National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

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Sowing Technology Seed Corn

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Sowing Technology Seed Corn
Spotlight on Potentially Transformative Space Technologies

In this issue of CuttingEdge, we focus on emerging technologies that, while early in their development, hold significant promise in transforming how NASA explores space. Some of these efforts are funded by a new program — called the Goddard Fellows Innovation Challenge (see story below) — while others are supported by the center's Internal Research and Development program.

When Failure Is an Option

New R&D Program Supports Fledgling Concepts

What do inventors do when their ideas are so new, so different that they're not even sure they will work? The Goddard Senior Fellows — a distinguished group of center technologists, scientists, and engineers — are providing an outlet for center innovators.

Last year, with the endorsement of Center Director Chris Scolese, the group rolled out the Goddard Fellows Innovation Challenge, or GFIC. This research-and-development funding program is distinct from Goddard's Internal Research and Development, or IRAD, program and others that award funds based on whether proposals address specific scientific and technology goals.

Rather, GFIC supports very early-stage, potentially radical or high-risk innovation and exploratory research not necessarily aligned to areas in which Goddard excels, proposed missions, or goals, but promise dramatic longer-term consequences for scientific concepts and engineering practices.

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About the Cover

A relatively new program, the Goddard Fellows Innovation Challenge, was purposely created to support early stage, potentially transformative technologies that could revolutionize the way NASA explores space. Its creators believe the program is sowing technology seed corn that will yield big results later.

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"The senior fellows were chosen to sponsor and review proposals because of their extensive knowledge of the Goddard mission and their standing in the world's technical communities," Scolese explained.

"And we started this program because we saw a need," added Senior Fellow Dave Folta. "Research is a process. It starts with an untried idea and if it works, it advances typically with support from other funding programs. Ultimately, it's infused into a flight program. What was lacking at Goddard was a specific program for nurturing fledgling ideas that might work or might not. The point is giving an innovator a chance to try the idea. Failure is an option."

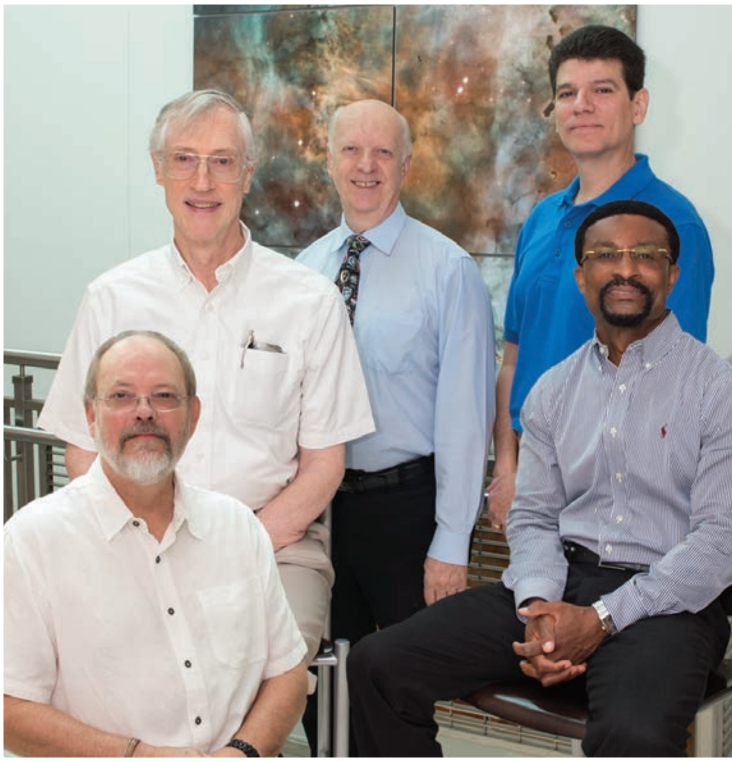

Photo Credit: Bill Hrybyk/NASA

The Goddard Senior Fellows — a distinguished group of center technologists, scientists, and engineers — started a new research funding program geared to very early-stage, potentially radical or high-risk innovation and exploratory research projects. Some of the individuals who were instrumental in the program's creation are (from left to right): Ted Swanson, John Mather, Dave Folta, Fernando Pellerano, and Moses Adoko.

The Senior Fellows, whose members are appointed by Scolese and serve as advisors to him, agreed that the reestablishment of something similar to the now-defunct Director's Discretionary Fund, or DDF, could help fill the emerging technology R&D void. Like GFIC, the DDF had supported untried ideas not necessarily linked to a line of business or mission start. The DDF program, which was active in the 1990s to early 2000s, was the seed corn for a number of very successful Goddard technologies and missions.

For example, the original DDF program funded the development of the first analogue-waveform laser altimeter in space. Called the Shuttle Laser Altimeter, or SLA, the experimental instrument flew successfully on STS-72 in 1996 and again on STS-85 one year later.

Its success didn't end there. This Goddard-led and -developed instrument then served as a pathfinder for the Mars Orbiter Laser Altimeter, the Lunar Orbiter Laser Altimeter, and the Mercury Laser Altimeter and to the development of the Global Ecosystem Dynamics Investigation, or GEDI, mission. Soon to be launched to the International Space Station, GEDI will become the first space-borne laser instrument to measure the structure of Earth's tropical and temperate forests in high resolution and three dimensions.

Since its inception in 2017, a total of 20 teams have received GFIC funding to investigate everything from the use of new techniques for studying extraterrestrial rock samples to the development of online tools, materials, instruments, and components. In March, the Senior Fellows announced the recipients of this year's competition. Like the preceding winners, these researchers are pursuing a diverse range of research topics: detectors, new materials, and observational techniques, just to name a few (see related stories on pages 4 and 8).

What they all have in common, said another Senior Fellow, Ted Swanson, is the fact that the proposals are innovative and offer compelling concepts and engineering technologies. "These efforts represent our super seed corn, efforts that could enable our future," Swanson said. ❖

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Spotlight on Potentially Transformative Space Technologies

Goddard Teams Study Space Applications for Gallium-Nitride Crystals

An exotic material, which is poised to become the semiconductor of choice for power electronics because it's far more efficient than silicon, is being eyed for potential, completely different applications in space.

Funded by the Goddard Fellows Innovation Challenge, two center teams are examining the use of gallium nitride, a crystal-type semiconductor compound first discovered in the 1980s, and currently used in consumer electronics, such as laser diodes in DVD readers.

Among its many attributes, gallium nitride — GaN, for short — demonstrates less electrical resistance, and thus loses only a small portion of power as heat. The material can handle 10 times the voltage of silicon, enabling smaller, faster, and more efficient devices. In addition, it's tolerant to a wide range of temperatures, resistant to radiation, and as it turns out, adept at detecting energetic particles.

It's no wonder then that scientists and engineers are interested in seeing how they could tap into this versatile material to enhance space exploration.

With their funding, Goddard engineer Jean-Marie Lauenstein and scientist Elizabeth MacDonald are investigating Gallium-Nitride High Electron Mobility Transistors, or GaN HEMTs, for use in studying how Earth's magnetosphere couples to its ionosphere — a key question in the field of heliophysics. Stanley Hunter and Georgia de Nolfo, meanwhile, are investigating the material's use on a solid-state neutron detector that would be relevant to both science and homeland security.

Gallium-Nitride Transistors

Gallium-nitride transistors or semiconductors became available commercially in 2010, but they have not yet found their way into space scientists' instruments, despite their potential to reduce an instrument's size, weight, and power consumption.

There's a reason for that, said Lauenstein. Even though gallium nitride is predicted to be resistant to many types of radiation damage, neither NASA nor the U.S. military has established standards for characterizing the performance of these transistor-enabled devices when flown in space.

When struck by galactic cosmic rays or other energetic particles, electronic equipment can experience catastrophic or transient single-event upsets. "We have standards for silicon," Lauenstein said. "We don't know if the methods for silicon transistors would apply to gallium-nitride transistors. With silicon, we can assess the threshold for failure." With the GFIC funding, Lauenstein and MacDonald

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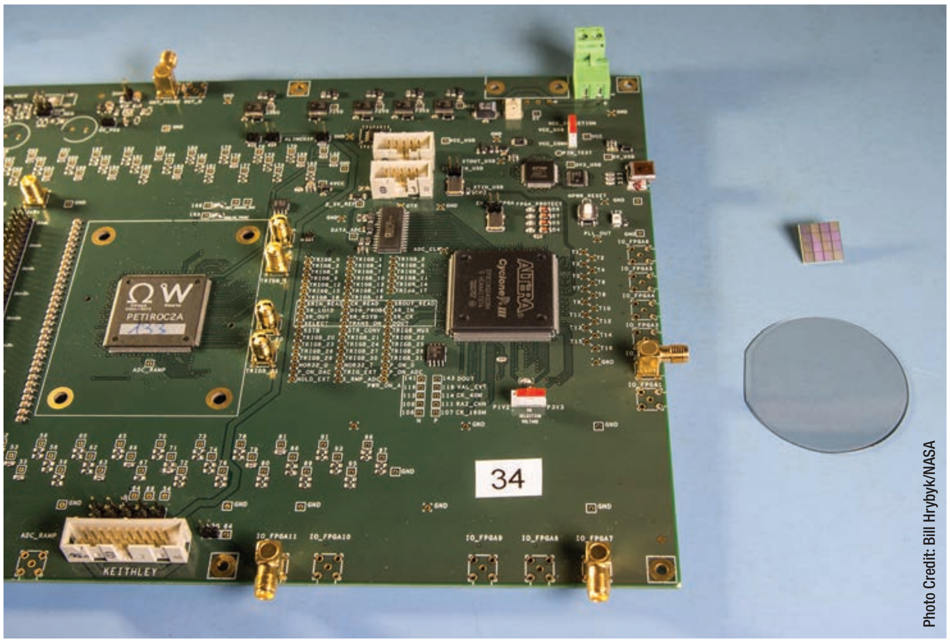


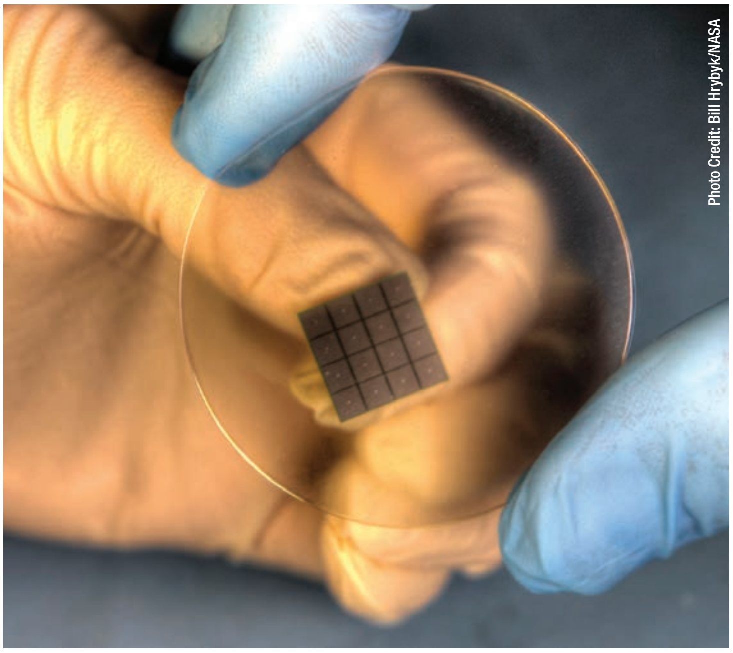
Photo Credit: Bill Hrybyk/NASA

This is a prototype of the gallium-nitride-based neutron detector that scientists Georgia de Nolfo and Stan Hunter are developing with Goddard Fellows Innovation Challenge funding. Silicon photomultipliers are positioned to the upper right of the board and the crystal is located to the lower right.

are teaming with the Los Alamos National Laboratory in New Mexico, a parts manufacturer, and NASA Electronic Parts and Packaging to establish criteria assuring that a GaN-type device could withstand the effects of potentially harmful particles produced by galactic cosmic rays and other sources.

This is important to scientists because the material could be useful in electron-beam accelerators — comprised of gallium-nitride transistors — built to map specific magnetic lines in Earth's protective magnetosphere to their footprints in Earth's ionosphere where aurora occur. This would help show how the two regions of near-Earth space connect.

"The team's research on radiation tolerance helps us understand how to fly these accelerators in the harsh space environment over the mission's lifetime," MacDonald said.



The gallium-nitride disk and the photomultiplier array offer a potential solution for building a detector and imaging short-lived neutrons in Earth's protective magnetosphere.

According to Lauenstein, these standards will also benefit other scientific disciplines. "We need a path forward for this technology," she said. "This opens the door for others to incorporate this technology into their own missions."

Potentially "Game Changing"

For de Nolfo and Hunter, gallium nitride offers a potential solution for building a detector and imaging neutrons, which are short-lived and typically expire after about 15 minutes. Neutrons can be generated by energetic events in the Sun as well as cosmic-ray interactions with Earth's upper atmosphere.

The neutrons generated by cosmic rays in the atmosphere can add to Earth's radiation belt — a swath of radiation surrounding Earth that, among other things, can interfere with onboard satellite electronics — when they decay. Researchers have discovered GaN can form the basis of a highly sensitive neutron detector.

"The gallium-nitride crystal could be game-changing for us," de Nolfo said.

Under their concept, Hunter and de Nolfo would position a gallium-nitride crystal inside an instrument. As neutrons enter the crystal, they would scatter off gallium and nitrogen atoms and, in the process, excite other atoms, which then would produce a flash of light revealing the position of the neutron that initiated the reaction. Silicon photomultipliers and their associated read-out devices attached to the crystal would convert the flash of light into an electric pulse to be analyzed by the sensor electronics.

Ultimately, the team wants to build six of these modules and mount them on the faces of a cube to form an imager.

"Gallium nitride is reasonably well understood in the photo-electronics industry, but I think we're pushing the envelope a little on this application," Hunter said, adding that the beauty of the concept is that it would contain no moving parts, use little power, and operate in a vacuum.

If it works, the instrument would benefit multiple space science disciplines and the military in detecting nuclear material, he added. ❖

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Finding the Detergent

Scientist Develops Instrument Concept to Measure Methane-Cleansing Chemical

Steve Bailey helped physical chemist Tom Hanisco develop a portable instrument to measure hydroxyl, a chemical that cleanses the atmosphere of highly damaging methane. With this instrument, Hanisco obtained initial measurements from a rooftop at the Goddard Greenbelt campus.

Methane may not loiter in the atmosphere as long as carbon dioxide does, but it can be far more devastating because of how effectively it absorbs heat. The challenge for scientists — especially those who model climate impacts — is measuring the one chemical that acts as a type of detergent, cleansing the atmosphere of this powerful greenhouse gas.

Goddard physical chemist Tom Hanisco and his team believe they could help pin down the abundance of this radical — called hydroxyl, or OH, for short — with an instrument that employs a tried-and-true measurement technique that has never been used for this particular task. He wants to test his cavity-enhanced gas filter and compare its measurements against those gathered by a proven, high-resolution ground-based instrument operated by the Jet Propulsion Laboratory, or JPL.

Methane Life Proportional to Its Impact

"The lifetime of methane is directly proportional to its impact on the climate," Hanisco said. "And its lifetime is determined by hydroxyl," which is formed in nature by the reaction of ultraviolet light from the Sun that disassembles water vapor to produce a hydrogen atom and oxygen. They combine to form the hydroxyl radical.

However, because hydroxyl is highly reactive, short lived, and exists in very small amounts measured in only the parts per trillion, "it's really hard pinning down hydroxyl numbers," Hanisco continued.

Other than for the localized measurements collected by the Fourier Transform Ultraviolet Spectrometer at JPL's Table Mountain Facility near Wrightwood, California, no one knows the abundance of hydroxyl in an atmospheric column globally or regionally — that is, the levels of this chemical in a vertical column extending from Earth's surface to the top of the atmosphere. No airborne or space-based instrument exists to gather this important measurement.

As a result, all hydroxyl-abundance estimates are based on computer models, Hanisco said. "If you're going to make a prediction about climate change, you better be sure it's based on the facts. Everyone in this field knows we need to measure OH to better inform the models."

Think Differently

Given the need for more precise data, Hanisco thought it time to approach the challenge differently. While JPL's spectrometer is well respected and has provided useful data for several years, it's very

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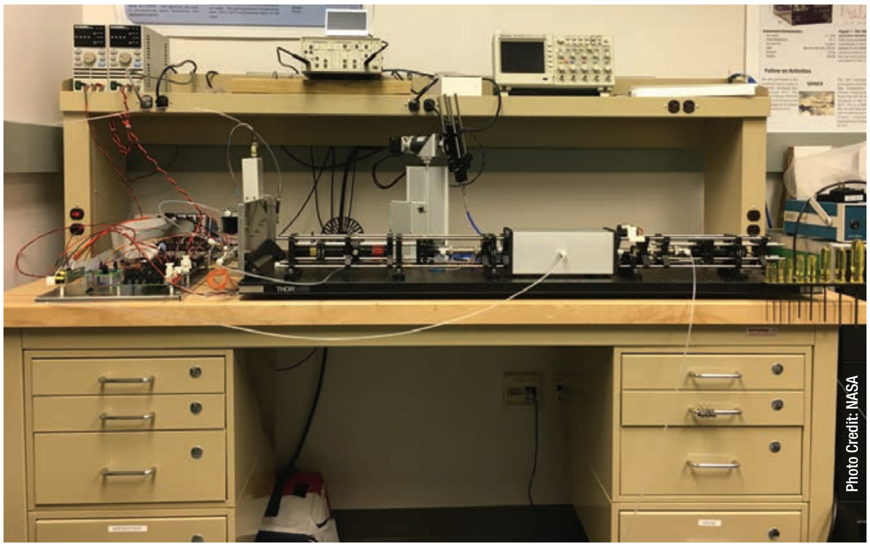
large and its measurements are limited to what's happening in the immediate environment around the Table Mountain Facility.

Hanisco wanted to create an instrument that could fly on a research aircraft and ultimately in space where global measurements could be taken daily. He applied for and received funding under Goddard's Internal Research and Development program to find out if a technique called gas filter correlation spectroscopy, which scientists have used to measure other types of atmospheric gases, would work equally well with hydroxyl.



Goddard scientist Tom Hanisco plans to take this portable, experimental instrument to JPL's Table Mountain Facility in California to measure hydroxyl.

"Atmospheric gases absorb sunlight at specific wavelengths of light," Hanisco said. Typically, costly spectrometers separate these wavelengths, producing spectra that reveal how much of a certain gas is getting absorbed in the atmosphere. "Our approach uses a gas filter cell to differentiate between the wavelengths of light," he said.

It works with an "on-off" switch. When on, the gas filter fills with hydroxyl and blocks all of the light at the wavelengths that hydroxyl absorbs. "This gives us the signal from the Sun that contains all of the absorbers in the atmosphere except hydroxyl," he said. When the gas filter cell is "off," light that hydroxyl has affected is included in the detected signal. The difference between the two signals is proportional to the abundance of hydroxyl in an atmospheric column, Hanisco said.

Making Hydroxyl

The difficulty is assuring that the cell contains enough short-lived hydroxyl to make a useful measurement.

To produce hydroxyl, the instrument employs a chemical process called photolysis by which molecules are broken down into smaller units through the absorption of light. In this case, hydroxyl forms from the breakdown of water. And by controlling the concentration of water, the instrument can make hydroxyl appear and disappear.

The instrument also employs highly reflective mirrors that essentially create a 457-foot-long optical path inside its 20-inch cavity. This special optical cell obtains this long path length by reflecting the light 1,000 times before the light can leave the cavity. This long path length makes it possible for even miniscule amounts of hydroxyl to absorb all of the light at wavelengths specific to hydroxyl.

Hanisco has taken preliminary measurements on a rooftop and the next step is showing that his instrument can make reliable and scientifically useful measurements at JPL's observatory soon.

"Sometimes Crazy Ideas Pay Off"

Should his instrument work, Hanisco believes its small size would make it ideal for aircraft campaigns, and ultimately, for use in space. "The near and long-term understanding of methane oxidation requires regional to global measurements with a portable instrument, preferably aircraft based and ideally space based. Our instrument concept is small enough to fill that role," he said.

If it doesn't work, Hanisco takes heart: "Sometimes these crazy ideas pay off. If you can measure hydroxyl with a small, highly portable instrument, people will be interested." ❖

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How Does the Wind Blow?

Goddard Scientist Pursues CubeSat-Compatible Instrument to Measure the Solar Wind

The solar wind streams off the Sun constantly, sometimes reaching supersonic speeds. Shockwaves that travel in this solar wind generate energetic particles that can pose threats to terrestrial power grids, telecommunications systems, aviation, and GPS — to say nothing of astronauts living and working in space — if it collides with Earth's magnetic field. That's why an early-warning system is so imperative.

Photo Credit: Bill Hrybyk/NASA

Goddard scientist EJ Summerlin (left) and University of Maryland astrophysicist Robert Michell (right) are altering an already-miniaturized spectrometer — the Dual Electrostatic Analyzer, or DESA — to measure protons within the solar wind to obtain details about its temperature, velocity, and density, among other physical conditions.

Goddard scientist Errol "EJ" Summerlin believes that a constellation of CubeSats, which individually are often no larger than a loaf of bread, could augment the space-based assets now monitoring the charged particles or plasma and embedded magnetic fields that make up the ever-varying solar wind. A constellation of identically equipped CubeSats could provide multipoint measurements that would help inform space weather alerts and forecasts.

But there's a hitch.

Replacing the State of the Art

The highly effective, go-to instrument for measuring the speed, temperature, and density of the solar wind aboard larger, more traditionally sized spacecraft — the so-called Faraday Cup — isn't easily miniaturized and could not be flown on a diminutive CubeSat.

However, Summerlin and his collaborator, University of Maryland astrophysicist Robert Michell, have devised a potential solution.

With funding from the Goddard Fellows Innovation Challenge, the team is altering an already-miniaturized spectrometer — the Dual Electrostatic Analyzer, or DESA — to measure protons within the solar wind to obtain details about its temperature, velocity, and density, among other physical conditions.

According to Summerlin, DESA was originally designed to measure energetic electrons in the magnetosphere. DESA does this by applying a voltage that curves the path that charged particles travel and deflects them onto a detector. For both protons and electrons, the amount of voltage applied depends only on the energy of the particle, he said.

However, in the solar wind, protons are a much more reliable measure of solar wind properties. Electrons come at the spacecraft from all directions and while they do, on average, move away from the Sun at roughly the same speed as the protons, the protons travel in roughly the same direction. The electrons travel more erratically. Their omnidirectional nature and susceptibility to spacecraft charging make electrons a poor choice for measuring bulk solar-wind properties, Summerlin said.

However, with a small adjustment to the polarity of the applied voltage, the DESA instrument can observe protons to reveal details about the solar wind.

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The Wind spacecraft has spent much of its time in space out in front of the magnetic fields – the magnetosphere – that surrounds Earth, observing the constant stream of particles flowing by from the solar wind. A Goddard scientist is creating a CubeSat-compatible instrument that would also study the solar wind.

"So, switching an electron spectrometer to detect protons is basically just a simple matter of reversing the polarity of the voltage applied," Summerlin said. The energies targeted by DESA are also the "sweet spot" for solar-wind proton measurements. Most of the protons in the solar wind have energies around that value.

The effort isn't without its technical challenges. Ideally, the instrument would be able to find the solar wind, which can suddenly change in intensity and direction. "Our instrument will scan all the different look directions looking for the solar wind and lock onto it. If the solar wind shifts suddenly, it starts to scan again to find the direction of the solar wind. These scans need to happen quickly, and that is a bit of a challenge for the electronics."

Instrument Characterization

With the funding, Summerlin and Michell are tackling the technical obstacles and building a virtual instrument that will be characterized through simulation. With a fully characterized design, they will be prepared to propose to other R&D funding opportunities to build a prototype instrument.

The timing is important, Summerlin said. The CubeSat revolution has already begun and the feasibility for deep-space small satellites and CubeSats is rapidly approaching. Summerlin has already identified several opportunities that could benefit from the instrument concept.

In one potential application, scientists would place as many as six CubeSats in a tight formation at the so-called L1 orbit about 932,000 miles from Earth toward the Sun — the same orbit that several other space weather-monitoring satellites have occupied. The most recent addition is NOAA's Deep Space Climate Observatory, or DSCOVR, which is now providing real-time solar wind data to inform alerts and forecasts. L1 is a good position from which to monitor the Sun because the constant stream of particles reaches L1 about an hour before reaching Earth.

With multiple CubeSats, scientists could use the multi-point measurements to study small-scale variations in the solar-wind plasma and magnetic fields.

Another application would spread as many as six small satellites along Earth's orbit both ahead and behind it. They would take images of the Sun in three dimensions and use an instrument like the one he and Michell are devising to measure the solar-wind plasma at those spots. As with terrestrial weather forecasting, these extra weather stations would allow scientists to improve the models and better predict space weather.

"This is an example of an instrument not staying in its lane," Summerlin said, referring to his concept and quest to use much smaller, less expensive spacecraft to keep tabs on the Sun and its weather. "It has the potential to negate the need for Faraday Cups and dramatically expand solar-wind measurement capabilities." ❖

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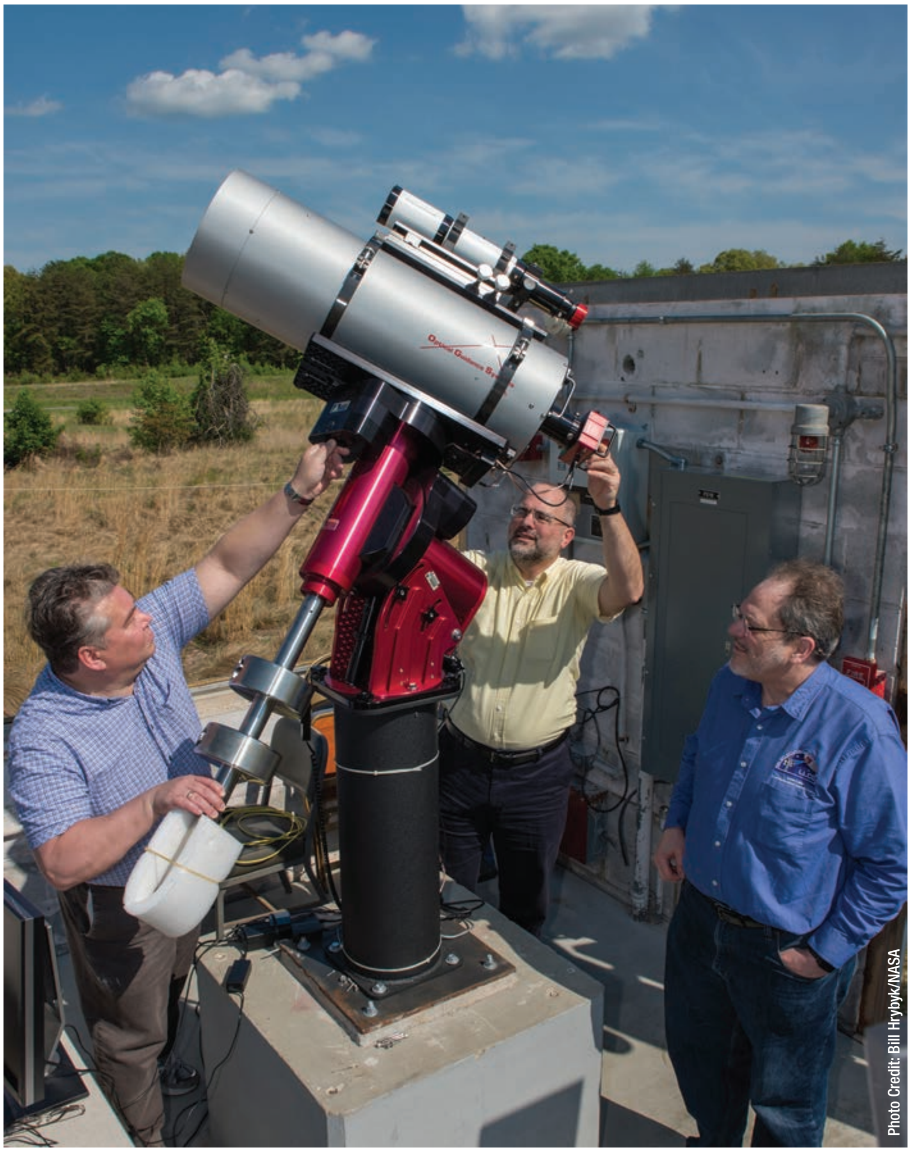
Goddard Team to Demonstrate Laser Communications with Low-Cost Ground Terminal

Delivering satellite data collected in low-Earth orbit and beyond involves zapping the information over radio frequencies. Once a ground-based receiving station gets the signal, ordinary telecommunications links route the information to the science center running the mission.

If NASA scientists and engineers have their way, however, terabytes of data would be encoded and transmitted on laser light to portable optical ground terminals set up at a scientist's place of work — a more direct route.



Engineers (from left to right) John Speer, Armen Caroglanian, and Robert Lafon have created a low-cost laser communications ground terminal that could help expand the use of this emerging technology.

To realize the vision, a Goddard team has assembled a low-cost optical, or laser, communications ground terminal at the Goddard Geophysical and Astronomical Observatory, or GGAO. The team wants to demonstrate the GGAO terminal — along with an important enabling technology called photonic lanterns — as it tracks and receives laser transmissions from two CubeSats making up NASA's Optical Communication and Sensor Demonstration, or OCSD, mission launched in late 2017.

Funded by NASA's Small Satellite Technology Program, the OCSD mission is demonstrating accurate optical communications between two small satellites working closely together in low-Earth orbit as well as downlinks to ground stations. The GGAO demonstration, which could happen in late summer or early fall, is not part of that effort. However, the GGAO team has requested that the OCSD mission point its laser at the Goddard terminal.

In addition to OCSD, NASA is sponsoring a number of laser communications projects. The emerging technology is important to the agency because it can provide data rates as much as 100 times higher than current radio frequency systems, using less mass and power.

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This panoramic image shows various facilities at the Goddard Geophysical and Astronomical Observatory — the location of a low-cost laser communications terminal.

Commercially Available Components Key

"Data rates are increasing very fast, but we need to build the infrastructure to make it easier to adopt the laser communications technology," said Robert Lafon, an optical physicist for Goddard's Laser and Electro-Optics Branch and one of the team members who developed the terminal. Lafon, electronics engineer Armen Caroglanian, and Goddard contractor John Speer believe ground receivers equipped with low-cost, commercially available telescopes and other components could hasten the widespread adoption of the technology.

"If we make ground terminals as inexpensive as possible by using commercial components, we think we can expand the user base and build the infrastructure," added Michael Krainak, a Goddard electro-optics engineer.

Having already tested the GGAO terminal by tracking and imaging the International Space Station as it zipped around Earth as well as a number of satellites, the team is optimistic about the terminal's ultimate success. "We have tracked and imaged satellites in low-Earth to geostationary orbit," Speer said.

Overcoming the Atmosphere

Earth's atmosphere, however, poses a real obstacle to a successful demonstration. As light travels through the air, it blurs the light and prevents a telescope from forming a sharp image. In fact, turbulence is what makes stars appear to twinkle.

Ground-based astronomical observatories have overcome the challenge by using systems, called adaptive optics, that sense and correct the aberrations by tipping and tilting a secondary mirror several times a second and splitting the incoming light into many small elements and correcting each element separately.

"Laser communications ground receivers often require that the signal they collect enter tiny optical fibers. Unfortunately, atmospheric turbulence blurs the received light and makes getting it into a small-diameter optical fiber very difficult. One way to get around this blurring effect is to use very costly and complicated adaptive optics systems to remove it, just like ground-based observatories do," Lafon said.

Photonic lanterns potentially offer a simpler alternative for low-cost laser communications terminals on the ground. This fiber-optic device has a large input optical fiber that allows users to capture the large turbulence-blurred spot. It then smoothly guides the light into the smaller fibers that the receiver uses. "It's like a large pipe that lets you catch all the light you receive and then guides it to smaller pipes where it can be more easily used by the receiver," Lafon explained.

For the GGAO demonstration, funded through Goddard's Internal Research and Development program, the team collaborated with Sarah Tedder, a Glenn Research Center technologist, and Sergio Leon-Saval, a University of Sydney researcher and one of the technology's original developers, to fabricate a couple different photonic lanterns. Both will be tested during the GGAO demonstration, Lafon said.

In the long term, the team envisions a future where scientists could use portable, low-cost terminals to directly receive their data. "If you can build a standardized network, it will make it easier for potential users to adopt it. I believe it's just a matter of time. Laser communications are inevitable," Lafon said. ❖

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The Next Step in NASA's Hunt for Life

Scientist Begins Developing Instrument Concept for Finding Extraterrestrial Bacteria

A Goddard scientist wants to create a planetary robot that would mimic what biologists do every day in terrestrial laboratories: look through microscopes to visually identify microbial life living in samples.

Goddard scientist Melissa Floyd holds her 3D-printed FISHbot prototype, which she is advancing to search for bacterial life on Mars and other solar system targets.

Although very early in its technology development, the concept would take NASA's hunt for extraterrestrial life to the next level by actually looking for Bacteria and Archaea in soil and rock samples. So far, NASA's rovers have carried tools and instruments designed to look for biosignatures or signs of life that indicate habitability, not life itself, regardless of how primitive.

"Life exists everywhere on Earth, even in places that are incompatible to humans," said scientist Melissa Floyd, who is using Goddard Internal Research and Development program support to automate subsystems for a laboratory breadboard called FISHBot. "I had this idea, actually a major assumption on my part: what if life evolved on Mars the same way it did here on Earth? Certainly, Mars was bombarded with the same soup of chemistry as Earth."

It's not a huge assumption to make, she added. Nucleotides — the molecules that form deoxyribonucleic acid and ribonucleic acid — have been found in comets. Better known as DNA and RNA, these molecules store and transfer genetic information at a cellular level in all living organisms on Earth.

Search for Bacteria and Archaea

To find life on another planet, Floyd's robotic instrument would concentrate on identifying Bacteria and Archaea, members of a large group of single-cell microorganisms that thrive in diverse environments and are thought to be the first organisms to appear on Earth about four billion years ago. On Earth, one gram of soil typically contains about 40 million bacterial cells and a milliliter of fresh water usually holds one million cells.

Her concept, which she believes could deploy as a stand-alone robot or one of several instruments on a rover, relies on a widely used technique called fluorescent in situ hybridization — or FISH — developed to detect and locate the presence or absence of RNA or single-stranded DNA sequences on chromosomes. These threadlike structures are found in the nuclei of most living cells and carry genetic information in the form of genes. Since its development, FISH has been used for genetic counseling, medicine, and species identification.

When performed in a laboratory, FISH involves, among other things, applying a sample to a slide, fixing the cells to increase cell-wall permeability, adding a nucleotide "probe" — a short sequence of typically 15 to 20 nucleotides along with a fluorescent tag for faster identification — and heating the sample. The slide is then placed under a microscope. When the nucleotide probe attaches to a similar nucleotide in the sample, it literally fluoresces or glows under a fluorescence microscope, helping researchers to identify the organism.

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"I'm trying to determine whether I can do the same thing with a robot," Floyd said, adding that she would want the system to carry as many as 10 probes to identify a broad range of single-cell organisms. "If there are even fragments of highly conserved genetic sequences that we see in every corner of Earth, FISH will be the tool capable of detecting it."

The Automation Challenge

The challenge, she said, is simplifying and automating the process so that samples can be prepared on individual slides, heated, and automatically rotated for viewing under a microscope, which likely would have to be focused many times to see deep within the sample. With her funding, Floyd is developing the automated subsystems, including a focuser.

"The idea here is to replace with a robotic system what a scientist does in the lab," she said. "I could be completely wrong" about life taking root on Mars or another solar system body in the same way that it did on Earth. "But how do we know? We've never looked." ❖

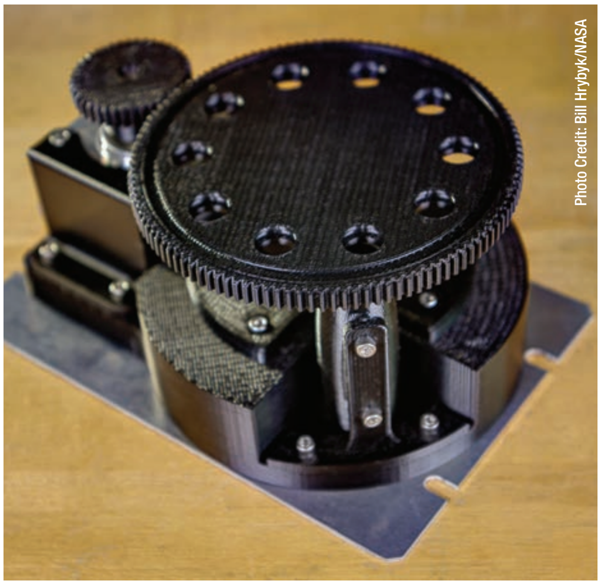

Photo Credit: Bill Hrybyk/NASA

This is a close-up of the FISHbot prototype.

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Conclusion of SPECIAL REPORT

Goddard-Developed Coating Investigated for Protecting Smithsonian Specimens

A technology that has shielded some of NASA's highest-profile space observatories from potentially harmful molecular contamination is now being evaluated as a possible solution for protecting the Smithsonian Institution's cultural artifacts and natural-science specimens.

Under a Space Act Agreement with the Smithsonian Institution's National Museum of Natural History, Goddard Thermal Coatings Engineer Nithin Abraham, her team, and museum conservators are testing the effectiveness of a patent-pending, sprayable coating that Goddard engineers originally created with center R&D funding to entrap outgassed molecular contaminants and prevent them from adhering to sensitive instruments and components.

Made of zeolite, a mineral widely used in water purification, and a colloidal silica that acts as a glue holding the coating together, the Molecular Adsorber Coating, or MAC, is highly permeable and porous — attributes that allow it to trap contaminants that outgas in a process similar to what creates the new car smell in vehicles. Because it doesn't contain volatile organics, the coating itself doesn't cause additional outgassing. Easy to use, the coating can be applied directly to the hardware itself or on varying-sized panels that are inserted inside instrument cavities and test chambers.

Target Contamination: Mercury Vapor

Under the one-year research effort begun last summer, Goddard and museum personnel are determining whether MAC can reduce the presence of mercury vapor and other contaminants that offgas from plant and mineral specimens, tainting specially

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Goddard Thermal Coatings Engineer Nithin Abraham removes samples treated with a patent-pending adsorber from specimen-storage cabinets at the Smithsonian's Museum Support Center in Suitland, Maryland, a sprawling storage facility that holds more than 54-million collection items. Image Inset: The adsorber technology that Goddard technologists originally developed to trap harmful contaminants that outgas from instrument components is highly porous — a characteristic that allows it to entrap contaminants.

designed metal cabinets at the Museum Support Center in Suitland, Maryland, a sprawling storage facility that holds more than 54-million collection items.

These offgassed chemicals pose health risks to humans and degradation to specimens, said Collections Program Conservator Catharine Hawks, who has used a wide range of techniques and materials to take up and hold vaporized contaminants in both exhibit and stored specimens. "Conservators are constantly faced with problems of volatile contaminants — either cross-contamination among collection materials or contaminants that come from materials used with collections," she said. "Consequently, we're always in need of technologies to provide protection."

Learning of the Goddard-developed coating, Hawks said she and other museum conservators thought it worthwhile to explore MAC's effectiveness in artifact protection. Abraham agreed. "We thought this collaboration presented us with an interesting opportunity to explore how MAC would perform in terrestrial environments," she said. "We have quite extensively tested the coating to mitigate outgassing in vacuum environments for space applications, but not in ambient conditions."

NASA Uses

To date, NASA engineers have used the coating to entrap hydrocarbons, plasticizers, and silicones that outgas and spread easily inside thermal-vacuum chambers and other test facilities. To prevent these contaminants from affixing, Abraham and her team treated specially made panels with MAC and placed them in strategic locations inside these facilities. The James Webb Space Telescope, the Advanced Topographic Laser Altimeter System, the Global-scale Observations of the Limb and Disk, and the Magnetospheric Multiscale Mission, among others, have all benefited from MAC, Abraham said.

However, its use hasn't been restricted to ground-based vacuum chambers. NASA's Ionospheric Connection Explorer, or ICON, mission, which will study the dynamic zone in the atmosphere where Earth weather and space weather meet, makes use of the coating.

"This is the first flight application of MAC within an instrument cavity," Abraham said. Several MAC-treated plates will mitigate on-orbit molecular

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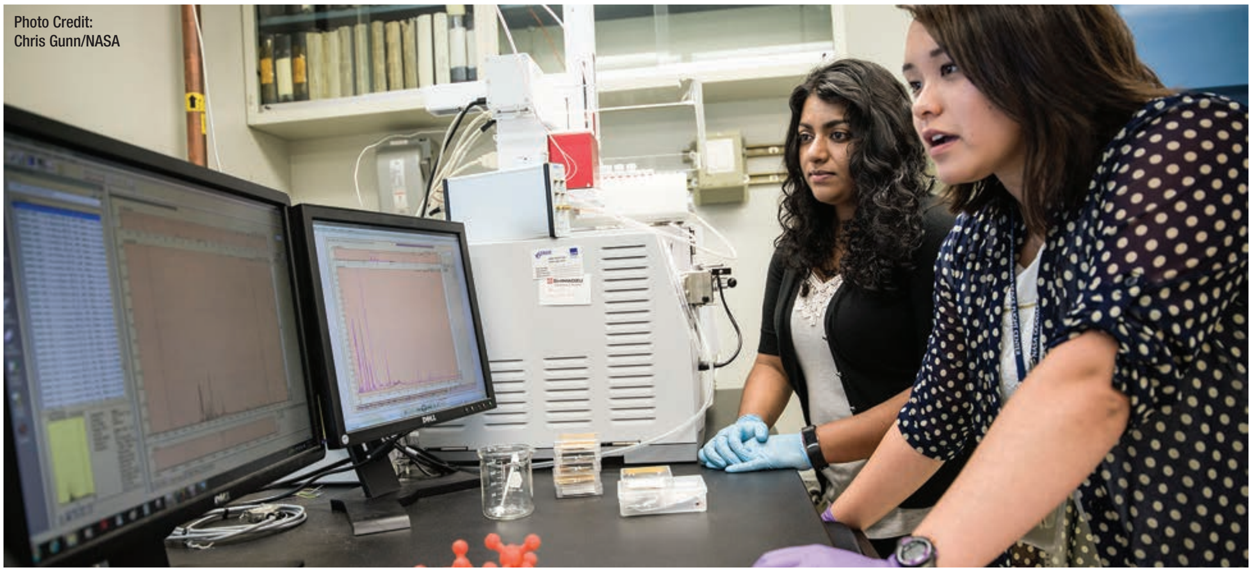

Jennifer Domanowski (forefront) and Nithin Abraham begin evaluating the effectiveness of a Goddard-developed adsorber coating for removing mercury vapor and other contaminants inside Smithsonian-owned specimen-storage cabinets.

outgassing within ICON's sensitive far-ultraviolet instrument. In addition, NASA's Global Ecosystem Dynamics Investigation, known as GEDI, also plans to fly the coating when it launches later this year.

Analysis Underway: Jury is Out

The goal of the museum experiment initially focused on determining if more than 100 MAC-treated samples affixed to the doors of three storage cabinets could adsorb mercury vapor from both botanical and mercury-based mineral ores. Although the museum never used mercury-based chemicals to preserve its plant specimens, Hawks said many collectors and preparators used them widely for nearly two centuries. Given the fact that the Smithsonian's collections come from institutions worldwide and, in some cases, are very old, mercury offgassing has become a persistent problem.

The more recent use of vapor-impermeable bags has helped mitigate the offgassing, Hawks said. However, before their use, the mercury vapor had already contaminated the cabinets and is proving resistant to cleaning. "We wondered if MAC panels could be used to take up the residual vapor that is coming from these surfaces," she said. The experiment has since been expanded to determine exactly which contaminants MAC adsorbs in ambient conditions, where atmospheric offgassing of materials occurs.

After spending a year affixed to the doors, it's not yet clear whether MAC is effective at trapping mercury vapor. "It's been a challenging yet insightful process evaluating this," Abraham said. Abraham's team will collect all the samples by early August and is now testing earlier exposed samples to see what chemical constituents the coating did collect. However, initial analysis has indicated that the samples are trapping a number of other contaminants. She expects final results in a couple months.

"We really won't know how well the MAC is working until after Nithin completes the analysis. Whether or not the MAC is successful for mercury, we'll be very interested in knowing about any chemical species the technology adsorbs," Hawks said.

Abraham is equally interested. The collaboration allowed her to study how well the technology works in ambient or non-vacuum conditions, and how she and her team could possibly tailor the coating to make it even more effective for both space and terrestrial applications. She also believes this work could lead to future museum collaborations, which could lead to additional technology improvements, to say nothing of the potential licensing opportunities with companies that manufacture cabinets for specimen storage.

"This was definitely a worthwhile learning experience," Abraham said, adding that the team plans to write a technical paper about the coating's effectiveness once testing is complete. "We have gained valuable knowledge on better ways to test the coating and advance the technology for distinct applications." ❖

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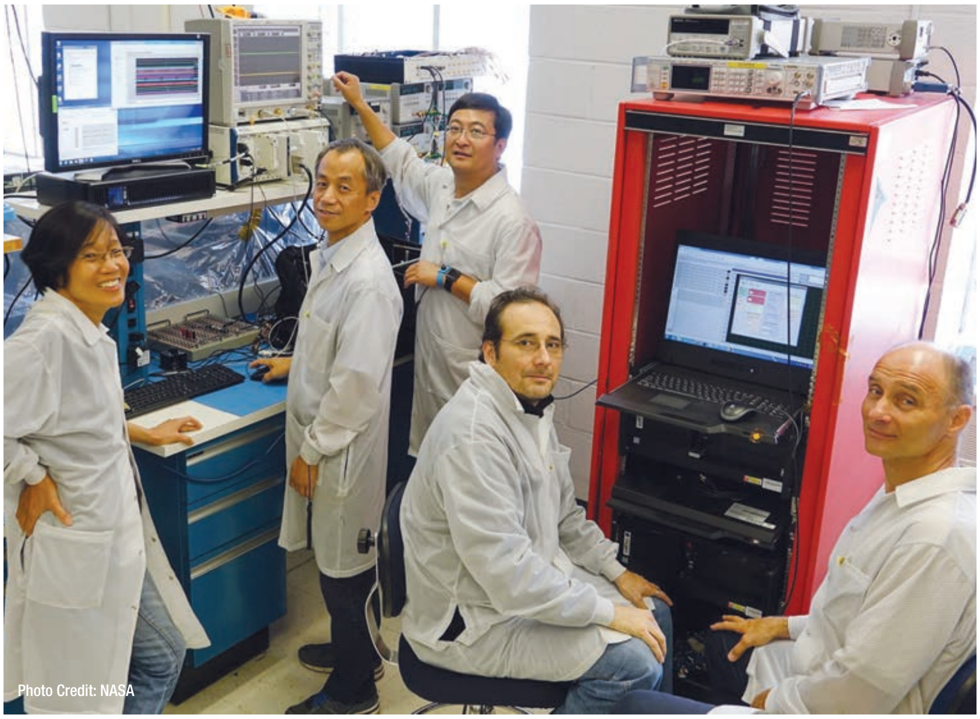
Disruption Tolerant Networking to Demonstrate Internet in Space

NASA's Human Exploration and Operations and Science Mission Directorates are collaborating to make interplanetary internet a reality.

They've identified an Earth science mission as the first to demonstrate Delay/Disruption Tolerant Networking, or DTN — a technology that sends information much the same way as conventional internet does. Information is put into DTN bundles, which are sent through space and ground networks to its destination.



NASA's new Plankton, Aerosol, Cloud, ocean Ecosystem, or PACE, mission has been identified as the first space mission to use a new communication technology. From left to right are the engineers helping to build the mission: Nga Cao, Steve Feng, Wei Lu, Chris Zincke, and Zoran Kahric.

Unlike the internet, where data packets are discarded when encountering a disconnection, DTN guarantees delivery even if interruptions occur. If the bundle fails to transmit because of unavailable links, DTN stores the bundles and waits until the next communication path opens. Each DTN node or router can accept custody of the bundle and forward or retransmit the data, eliminating the need for an entire data retransmission from the original source should a disruption occur. This, in turn, saves time and more quickly frees up the limited data memory aboard a spacecraft — an important feature given the large amounts of data collected by satellite instruments.

PACE Identified as First User

The Science Mission Directorate has identified the Plankton, Aerosol, Cloud, ocean Ecosystem, or PACE, mission as the first key opportunity to demonstrate this revolutionary capability.

The Jet Propulsion Laboratory first tested DTN during a science mission to a comet in 2008. That technology demonstration proved the DTN capability as part of the Deep Impact-EPOXI mission. PACE will take an important next step in using DTN as part of daily operations.

"Speaking for myself, I'm delighted that PACE is identified as the first science mission to employ the technology," said David Israel, Goddard space communications architect and DTN development team member.

Targeted to launch in the early 2020s, PACE will advance scientists' ability to assess the health of Earth's oceans by measuring the distribution of phytoplankton, tiny plants, and algae that sustain the marine food web. It will also continue systematic records of key atmospheric variables associated with air quality and Earth's climate.

Antarctica Demonstration

The decision to infuse DTN on a space platform comes just months after NASA engineers demonstrated the technology from the National Science Foundation's McMurdo Station in Antarctica — a

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highly remote location with limited communications infrastructure.

The demonstration showed that NASA could operate "internet style" between two endpoints within two different networks that do not have a continuous path between them, Israel said.

DTN could become a communication necessity for all types of terrestrial applications. Any remote location on Earth that has limited network connectivity is a candidate for DTN, Israel said.

Taken at the National Science Foundation's McMurdo Station in Antarctica, this selfie made its way to the space station on Nov. 20, 2017 using a technology called Disruption Tolerant Networking. NASA engineers Mark Sinkiat, Peter Fetterer, and Salem El-nimri held up a picture of Vint Cerf, a distinguished visiting scientist at NASA's Jet Propulsion Laboratory who helped develop the technology.

NASA plans to build a Solar System Internet with international partners, beginning with NASA's Near-Earth Network, Space Network, and Deep Space Network, Israel added. Both the Solar System Internet concept and DTN are part of NASA's Decade of Light initiative, through which the agency is developing and refining next-generation communications and navigation technologies for use in future science and exploration missions. Exploration missions will use DTN to expand the network to the Moon, allowing communication between surface and orbiting elements and with Earth.

"We're really pushing to get DTN in use," Israel said, referring to NASA's identification of PACE as the first mission to use the technology for daily operations. "This is an important first step in that process." ❖

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Science on a Shoestring

Goddard Team Delivers Low-Cost, Ruggedized Radiometer for CubeSat Mission

A novel instrument that has already proven its mettle on field campaigns will attempt to measure atmospheric greenhouse gases early next year during a low-Earth-orbiting CubeSat mission called Mini-Carb — marking the first time this type of instrument has flown in space.

Goddard scientist Emily Wilson is teaming with the Lawrence Livermore National Laboratory, or LLNL, to fly a smaller, more ruggedized version of her patented mini-Laser Heterodyne Radiometer, or mini-LHR, on an LLNL-built CubeSat platform next year.

Wilson has demonstrated the ground-based mini-LHR during several field campaigns in Alaska, the Amazon River Basin, and the Royal Observatory in Edinburgh, Scotland, among other locations. Highly portable, the mini-LHR is comprised of commercially available components and literally can go anywhere to gather measurements.

Although NASA is currently measuring carbon dioxide from space, the agency has never flown a laser heterodyne radiometer to do the job.

The instrument's advantage is that it offers high-spectral resolution, is compact, and includes no moving parts, Wilson said. Furthermore, the instrument can measure three greenhouse gases: in addition to carbon dioxide, her instrument can simultaneously measure water vapor and methane in Earth's atmospheric limb. "And compared with more traditional instruments, our instrument costs a small fraction to build," Wilson said. "This is the epitome of science on a shoestring."

Flight Aboard New CubeSat Bus

About the size of a toaster, the flight version of her instrument will fly as the only payload on LLNL's new, 11-pound 6U CubeSat bus known as the CNGB — short for CubeSat Next Generation Bus.

The CubeSat Office at the National Reconnaissance Office originated the CNGB concept, funding researchers at LLNL, the Naval Postgraduate

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School, and the Space Dynamics Laboratory to develop a government-owned nano-satellite architecture that could support a broad range of missions. Mini-Carb is the first mission to do so.

Technologists integrate a Goddard-developed instrument into Lawrence Livermore National Laboratory's (LLNL) CubeSat bus. Those pictured include LLNL's Lance Simms (front) and from left to right: Vincent Riot (LLNL), A.J. DiGregorio (Goddard), Jennifer Young (Goddard), and Guru Ramu (Goddard).

"Emily had a payload without a satellite and we had a spacecraft without a payload," said Vincent Riot, an LLNL engineer who helped develop the CNGB bus, which offers users a plug-and-play capability that allows for rapid configuration and integration. "That's where this partnership formed. This is a proof-of-concept mission to show that we can do excellent science with the CNGB platform," Riot said.

The debut flight of both Wilson's instrument and LLNL's CubeSat is slated for January 2019. Wilson and her team recently delivered the instrument to LLNL where they helped integrate the instrument into the spacecraft in preparation for flight.

Upper Troposphere, Lower Stratosphere Targeted

Once in orbit, Mini-Carb will observe the region between the upper troposphere to the lower stratosphere between six and 18 miles above Earth's surface. Measurements in this atmospheric region provide important information about stratospheric circulation and how it responds to increasing greenhouse gas concentrations.

"Measuring stratospheric circulation and its variability is essential for projecting how climate change will affect the stratospheric ozone," Wilson said.

Scientists believe that the projected increases in methane and carbon dioxide this century will affect several physical processes that drive climate change, she said. Methane, which is especially long-lived, results in the increased production of stratospheric water vapor and hydroxide, which directly affects ozone, the layer that protects Earth from harmful ultraviolet radiation.

"Because of methane's role in the changing chemistry of the ozone layer and because of its long lifetime, methane measurements are especially valuable," Wilson said.

Like its ground-based sibling, the Mini-Carb instrument is made of commercial parts and operates passively — that is, it collects sunlight that has absorbed the targeted greenhouse gases. That light is combined with laser light tuned to the infrared wavelengths and then amplified. Through a series of other steps, the instrument can reveal the concentrations of the greenhouse gases contained in the atmosphere.

While Wilson originally developed both the ground- and space-based instruments for studying climate change on Earth, the instrument also could be employed on a probe or lander to study the atmospheric conditions on other planets, she said.

Gauging Success

The immediate goal, however, is demonstrating Mini-Carb in space.

"If we get one measurement, I'll consider it a success. There is potential for an extension if the mission works," Riot said. "If this works, our success could lead to bigger projects down the road," Wilson added. "This is a very big deal for us." ❖

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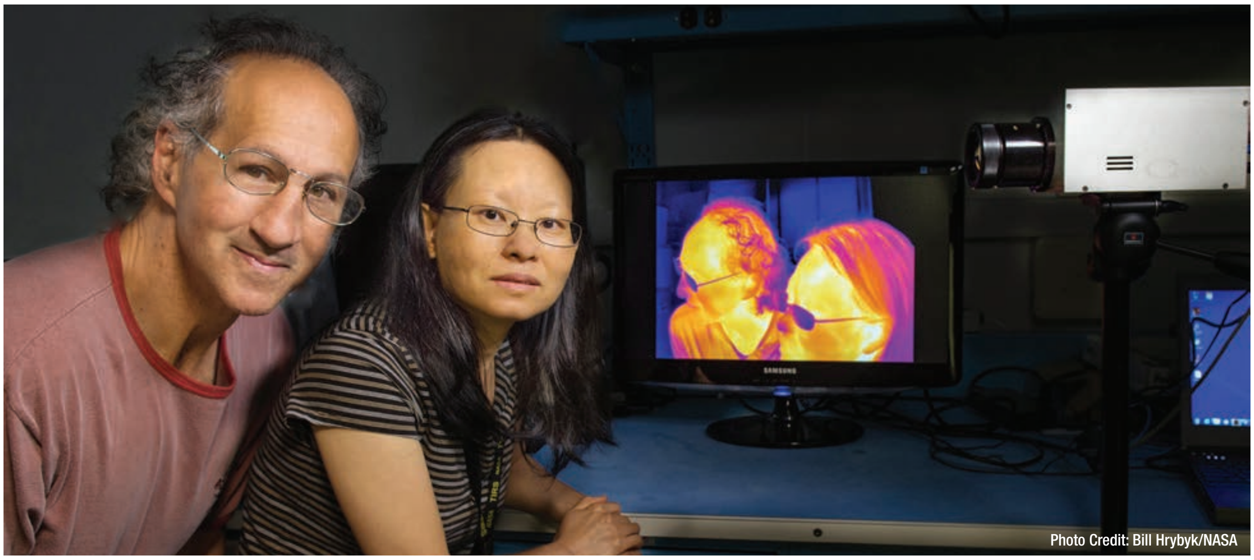
Next-Generation Photodetector Camera to Deploy During Robotic Servicing Demonstration Mission



Goddard detector engineer Murzy Jhabvala (left) and his team, including Anh La (right) and Don Jennings (not pictured), advanced a new detector technology called Strained-Layer Superlattice that is pictured in the background.

Testing tools and technologies for refueling and repairing satellites in orbit won't be the only demonstration taking place aboard the International Space Station during NASA's next Robotic Refueling Mission 3, or RRM3.

An advanced, highly compact thermal camera that traces its heritage to one now flying on NASA's Landsat 8 has been mounted in a corner of the RRM3 payload and from that position will image and videotape Earth's surface below once the SpaceX Dragon resupply vehicle delivers the payload to the orbiting outpost in November.

While RRM3 demonstrates its specially developed satellite-servicing tools advanced by Goddard's Satellite Servicing Projects Division, its hitchhiker companion, the Compact Thermal Imager, or CTI, will image and measure fires, ice sheets, glaciers, and snow surface temperatures.

CTI will also measure the transfer of water from soil and plants into the atmosphere — important measurements for understanding plant growth. Many of the conditions that Earth scientists study, including these, are easily detected in the infrared or thermal wavelength bands.

Strained-Layer Superlattice Technology Enables CTI

CTI's enabling technology is a relatively new photodetector technology known as Strained-Layer Superlattice, or SLS.

In addition to being very small, measuring nearly 16 inches long and six inches tall, SLS consumes little power, operates at liquid-nitrogen temperatures, is easily fabricated in a high-technology environment, and is inexpensive "almost to the point of being disposable," said Goddard detector engineer Murzy Jhabvala, who collaborated with his industry partner, the New Hampshire-based QmagiQ, to develop the SLS detector assembly.

The detector technology is also quickly and easily customized for different applications, he added. The Goddard Detector Development Laboratory, for example, recently fabricated a 1,024 x 1,024-pixel SLS array and plans to increase its size to 2,048 x 2,048 pixels in the very near future.

Another enabling technology that CTI and its SLS detectors will employ is the Goddard-developed SpaceCube 2.0, a powerful hybrid computing system that will control the instrument and process the images and video that it takes while in orbit.

The demonstration's goal, Jhabvala said, is to raise SLS's technology-readiness level to nine — or TRL-9 — meaning that it has flown in space and has demonstrated that it operates well under the extreme environmental conditions found in space.

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"This is a very important technology milestone," Jhabvala said. "We needed this mission. When we demonstrate our detector array, multiple copies can be made, assembled, and aligned into focal plane arrays that would allow us to image large swaths of Earth's surface from space in the future."

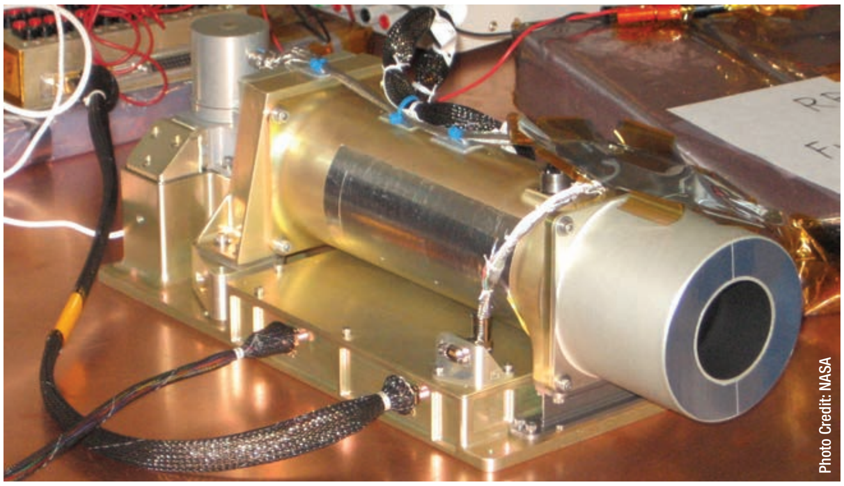

Photo Credit: NASA

This image shows the advanced detector technology that will be demonstrated on NASA's upcoming robotic servicing demonstration mission.

QWIP Based

SLS is based on the Quantum Well Infrared Photodetector, or QWIP, technology that Jhabvala and his government and industry collaborators spent more than two decades refining. The QWIP detectors are now operating on Landsat 8 and will be flying on the upcoming Landsat 9 Thermal Infrared Sensor instrument, which Goddard scientists built to monitor the ebb and flow of land-surface moisture levels and the health of vegetation — data that western states use to monitor water consumption.

Like its QWIP predecessor, SLS is a large-format detector. The arrays are fabricated on a semiconductor wafer. The wafer's surface consists of hundreds of alternating, very thin layers of differing materials that are epitaxially grown and tuned to absorb infrared photons and convert them into electrons — the fundamental particles that carry an electric current. Only light with a specific energy, or wavelength, can release the electrons. A read-out chip directly mated to the array then converts the electrons to a voltage that a computer uses to recreate an image of the infrared source. The CTI can also capture video from its orbit nearly 249 miles above Earth's surface.

Ten Times More Sensitive

Compared with its QWIP predecessor, SLS detectors are 10 times more sensitive and operate over a broader infrared spectral range and at substantially warmer temperatures — 70K (about -334 degrees Fahrenheit) for the SLS array compared with 42K (about -384 degrees Fahrenheit) for the QWIP array.

The increase in operating temperature will have multiple positive effects on future missions, Jhabvala said. Infrared radiation is sensed as heat. Therefore, detectors designed to measure infrared wavelengths must be cooled to prevent heat generated inside an instrument or spacecraft from contaminating the measurements of the object being observed. That's why engineers use cryocoolers and other devices to keep the detector arrays and other critical instrument components as cold as necessary.

Because Jhabvala and his team have created an array that can operate at warmer temperatures, its cooling system is smaller and consumes less power. In the future, these attributes will lead to smaller satellites, increased longevity, shorter build cycles, and lower costs, Jhabvala said.

Just a few months before the RRM3 launch, Jhabvala reflected on the evolution of his photodetector technology and collaboration with QmagiQ, which has received NASA Small Business Innovation Research grants to create the technology that the CTI team then ruggedized for use in space.

"Together, with this company, we have made some outstanding achievements over the years," Jhabvala said. "Our on-going collaboration has yielded some truly extraordinary returns for NASA and the U.S. government. I give QmagiQ and NASA a lot of credit." ❖

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Cutting edge Goddard's Emerging Technologies

CuttingEdge is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Maryland. The publication describes the emerging, potentially transformative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, *Peter.M.Hughes@nasa.gov*. If you wish to be placed on the publication's distribution list, contact Editor Lori Keesey, *Lori.J.Keesey@nasa.gov.* NP-2018-07-233-GSFC