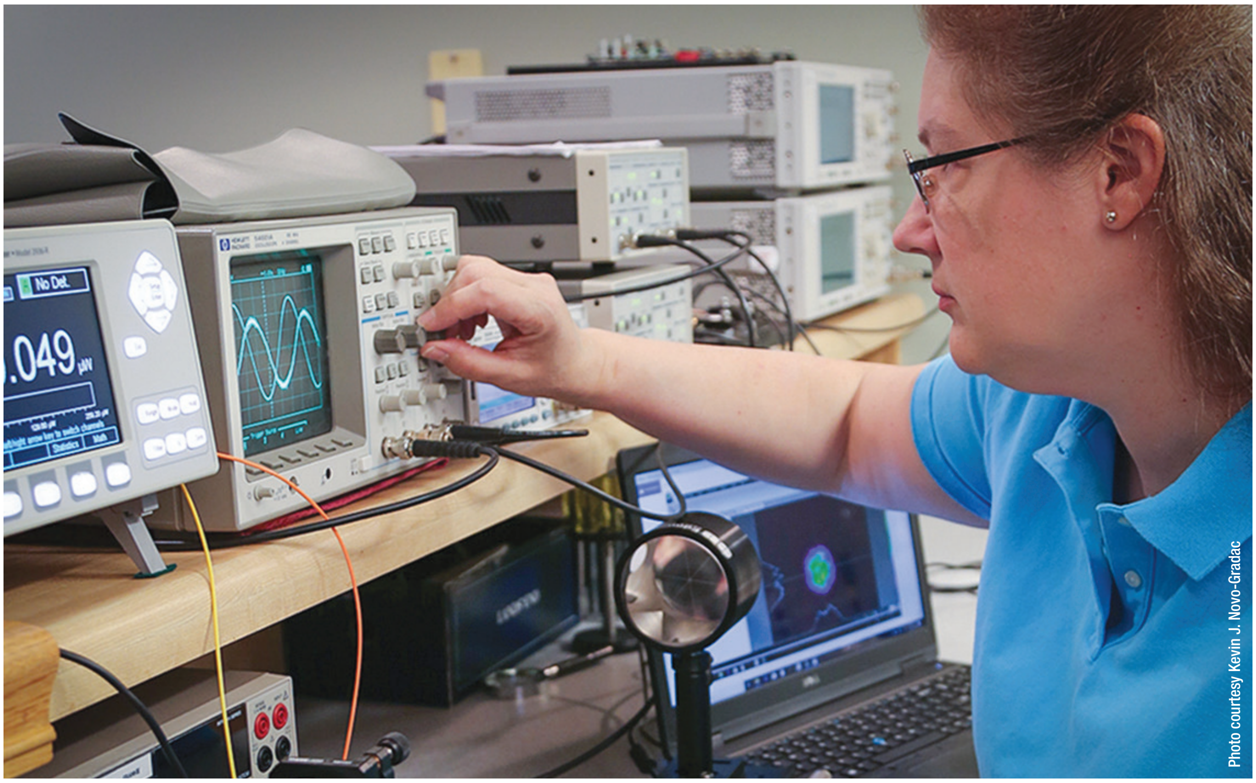

Photo courtesy Kevin J. Novo-Gradac

This home workbench, adapted from a serving space in Anne-Marie Novo-Gradac's family room, has an ideal second level to hold instruments and monitors for her project.

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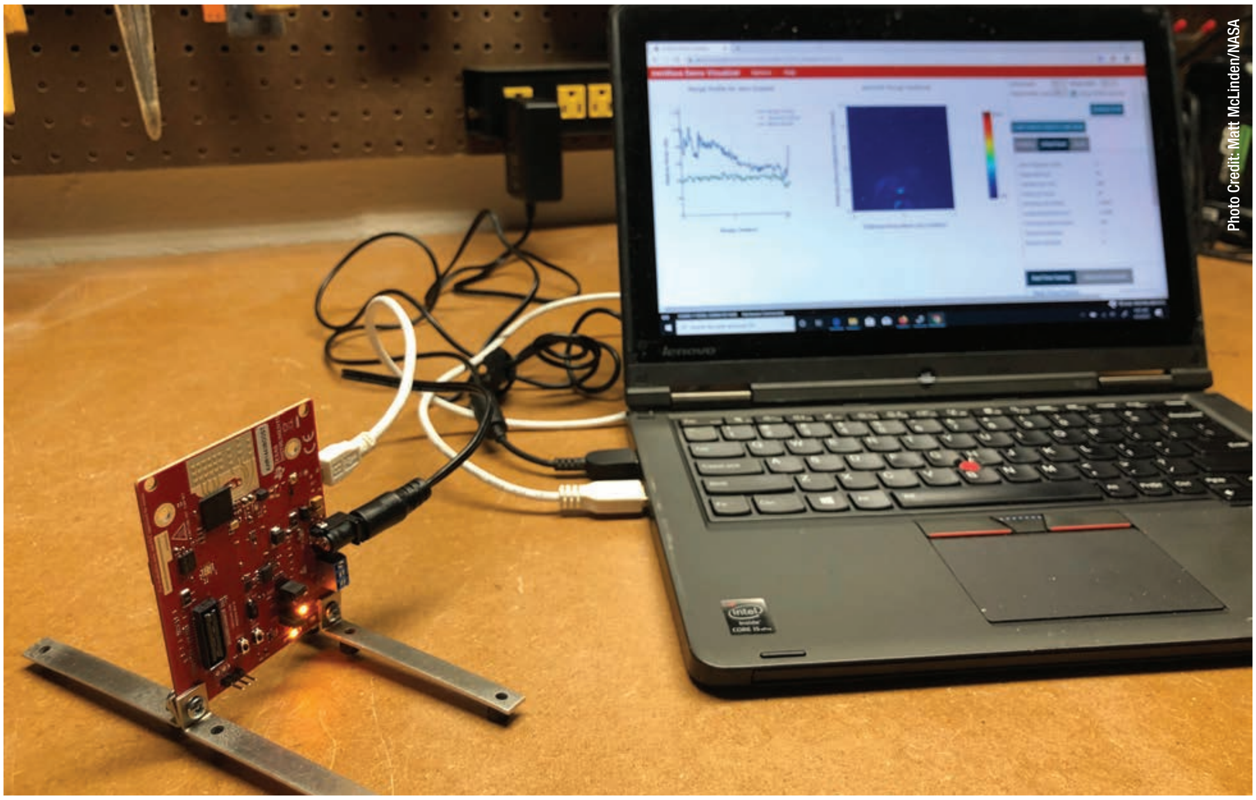

Matt McLinden cleared space in his home workshop to continue working on analyzing automotive radars in partnership with Ian Adams. They plan to repurpose the off-the-shelf technology to measure precipitation on Earth and possibly other planets and moons.

NASA selected CoSSIR to fly on the Earth Resource 2 (ER-2) science aircraft. ER-2 flies at 70,000 feet, an altitude that allows scientists to simulate the power of satellite observations. "We can get over the highest thunderstorms with that aircraft and get a really good view of weather events," Adams said.

Particularly, he and his team want to adapt the imager to do tomography — cross sections of clouds.

"It's getting to the point where all there is left to do is hardware work," Adams said, adding that flexibility from IRAD and the Earth science team were crucial to his team's progress. "We can't do that outside of the lab. We've adapted as well as we can."

A Lucky Friday the 13th

Having heard rumors of a potential work-at-home order in late February, Integrated Design Center (IDC) Manager Jennifer Bracken and her team jumped into action. In just a few weeks, they assembled all the virtual tools her team would need to collaboratively execute detailed mission and instrument design studies from their homes — efforts that would normally occur in large conference rooms configured for face-to-face interactions and decision making.

"I receive copies of management council notes and our center managers had been discussing the possibility of mandatory telework for a couple of weeks. I told our team that we needed to be prepared for this," said Bracken, whose organization operates two state-of-the-art labs that offer conceptual end-to-end analyses of mission and instrument concepts — insights that help her customers prepare successful mission and instrument proposals.

She and her team didn't miss a beat. On Friday, March 13 — just three days before NASA ordered all employees to work from home — her team carried out a trial run using Cisco WebEx, NASA's VPN, and Microsoft Teams virtual meetings to determine if they could carry out studies in a completely virtual environment.

Friday, the 13th proved to be a lucky day: "We assured ourselves we could do it," Bracken said.

Three days later, the team launched its first completely virtual study. "We had very little time to prepare for these circumstances," said Justin Jones, the principal investigator of an X-ray Computed Tomography instrument concept. While challenging due to the number of multiple teleconferences

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Jennifer Bracken, manager of Goddard's Integrated Design Center, manages detailed mission and instrument design studies from her home.

running in parallel, Bracken's team "did a superb job of maintaining a schedule and juggling the technical hurdles associated with coordinating 20 to 30 folks remotely," he said.

Other than for one study that needed to be delayed for reasons unrelated to the pandemic, Bracken said her organization has remained on schedule. The Instrument Design Lab has carried out five studies, while the Mission Design Lab has completed four as of the end of June. Other studies are planned for July and August as well as into the new fiscal year.

"We couldn't envision how this would work out," Bracken said, now with a handful of studies successfully executed under her belt. "But it's gone well. I believe our customers are grateful for their data products."

Uncertainty About the Future

What happens next remains to be seen. Innovating at home is one thing, but Goddard technologists also spoke about the uncertainty of not knowing how long work-from-home protocols would be in place. They also recognized that priority will go to flight-level projects once Goddard's more spacious and well-equipped labs open again.

"We understand we're probably going to be like this for a while," Adams said. "We need to come up with a plan that makes the most sense to move forward." ❖

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Heeding the Call

Goddard-Provided Instruments to be Among the First to Fly on Gateway

When NASA issued a call for fast-turnaround instruments that would be among the first to fly on its orbital outpost, Gateway, Goddard scientists responded and were rewarded mightily for their efforts.

Of the four individual instruments that will make up a space weather instrument suite to be integrated onto Gateway's power and propulsion module, Goddard heliophysicists will provide three. The University of California-Berkeley will provide the fourth.

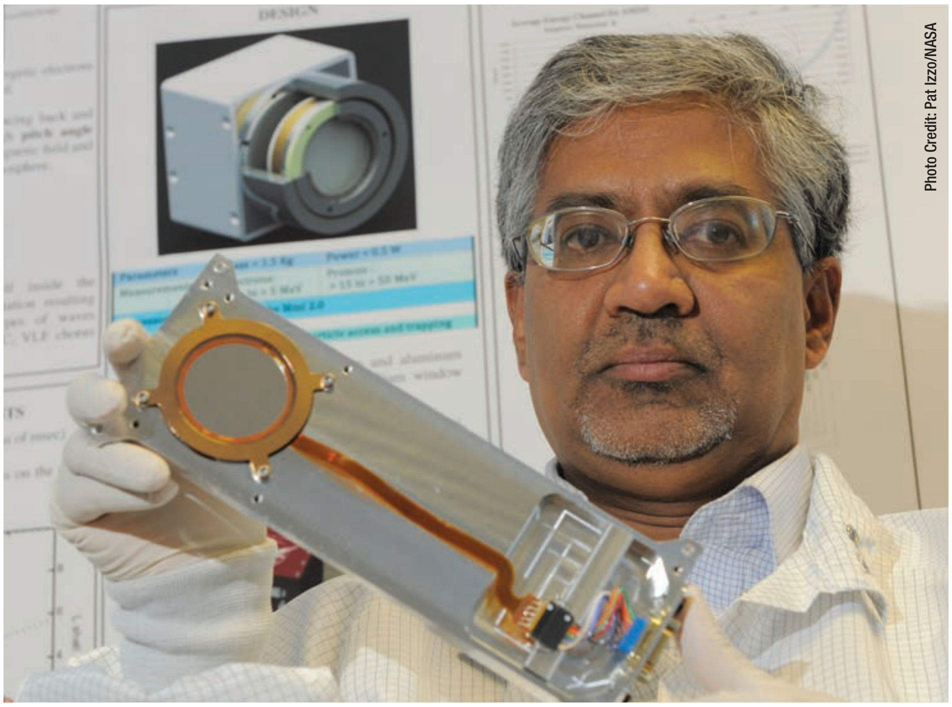

Photo Credit: Pat Izzo/NASA

Shri Kanekal holds a very early version of a detector that he further modified for the Miniaturized Electron pRoton Telescope, one of the instruments that will fly on NASA's Gateway.

As NASA moves deeper into space, human and robotic explorers will face greater challenges from the Sun's sometimes violent and unpredictable outbursts. Together, these instruments will observe solar particles and solar wind and gather data that will help scientists forecast events that could affect astronauts operating on and around the Moon.

Stepping Stone to Mars

As part of NASA's plans to create a sustainable presence on the Moon and pave the way for human exploration of Mars, astronauts will periodically occupy Gateway. The agency will deploy the facility in a near-rectilinear halo orbit, which follows a highly eccentric path. At its closest, Gateway will pass 1,864 miles (3,000 kilometers) from the lunar surface and at its most distant, 43,496 miles (70,000 kilometers).

In 2019, NASA competitively awarded Maxar Technologies a contract to develop Gateway's power and propulsion module, currently planned to launch on a commercial launch vehicle in 2023. The agency is negotiating with Northrop Grumman to build the habitation and logistics outpost.

In addition to selecting the space weather instrument suite — referred to as Gateway HERMES, which is short for the Heliophysics Environmental and Radiation Measurement Experiment — NASA selected a radiation package built by the European Space Agency. It will monitor radiation to gain a more complete understanding of cosmic and solar rays, and more particularly how to keep astronauts safe in Gateway's unique orbit.

Proud to Support

"We're proud to support NASA's efforts to return to the Moon," said Steven Christe, a Goddard heliophysicist who led the center's response to NASA's request for Gateway instruments. "All of our instruments have been supported through Goddard's IRAD (Internal Research and Development) program, which is the reason these instruments exist in the first place."

Furthermore, all have flight heritage and are small, adding to their attractiveness to NASA decision-makers, Christe added.

MERiT

For instance, the Miniaturized Electron pRoton Telescope (MERiT), created by Principal Investigator

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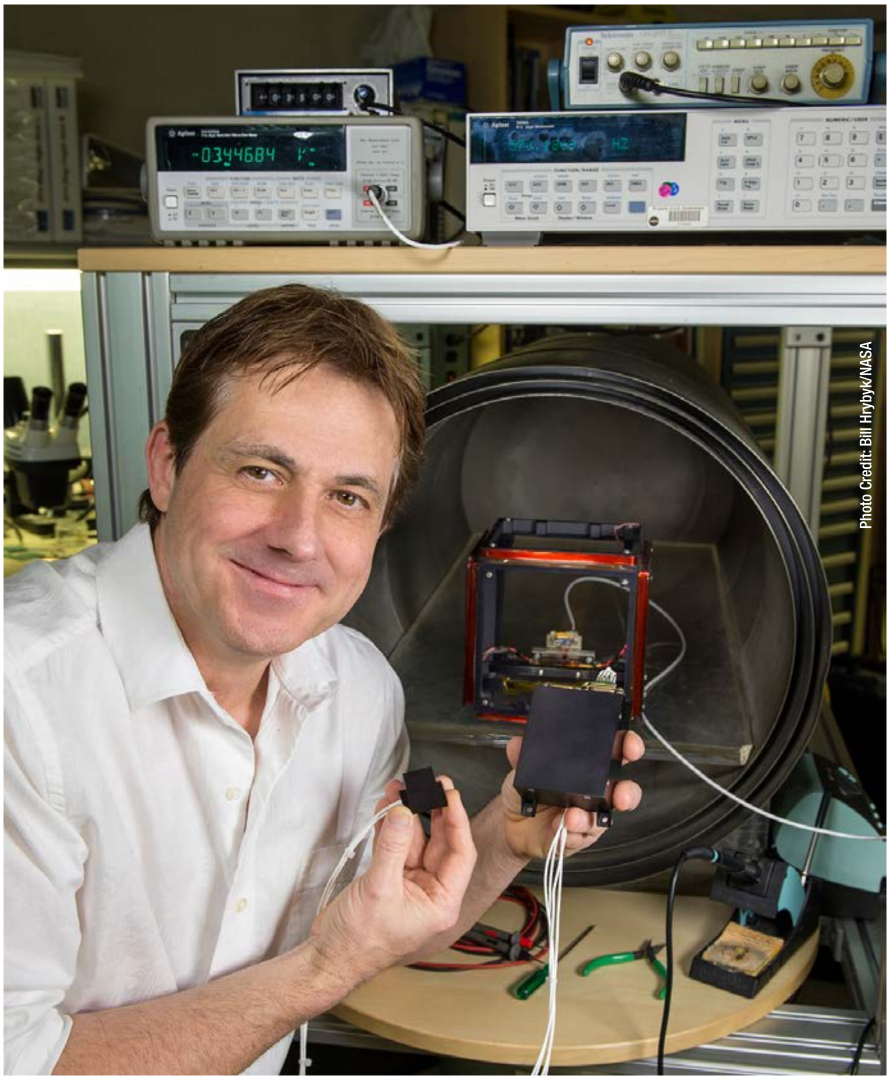
Shri Kanekal, is one of three instruments to fly on a future spacecraft called the CubeSat mission to study Solar Particles (CuSP). This instrument traces its heritage to a similar sensor that Kanekal originally flew on the Compact Radiation Belt Explorer (CeREs) mission (*CuttingEdge*, Spring 2014, Page 8).

According to Kanekal, the HERMES MERiT will study processes in the inner heliosphere that affect solar electrons and protons as well as energetic electrons in Earth's radiation belts. Because energetic particles adversely affect spacecraft and are a hazard to humans in space, NASA needs to measure and characterize them.

"It is gratifying to know that the measurements to be made by MERiT will not only help science, but also contribute to the safety of our astronauts in space," Kanekal said.



Todd Bonalsky holds a miniaturized fluxgate magnetometer that he and colleague Eftyhia Zesta developed originally for CubeSat missions. It will be among the first instruments to fly on NASA's Gateway.

Fluxgate and Magneto-Inductive Magnetometers

Principal Investigator Efthyia Zesta and her team, which includes the University of Michigan, will provide a set of three miniaturized three-axis magnetometer sensors to study the structures that form within the solar wind before they collide with Earth as well as the distant magnetotail that extends past the Moon.

The IRAD-supported fluxgate magnetometer, which Goddard flew previously on the Dellingr spacecraft, will be positioned at the end of a boom — as far away as possible from the magnetic noise generated by the Gateway's power and propulsion module. From this location, it will measure variations in the background magnetic field. Two university-provided magneto-inductive sensors, which are smaller than even the fluxgate sensor, will be mounted on Gateway's HERMES platform to detect and subtract magnetic noise generated by the power and propulsion module itself.

"The whole point is to understand the magnetic environment around the Gateway," Zesta said. "Electrons and ions can damage instruments and pose health threats to humans. The instruments that will measure these damaging particles need to know where the magnetic field is in terms of its orientation and magnitude, and we will be providing that. It's exciting to finally see the fruits of our long efforts through IRAD developments. We are, I believe, a poster child for our IRAD program."

Electron Electrostatic Analyzer

The Electron Electrostatic Analyzer (EEA) builds on the development of the Dual Electron Spectrometer instruments, which are currently flying on NASA's Magnetospheric Multiscale mission as part of the Fast Plasma Investigation suite. Miniaturized versions of EEA's components have been

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Goddard Performs Well in Explorer Program Competition

Goddard astrophysicists and engineers fared well in NASA's recent selection of potential Explorer-class missions, participating in three of the four teams chosen to further flesh out their concepts with Phase-A funding.

"I'm pleased with Goddard's performance in the competition," said Keith Jahoda, the chief technologist for the center's Astrophysics Division. "We are leading one mission and contributing important technologies and capabilities to two others. Many of these technologies trace their heritage to Goddard's Internal Research and Development program — a fact that testifies to its strength and value to our community."

From these competitively selected proposals, NASA is expected to choose one full Small Explorer (SMEX) mission and one or two Missions of Opportunity (MO) by the end of 2021.

"Regardless of which team wins, Goddard will have a role in at least one of NASA's next Missions of Opportunity targeted for a 2025 launch," Jahoda added.

Dorado: Filling a Critical Gap

Dorado, formerly known as GUCI, is an MO led by Goddard scientist Brad Cenko. It's expected to fill a critical gap in the emerging field of multi-messenger astrophysics. This new discipline involves the coordinated observation of a cosmological event using different signals, including electromagnetic radiation, gravitational waves, neutrinos, and cosmic rays. By merging data gathered by both ground- and space-based observatories, all focused on the same target, scientists can get a more complete view of the high-energy universe.

Scientists demonstrated the value of multi-messenger astrophysics in 2017 when more than 70 telescopes and observatories operating across the entire spectrum trained their sights on the merger of two neutron stars in the constellation Hydra — an event known as GW170817.

This first-ever coordinated measurement wouldn't have happened without the Laser Interferometer Gravitational Wave Observatory (LIGO) and Europe's Virgo Interferometer. The cataclysmic collision produced gravitational waves — literally, ripples in space-time — that LIGO and Virgo first detected, triggering the coordinated measurement.

While more than 70 facilities observed the aftermath of GW170817, a critical piece of information was missing — early ultraviolet measurements, particularly those gathered within 15 hours of the event.

Dorado, if selected, would fill the ultraviolet gap.

"We only have a handful of ultraviolet telescopes and all have small fields of view; they can only see a small fraction of the sky," Cenko said. "Furthermore, only the Neil Gehrels Swift Observatory can respond rapidly. Dorado would offer both a wide field of view and rapid response. No other satellite can do this."

Dorado would consist of two independent small satellites individually no larger than two shoeboxes.

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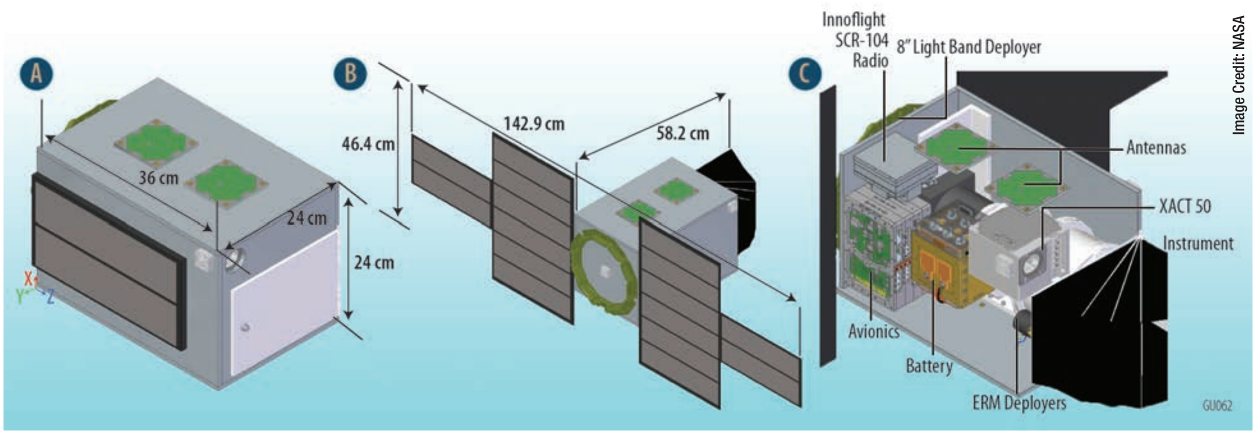
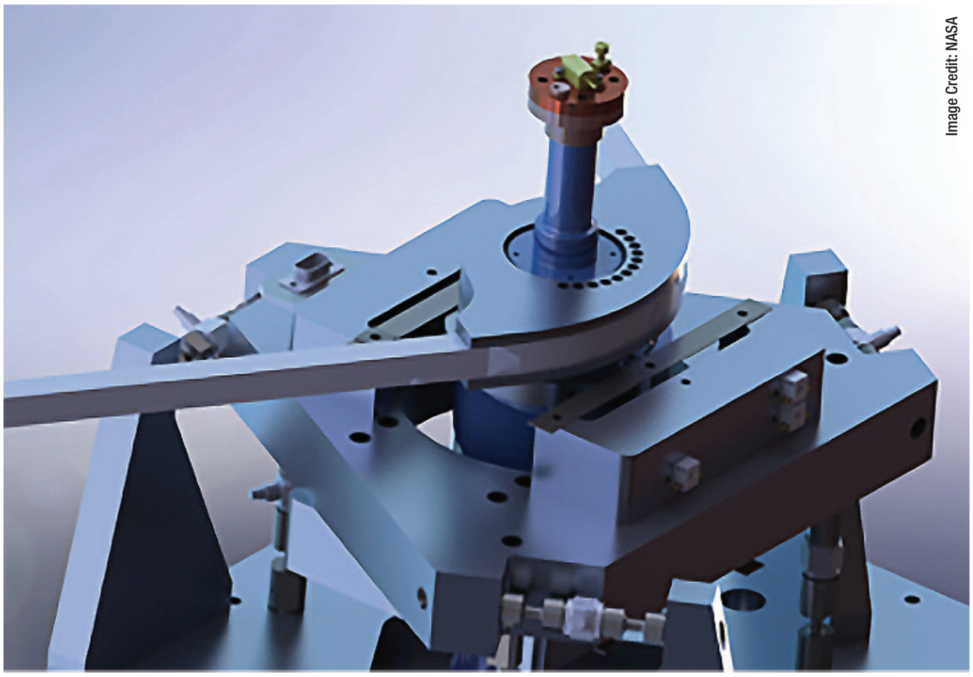


These drawings show a proposed CubeSat mission called Dorado. Led by Goddard scientist Brad Cenko, Dorado, if chosen, would fill a critical gap in the emerging field of multi-messenger astrophysics.

Operating from a low-Earth orbit, they would focus primarily on binary neutron star collisions, natural sites for the formation of the heaviest elements, including gold and platinum.

Because the Dorado spacecraft are relatively small, Cenko and his team must equip the mission's five-inch (13-centimeter) telescopes with small, compact refractive optics. "At the same time, we want to limit aberrations over the large field of view," Cenko said. To do this, the team is using six silica or glass lenses that would bend the incoming ultraviolet light and correct for errors as the light travels to the detector.



This image shows COSI's thermal system developed by Goddard scientist Terri Brandt.

For the telescopes to do their jobs, technicians must apply a highly on the surfaces of each lens to prevent glare and assure that most of the incoming light reaches the detector. These coatings are not only sensitive to temperature and humidity on Earth, but degrade over time in space. If not manufactured with the right ingredients, they can also absorb ultraviolet wavelengths, rather than reflect, them.

With IRAD funding, optical engineers Manuel Quijada and Javier Del Hoyo are advancing three potential coating recipes using different types of fluorides to assure a robust coating. "We're making good progress," Quijada said. "We're not finished yet, but we've produced successful prototypes."

The Jet Propulsion Laboratory is expected to contribute silicon-based detectors, and the Utah-based Space Dynamics Laboratory the two spacecraft.

LEAP: Modeling Background Radiation

Goddard scientists John Krizmanic and Steve Sturner are lending their modeling expertise to the LargE Area burst Polarimeter, or LEAP, led by University of New Hampshire researcher Mark McConnell. NASA also selected LEAP in the Explorer Program MO competition.

Mounted on the International Space Station, LEAP would study the energetic jets launched during the explosive death of a massive star, or the merger of compact objects like neutron stars.

To assure LEAP's accuracy, Krizmanic and Sturner are working with the LEAP team in modeling the behavior of LEAP's polarimeter — an instrument that measures the degree of rotation of polarized light. The goal is determining how the instrument's sensitivity is affected by background radiation and offer recommendations on how to mitigate adverse effects.

The team provided the same services for another mission of opportunity, also operating aboard the space station, the Goddard-developed Neutron star Interior Composition Explorer (NICER). For NICER, the team recommended additional lead shielding in strategic locations to reduce background radiation coming from a device aboard the Russian Soyuz spacecraft, which dock at the space station. "John and Steve modeled all that," said NICER Principal Investigator Keith Gendreau.

"Steve and I are really happy we helped the NICER team," Krizmanic added. "This success helped inform the reputation we have for this type of work."

COSI: A Strategic Partnership

Goddard astrophysicist Terri Brandt, in a strategic partnership with the University of California-Berkeley, is providing a thermal-control system for the

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Goddard's ANGEL Beacons: Artemis' Saving Grace

On Nov. 1, 2018, the USS John P. Murtha recovered the test version of the Orion capsule at sunset in the Pacific Ocean. Orion astronauts will be equipped with special search and rescue beacons that will provide highly accurate location data to help Exploration Ground Systems retrieve the returning adventurers.

Returning from the Moon, Artemis astronauts aboard the Orion capsule will streak through the sky at speeds exceeding a blistering 20,000 miles per hour. Atmospheric friction and the grand unfurling of parachutes will slow the spacecraft to under 20 miles per hour, swaying gently in the air before splashdown on Earth's vast oceans.

Under normal circumstances, NASA's Exploration Ground Systems — in partnership with the U.S. Navy and U.S. Air Force — will scoop up the capsule and its lunar voyagers within a few hours. But what happens if something goes wrong and astronauts need to exit the capsule into the open ocean, braving treacherous waters?

NASA survival systems engineers furnish these explorers with everything they'll need: Johnson Space Center (JSC) has developed life preservers and rafts and Goddard's Search and Rescue office has developed specialized emergency beacons for the life preservers. These beacons will provide highly accurate location data from anywhere on the globe, helping Exploration Ground Systems to retrieve the returning adventurers.

Long Tradition in Search and Rescue

"Our office has long shared NASA expertise with the international search and rescue program, creating beacons that provide users worldwide with accurate distress location services," said Search and Rescue Mission Manager Lisa Mazzuca. "To support Artemis and other crewed exploration missions, we're providing astronauts with enhanced technologies and will pass those benefits on to everyday users."

Since 1979, the Search and Rescue office, a project within the Flight Projects Directorate's Exploration and Space Communications Projects Division, has provided communications and navigation technology to Cospas-Sarsat, the international satellite-aided search and rescue program. Goddard designed the global system's original architecture, as well as recent upgrades that improve the technology's accuracy by an order of magnitude, from one kilometer to under a hundred meters.

They've dubbed the second-generation models, which they created for the Artemis effort, as the Artemis Advanced Next-Generation Emergency Locator (ANGEL) beacons. The technology takes full advantage of upgrades to the search and rescue network's space and ground segments and will let NASA know near instantaneously where to deploy personnel to retrieve the astronauts.

NASA astronauts aren't the only people who will benefit from this second-generation beacon technology. Similar beacons will hit the commercial market in the coming years. The Search and Rescue office provides the technology to beacon manufacturers that sell devices to help first responders worldwide locate people in distress.

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Supporting the Commercial Crew Program

In addition to Artemis, Goddard's Search and Rescue office also supports NASA's Commercial Crew Program at JSC, which works with the American aerospace companies developing and operating a new generation of spacecraft and launch systems capable of carrying crews to the International Space Station. Goddard's Search and Rescue office has partnered with Goddard's Human Space Flight Communications and Tracking Network to provide commercial crew astronauts on the Boeing Crew Space Transportation-100 Starliner and the SpaceX Dragon crew spacecraft with responsive location services.

Photo Credit: NASA

Survival and rescue systems engineers at Johnson Space Center in Houston test astronaut beacons in a pool. NASA's Search and Rescue team, including mission manager Lisa Mazzuca (center), helped with the testing.

The spacecraft are equipped with an emergency beacon that can provide an accurate location anywhere in the world upon activation. Crew members are also equipped with a personal locator beacon to be used if they need to egress before their capsule can be recovered.

"We recently supported the second SpaceX Crew Dragon demonstration mission through real-time monitoring of potential crew distress beacons from our ground station at Goddard," said Search and Rescue Deputy Mission Manager Tony Foster. "Our team was on the console to make sure that NASA could quickly retrieve our astronauts should anything go wrong. Fortunately, the launch was an enormous success and no distress activations were necessary."

Beyond Earth's Bounds: LunaNet

Beyond Earth's bounds, Goddard's Search and Rescue office is conceptualizing a search and rescue network for astronauts working on the Moon. Search and rescue services will be offered as part of LunaNet, a Goddard-developed communications and navigation architecture that could provide robust, extensible network services for NASA exploration and science missions at the Moon (CuttingEdge, Spring 2020, Page 6). Based on linked network assets, or nodes, LunaNet could enable networking services anywhere in the solar system, first at the Moon and then on planets farther in space.

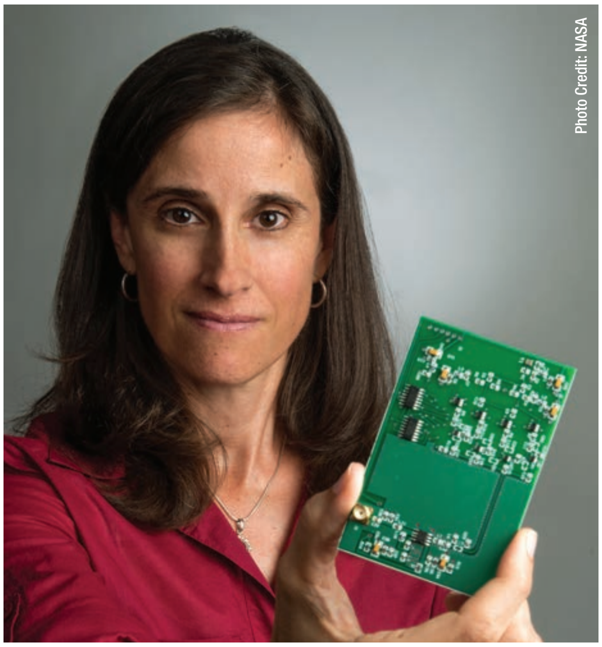

Photo Credit: NASA

NASA's Search and Rescue Mission Manager Lisa Mazzuca holds hardware from the second-generation beacon development effort. These beacons offer a host of benefits compared with first-generation beacons, including better accuracy, improved efficiency, and a more robust signal.

"Search and rescue will be a standard service of LunaNet," said Mazzuca. "By adding our technologies to this suite of network capabilities, we're extending our reach out into the solar system and enhancing astronaut safety far beyond Earth's bounds." ❖

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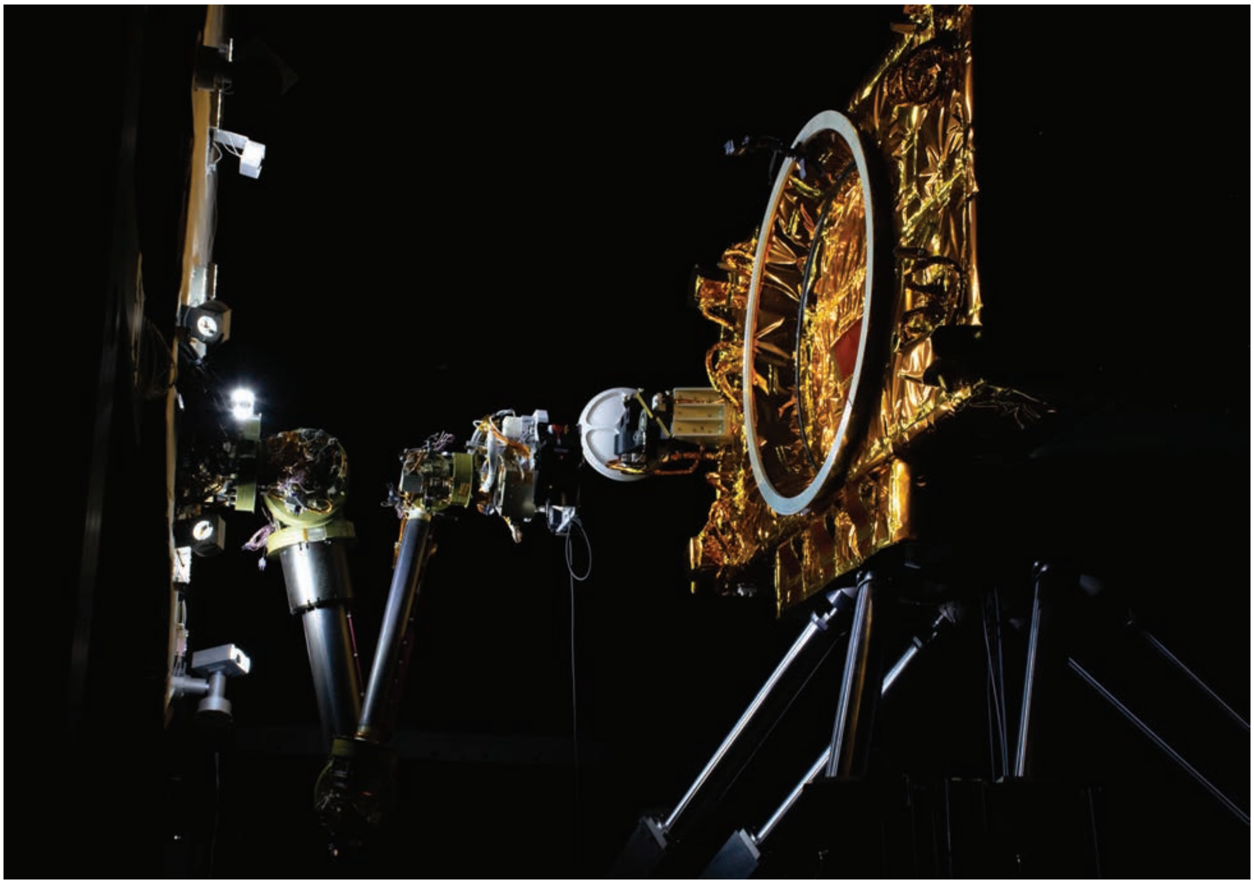
Foundations for the Future: Goddard Autonomous Technology to Drive Orbital Servicing



Goddard-developed autonomous navigation technologies will assist in a future satellite refueling mission called the On-Orbit Servicing Assembly and Manufacturing Mission 1, which NASA plans to launch in the mid-2020s.

Goddard technologies that have been refined over many years with multiple improvements will guide NASA's On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) mission in orbit.

Planned to launch in the mid-2020s, OSAM-1 will be the first spacecraft to refuel a satellite not designed to be refueled. Using robotic arms, OSAM-1 will rendezvous with, refuel, and relocate Landsat 7 or another client satellite.

After its primary mission, an attached payload called Space Infrastructure Dexterous Robot (SPIDER) will demonstrate the ability to robotically assemble and manufacture parts crucial to several spacecraft functions, including a communications antenna and a structural extension or beam (see related story, page 13).

To refuel Landsat 7, the mission has to first find and rendezvous with the Earth-observing satellite.

Kodiak Plays Critical Role

Nathaniel Gill is the principal investigator of the Kodiak 3D lidar technology that will play a critical role in rendezvous and proximity operations, making the spacecraft equivalent to a self-driving car in space. Kodiak will be powered by a modified computer system called SpaceCube, also developed through IRAD and multiple upgrades. Multiple flight missions use SpaceCube technology.

Kodiak uses a micro-electromechanical scanner and a photodetector to "paint" a scene with the scanning laser, while its detector senses the reflected light to create a 3D image with millimeter-scale resolution. This will provide OSAM-1 with precise information about Landsat 7's location and orientation relative to OSAM-1.

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"Kodiak takes over at 10 kilometers (6 miles) and drives it all the way up to one meter away," Gill said. "Then it will hold position, matching rates of motion with Landsat 7 at one meter until the robot arm autonomously reaches out and grabs Landsat."

At that point, operators on Earth begin refueling Landsat 7 to breathe new life into the remote-sensing satellite.

SpaceCube Assists

Kodiak runs on another IRAD-developed technology, SpaceCube, with two card modifications specific to laser range finding, Gill said. SpaceCube is the Goddard-developed spaceflight processor that has run on multiple missions and in a variety of configurations.

SpaceCube has a history with autonomous navigation. It is the enabling technology behind Raven, the ambitious experiment proving the concept of relative navigation and autonomous docking capabilities from the International Space Station (*CuttingEdge*, Spring 2017, Page 12).

While he works at home, waiting for the opportunity to return to Goddard to begin building the final

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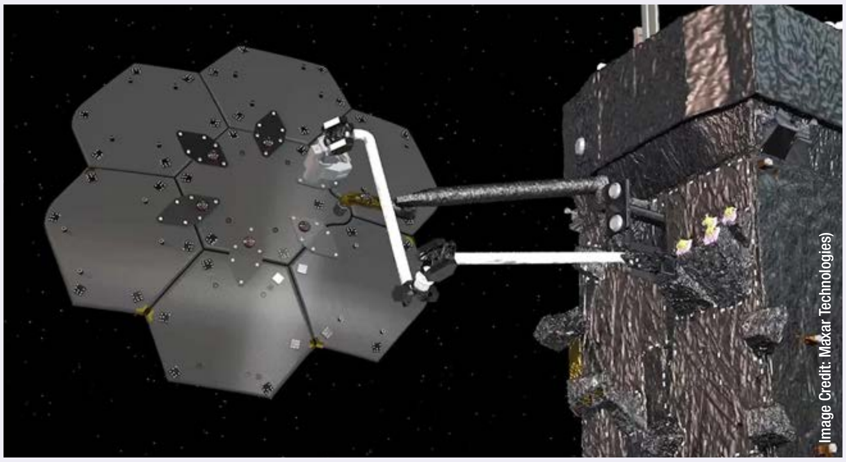
A Space-Faring SPIDER, Weaving Tech in Orbit

On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1), formerly known as Restore-L, was originally conceived as a mission to prove NASA can refuel a working satellite. Anticipating launch in the mid-2020s, OSAM-1 has since transformed into a wide-ranging mission to demonstrate in-orbit spacecraft servicing, assembly, and manufacturing, as reflected in the new name.



A robot arm assembles a Ka-band antenna in space and tests its functionality before disassembling and stowing it in this illustration.

Through the addition of a payload called Space Infrastructure Dexterous Robot (SPIDER), OSAM-1 will conduct a series of robotic operations that demonstrate in-space assembly and manufacturing capabilities. Built by Maxar Technologies, SPIDER will assemble and test, then disassemble and stow a Ka-band communications antenna comprised of seven reflector segments and a boom.

Following that operation, a manufacturing component built by Tethers Unlimited will produce a 32-foot (10-meter) structural beam of carbon fiber suitable for building structures in space. The beam, similar to some types used to construct buildings on Earth, will be created through a process called pultrusion. This process continuously pulls reinforcing fibers through a resin system for coating and subsequently through a heated die or mold that sets and strengthens the resin polymers.

"It's a technology demonstration mission," said Brent Robertson, project manager for OSAM-1 at Goddard. "We will be the first to demonstrate that we can assemble, disassemble, and reassemble complex structures in space. SPIDER will also use photogrammetry — taking pictures of the antenna with a built-in camera on the arm. This allows it to measure the antenna's shape to a high degree of precision to know that what we have built will work for Ka-band communications."

The capabilities being developed for OSAM-1 are important components of NASA's exploration efforts, including Artemis. They are critical to developing sustainable space architectures that allow spacecraft to live longer and journey farther, as well as enabling a sustainable human presence in space. ❖

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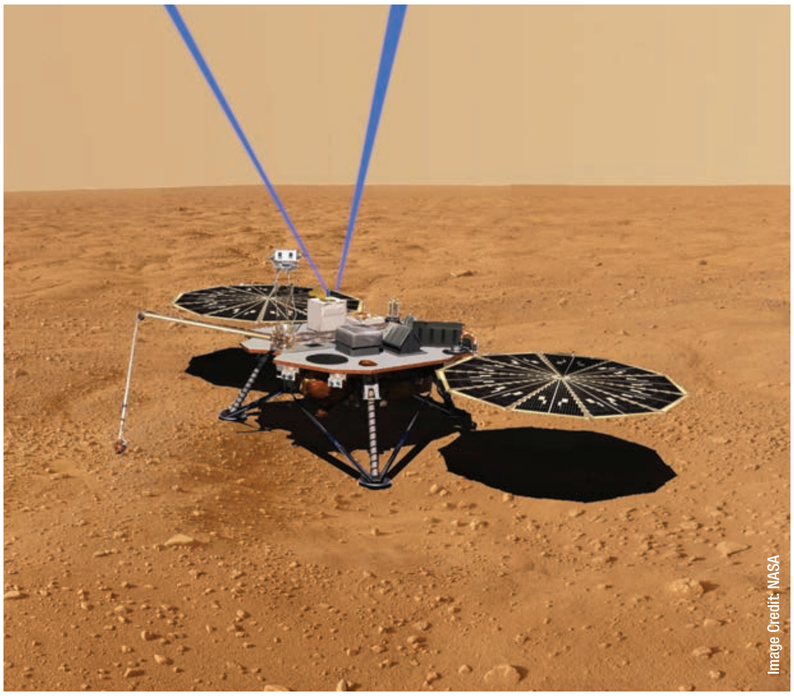
Goddard Scientists Win Funding to Advance Novel Lidar Concept for Planetary Studies

Raman Mass Spectrometer Also Selected

Insights and technology gleaned from creating a carbon-measuring instrument for Earth climate studies is being leveraged to build another that would remotely profile, for the first time, water vapor up to nine miles above the Martian surface, along with wind speeds and minute particles suspended in the planet's atmosphere.



This artist's rendition shows how a Mars lidar could be deployed on a landed mission to Mars.

Scientists Jim Abshire and Scott Guzewich have won NASA technology-development funding to build and demonstrate a small prototype atmospheric lidar for a future lander on Mars, and possibly Titan, Saturn's largest moon and the only one to have a dense atmosphere.

Selected for further development by the agency's Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) program, the concept traces its heritage to other similar-type instruments originally conceived through Goddard's Internal Research and Development (IRAD) program. Another IRAD-supported technology, a Raman mass spectrometer, also received PICASSO funding in the latest competition.

Understanding the Boundary Layer

Abshire and Guzewich are particularly interested in obtaining measurements of Mars's boundary layer, an atmospheric section that begins at the surface and can extend as high as nine miles (14.5 kilometers) above, depending on the time of day. Because this layer is difficult to measure from orbit, the team wants to deploy the lidar on a lander or rover that would directly gather around-the-clock data from the surface up — data that could reveal how conditions change over time and altitude.

This layer is important because it controls the transfer of heat, momentum, dust, and water and can reveal greater insights about the planet's modern climate, including the stability of its ice caps, how wind shapes the landscape, and how dust is lifted and transported. Furthermore, scientists can use this data to validate and improve general circulation models, Guzewich said.

"From a human spaceflight perspective, this layer is also critical for operations," Abshire said. "This is the environment in which landed missions will operate."

NASA has landed atmospheric lidars before, successfully measuring winds as well as aerosols, including dust and ice, but this particular instrument would provide the missing element — direct measurements of water vapor in vertical columns above the surface.

"We're motivated by science questions," Guzewich said. "We want to measure water vapor and winds at the same time. The whole point is understanding water and how it's being moved around through the atmosphere. We know where the water is, we just don't know how it moves."

To find out, the lidar would bounce a laser light tuned to 1911 nanometers — a specific wavelength in the near-infrared band ideal for detecting water vapor — into the sky and then analyze the reflected light or signal to learn more about the atmospheric dynamics occurring from the surface to nine miles above the surface. Equipped with a sesame seed-sized, already

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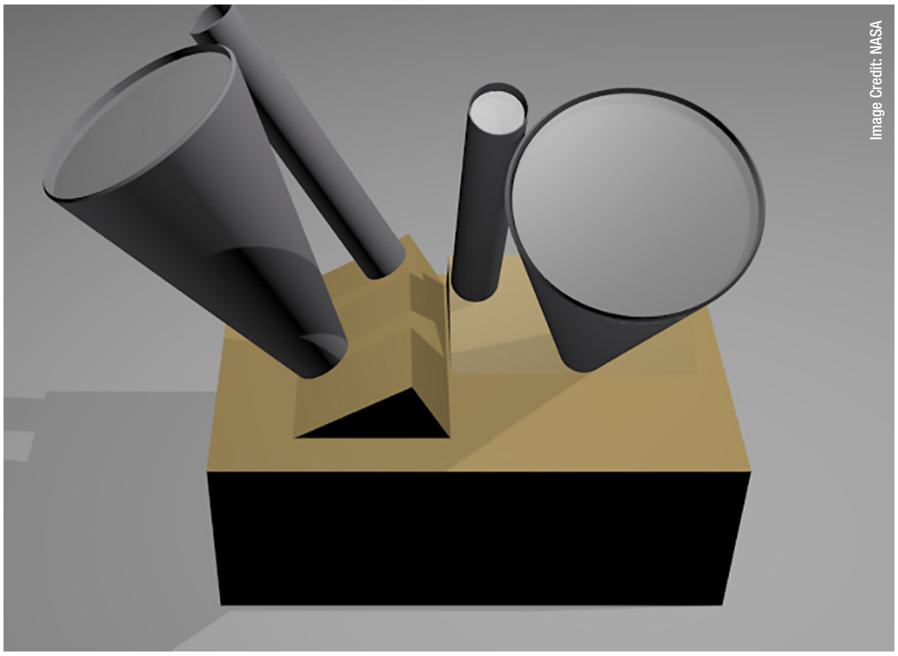
developed infrared detector (CuttingEdge, Summer 2015, Page 6), the instrument would be able to sense the returning signal at a single-photon level, providing unprecedented resolution.



This is a closeup of the lidar instrument, which would remotely profile, for the first time, water vapor up to nine miles above the Martian surface, along with wind speeds and minute particles suspended in the planet's atmosphere.

IRAD Heritage

"Our approach for profiling atmospheric water vapor and winds using a lidar at 1911 nanometers is new," Abshire said.

However, he and his colleagues have vast experience developing atmospheric lidar instruments. For Earth science, they built the CO2 Sounder lidar tuned to 1572 nanometers, which is effective for measuring carbon dioxide in the atmosphere (CuttingEdge, Summer 2016, Page 12). The new lidar also traces its heritage to the Mars Lidar for Global Climate Measurements from Orbit, which Abshire envisioned as an on-orbit instrument to measure wind speeds (CuttingEdge, Winter 2018, Page 17).

The challenge is producing an instrument that is robust, practical, yet small enough to fit onto a rover. "Our challenge is to show that we can do this. Fortunately, we can rely on the unique capabilities of Goddard, Abshire said. "We have great capabilities in lidar, space lasers, and detectors. There really is no other place that combines all this capability and expertise."

Raman Mass Spectrometer

Principal Investigator Andrej Grubisic also won a three-year award to advance RAMS, short for RAman Mass Spectrometer. Raman spectroscopy and mass spectrometry are two common analytical chemistry techniques for determining sample composition through identification of individual molecules and specific minerals.

With his PICASSO award, Grubisic said he and the RAMS team plan to demonstrate a hybrid instrument that would be capable of acquiring micron-level composition maps of organic molecules and mineral phases that exist in samples gathered on comets and asteroids as well as from samples acquired on the icy moons in the outer solar system, often called the Ocean Worlds. Such measurements would give scientists the necessary information to help them understand the origin of organic material in the solar system, the habitability of other planets, and the potential for life beyond Earth.

"Fine-scale spatial associations between specific organic and mineral phases are usually needed to ascertain the formation processes of prebiotic molecules or to confirm the detection of potential molecular biosignatures," Grubisic said.

The instrument Grubisic and his team are developing incorporates a mass spectrometer, a Raman spectrometer, and a shared laser unit tunable to either ultraviolet or visible optical wavelengths into a small, lightweight package that consumes less power. The Raman spectrometer presents a new development for Goddard, but both the mass spectrometer and the laser subsystems were previously advanced through Goddard's IRAD program.

"This level of instrument integration will allow us to gather data at an unprecedented level of detail for a spaceflight instrument within a compact footprint compatible with future missions to high-priority targets to Enceladus, Europa, and other icy moons, as well as comets or asteroids," Grubisic said. ❖

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Semiconductor Manufacturing Techniques Employed for New Gamma-Ray Detector

Postbaccalaureate researcher Isabella Brewer is a member of the team creating a next-generation gamma-ray detector called AstroPix.

Goddard astrophysicists and engineers are adapting detectors used by earthbound supercolliders and creating them the same way electronics companies produce all modern consumer devices, including cell phones and laptops.

The new pixel-based silicon detector technology could be used on next-generation gamma-ray observatories to detect highly energetic photons emanating from the most powerful events in the universe, including colliding galaxies and black holes. The new detectors would sense these photons much like a digital camera and use far less power than current space-based detectors.

Underground supercolliders, which have experiments employing the same silicon pixel-type detectors, accelerate protons and ions to near the speed of light in opposite directions at very high energies. Their collisions are designed to recreate the conditions that governed the universe after the Big Bang. Although highly efficient, current silicon pixel technology requires a lot of power, which would be a challenge if used in space where power is normally derived from solar panels.

Enter AstroPix

"The challenge is finding the best way to reduce the amount of power the pixel needs to use since instruments on the ground have access to all the power they want," said Regina Caputo, an astrophysicist and the principal investigator of Goddard's detector-development effort called AstroPix. Caputo and her team, which includes Goddard astrophysicist Jeremy Perkins and postbaccalaureate researcher Isabella Brewer, initially began their work with support from Goddard's Internal Research and Development (IRAD) program. The team has since secured technology-development support from NASA's Astrophysics Research and Analysis (APRA) program.

Like the particle community, Caputo is experimenting with a manufacturing process called complementary metal oxide semiconductor, or CMOS, used ubiquitously by the semiconductor industry to make modern electronic devices. "This process allows us to not only collect energy from particles that enter the detector, but also to amplify their signals all in

Continued on page 17

the same detector material. This makes these detectors less expensive and noisy," Caputo said.

With the APRA award, which Caputo and her team won after obtaining a detector from collaborators at Argonne National Laboratory, the team is designing new pixel detectors optimized for potential use in space and has sent its first version of AstroPix to a semiconductor foundry — the same facilities that manufacture computer chips — for fabrication.

"We hope to get AstroPix back this summer for testing," she said. "This is progress."

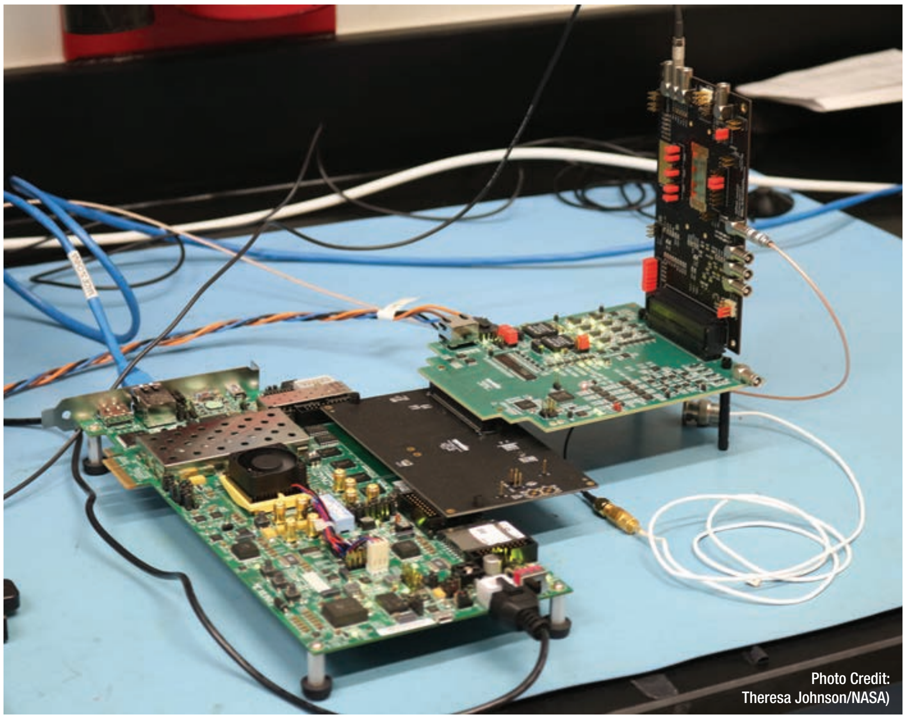

Photo Credit: Theresa Johnson/NASA)

This is a breadboard of a gamma-ray detector system that Principal Investigator Regina Caputo and her team assembled to test pixel-based silicon detector technology. The actual detector, provided by Argonne National Laboratory, is the rectangular piece positioned on the vertical board. The final design will be custom made and simpler.

Detector Advantages

AstroPix's advantage is best illustrated by comparing it with detectors flying on the Fermi Gamma-ray Space Telescope. Fermi also uses silicon-based detectors, but its sensors are comprised of silicon strips that are assembled in layers. These layers cross one another perpendicularly to create a grid that pinpoints the locations of high-energy particles created when a gamma ray hits a detector.

With AstroPix, however, particles would be recorded once they contacted a single pixel instead of multiple layers of silicon strips, giving the detector the ability to create a map of the particles' paths with fewer layers.

"Previous silicon strip-detecting technology went through a series of processes to convert charges to digital signals, while the new pixel-based technology can do all of them at once since the readout is integrated with each pixel, Caputo said. In this way, the pixel detector would reduce its power needs to function the best in space.

The team is testing the pixel detector in the astrophysics lab at Goddard using radioactive sources, such as cadmium, for the pixelated silicon to detect. The tests help determine whether the energy resolution of the pixel detector is the same or better than the silicon strip detectors. "These sources can partially reproduce the types of radiation found in space, although at a much lower dose," Brewer said.

If Proven, AMEGO Likely Beneficiary

Future gamma-ray missions, such as a mission concept called the All-sky Medium Energy Gamma-ray Observatory (AMEGO), has currently baselined Fermi-like strip detectors. Instead of looking at the universe in high-energy gamma rays, AMEGO would break new ground by extending Fermi's reach into lower energies at sensitivities previously unexplored.

The AMEGO project would benefit from silicon pixel detectors due to their improved position sensitivity, energy resolution, and lower power consumption. However, the team must prove their effectiveness before the technology could be incorporated into the mission design, Perkins said, adding that AMEGO's future is tied to the Decadal Survey on Astronomy and Astrophysics (Astro2020) process. If the mission ranks high in the survey next year, then the mission could fly later in the decade.

He said pixel detectors would easily be the best choice for any particle-detecting mission, like AMEGO, because they are easy to produce and inexpensive, especially compared with silicon strip detectors. ❖

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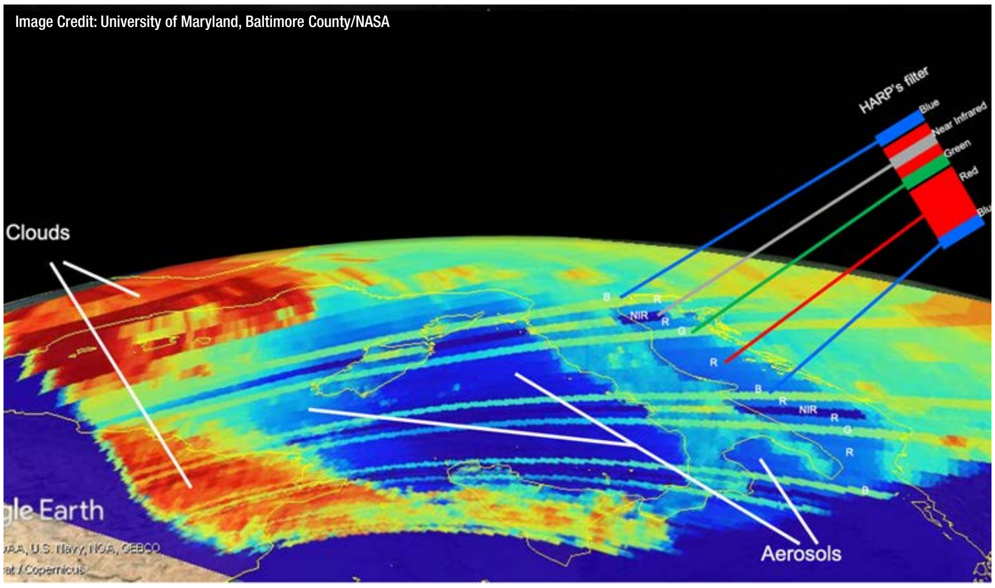
Tiny NASA Satellite Captures First Image of Clouds and Aerosols

As most scientists worked from home, the Hyper-Angular Rainbow Polarimeter (HARP) CubeSat toiled in low-Earth orbit, capturing its "first light" image of clouds and tiny particles in the atmosphere over Europe.

HARP's measurements are helping scientists better understand how clouds and aerosols affect weather, climate, and air quality.



The HARP CubeSat downlinked a first light capture on April 16, 2020. The data was a collection of 10 images from each sensor of the Earth's limb facing Europe from the south. The coastlines of Italy, Sardinia, and southeastern Europe are clearly seen in the image. The regions of high intensity toward western Europe correspond to clouds. This capture was validated by similar imagery from MODIS Aqua and Terra from the same day.

HARP, which captured its first image on April 16, 2020, marks NASA's first attempt to fly a polarimeter — a device that measures the polarization of light — aboard a CubeSat. HARP launched from NASA's Wallops Flight Facility on November 2, 2019, and three months later, the CubeSat floated away from the International Space Station to begin its orbit around Earth.

HARP could pave the way for future NASA missions involving a constellation of little satellites peering down at clouds and aerosols, said Vanderlei Martins, HARP principal investigator and physics professor at the University of Maryland, Baltimore County. Martins is affiliated with Goddard through the Joint Center for Earth Systems Technology and worked with Goddard scientists and engineers to develop HARP.

"HARP, as the first multiangle wide field-of-view cloud-aerosol CubeSat mission, is a great example of how a creative and innovative team can advance new technologies for atmospheric science observations," said Charles Norton, special advisor for small spacecraft missions at NASA Headquarters in Washington.

HARP filters light into four wavelengths and uses a prism to rotate that light to three polarization angles. Just as polarized sunglasses help block bright light to help people see past the sun's glare, HARP can block certain wavelengths and make observations from many angles. Its images reveal what is hidden to the naked eye: amounts and types of aerosols as well as the size of water droplets and ice particles inside clouds.

"Every time HARP flies over a region, we see that region from multiple perspectives," Martins said.

Chasing Clouds and Aerosols with Rainbows

Martins said he breathed a sigh of relief when his team first made contact with HARP in March 2020. "Since you cannot go there and touch it, you try to get as much information as you can in a ten-ish-minute timeframe as the satellite passes over the Wallops ground station," Martins said. HARP sent back a simple one-frame image to let its team know it was working.

"However, it was the next one that was really exciting," Martins said. That "next one" arrived on April 16 and combined 400 frames into one image. "As we include hundreds of frames into one image, we can start to do exciting science," Martins said.

"HARP will be able to provide much more information

Continued on page 19

about the microphysical properties of aerosols than was previously available," said Henrique Barbosa, a professor and scientist at the University of São Paulo in Brazil, who is collaborating with Martins on HARP and other projects. HARP's data can also be combined with ground-based observations and experiments to better extrapolate those results and reveal aerosol processes across a wider region, Barbosa said.

As a CubeSat, HARP has limited power and data capabilities; therefore, the team must strategically determine when it will collect data, Barbosa said. For instance, he would like to have HARP to collect data over the Amazon to learn more about the effect of the 2019 Brazilian Amazon rainforest fires, which were much larger and more intense than in previous years.

The Three HARPs

Martins may have originally conceived HARP as a CubeSat, but before it launched, it already had two siblings: AirHARP and HARP2.

AirHARP used the same polarimeter technology as HARP, but flew aboard two research aircraft in 2017. "We were able to simulate what HARP would do from space," Barbosa said, adding that the airborne version helped him and Martins develop procedures and algorithms that they would eventually use to help download and digest HARP's data.

However, unlike AirHARP, which followed a set flight path, HARP cannot be controlled once in space. "Once the CubeSat leaves the space station, its course is whatever it will be, and that's it," Barbosa said. Once scientists on the ground make contact with the orbiting HARP, they can predict its orbit and turn it on and off when they want to take a measurement over a particular region, but they can't alter its course.

HARP2, on the other hand, will be a much more powerful version of HARP. HARP2 will fly with NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, which is currently under development. Since PACE is a much larger spacecraft, with more power capabilities and a larger team behind it, HARP2 will be able to operate all the time and collect significantly more science data than HARP.

"The HARP CubeSat was perfectly planned," Martins said. "We will use HARP's data to prepare for HARP2." ❖

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CubeSat Mission, *continued from page 13*

Photo Credit: Maxar Technologies

The fuel tank that On-Orbit Servicing, Assembly and Manufacturing Mission 1 will use to refuel Landsat 7 and potentially other satellites is completed at a Maxar Technologies facility.

spaceflight hardware version of Kodiak, Gill said he is excited to see his long-term project incorporated into such a groundbreaking mission.

These technologies could help humans explore far beyond low-Earth orbit, he said, with potential applications on planetary rovers as well as future sample-return missions similar to the asteroid sample return mission, Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx). With IRAD funding, Gill has been working on various iterations of the navigation technology since 2013.

"It's kind of a dream come true," he said. "It's what I've always wanted to do, contribute to the cutting edge in space technology. Short of being an astronaut, this is really my dream job. If I can't be up there, it's good to know something I designed and built can be up there." ❖

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Heeding the Call, *continued from page 7*

developed for the past few years for such CubeSat missions as Dellingr and Dione (CuttingEdge, Spring 2020, Page 13) as well as for sounding rocket investigations. Goddard's IRAD program supported the development of the instrument's detection system.

Developed by Principal Investigator Daniel Gershman, EEA will measure electrons in the solar wind and in Earth's magnetosphere, the all-enveloping bubble of magnetism that protects Earth from most space weather events. The instrument will help determine the arrival time of interplanetary shocks, measure boundary crossings of the bow shock and magnetopause, and observe the effects of geomagnetic storms in the deep magnetotail.

"In addition to providing space weather measurements near the Lunar Gateway, our instrument will measure the electrostatic charging of the Gateway platform itself," Gershman said.

Challenges Ahead

The instruments must be completed by spring 2021. They will be integrated and then delivered to Maxar Technologies by late 2021, Christe said. Due to the pandemic, the deadline could present challenges for the project teams, the principal investigators agreed, adding that they need laboratory time to assemble and test their devices. "One of the biggest hurdles with such a short delivery date is making sure we can get all of the long-lead components we need from vendors in time to integrate and test," Gershman said.

However, all three have an advantage, Christe said. "Our IRAD program not only enabled this technology, but also put in place the teams necessary to build these projects. This is a great opportunity for our scientists. We'll be able to gather science in a different environment and help monitor for crew health — something these instruments were never originally designed to do." ❖

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Explorer Program, *continued from page 9*

Compton Spectrometer and Imager (COSI). The system is based on components designed and tested with IRAD funding.

A proposed SMEX mission led by Berkeley's John Tomsick, COSI would scan the Milky Way, measuring gamma rays from radioactive elements produced during stellar explosions. The data will help scientists map the recent history of star death and element production. The proposed SMEX mission evolved from a balloon program that gathered similar data.

"Goddard's strategic investment in my technology allowed me to work with the COSI team, both on the SMEX initiative and the balloon program," Brandt said, explaining that COSI's gamma-ray detectors must be kept very cold and protected from vibration, which could produce noise and contaminate the data.

The value of her technology is that it requires no coolant, yet can maintain the required operating temperature of 315 degrees Fahrenheit (80 Kelvin). During lab tests at Goddard and on the COSI balloon instrument, Brandt's system, which operates similarly to a refrigerator, also proved effective at mitigating vibrational noise, she said.

"We're helping to bring gamma-ray astrophysics to a whole new level," Brandt said, adding her cooling system is applicable to heliophysics and planetary missions. "This technology benefits any mission using actively cooled devices." ❖

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Cutting edge Goddard's Emerging Technologies

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