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Cutting edge

Goddard's Emerging Technologies

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Discovery in a Headset

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Better than Reality

Goddard Scientists Tap Virtual Reality to Make a Scientific Discovery

Many are familiar with virtual reality (VR) to experience out-of-this-world video gaming, but few may be aware that it can be used to make scientific discoveries.

Using a customized, Goddard-developed 3-D simulation that animated the speed and direction of four million stars in the local Milky Way neighborhood, Goddard astronomer Marc Kuchner and researcher Susan Higashio obtained a new perspective on their motions, which helped them classify star groupings.

Kuchner presented the findings at the annual American Geophysical Union (AGU) conference in early December 2019. Kuchner, Higashio, and Goddard engineer Tom Grubb also plan to publish a paper on their findings next year.

Astronomers have studied the same groups of stars in six dimensions using graphs, Higashio said. Groups of stars moving together indicate to astronomers that they originated at the same time and place, from the same cosmic event. However, their interpretations of which stars belonged together varied. By animating those same stars in virtual reality, they found stars that may have been classified in the wrong groups as well as star groups that could belong to larger groupings.

"Rather than look up one database and then another database, why not fly there and look at them all together," Higashio said. She watched these simulations hundreds, maybe thousands of times, and said the associations between the groups of stars became more intuitive inside the artificial cosmos found within the VR headset. Observing stars in VR will redefine astronomer's understanding of some individual stars as well as star groupings.

The 3-D visualization helped her and Kuchner understand how the local stellar neighborhood formed, opening a window into the past, Kuchner said. "We often find groups of young stars moving together, suggesting that they all formed at the same time," Kuchner said. "The thinking is they

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About the Cover

Goddard engineer Matthew Brandt, a member of Tom Grubb's AR/VR team, created a 3-D simulation that animated the speed and direction of four million stars in the local Milky Way neighborhood. Goddard astronomer Marc Kuchner and researcher Susan Higashio used the virtual reality program to obtain a new perspective on their motions, which helped them classify star groupings. They reported their findings at a recent scientific conference and an additional paper is planned.

Photo Credit: Chris Gunn/NASA

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Virtual reality technologies developed under Goddard and NASA R&D programs have allowed scientists to make a scientific discovery involving star groupings. The findings were reported during a recent scientific conference.

represent a star-formation event. They were all formed in the same place at the same time and so they move together."

"Planetariums are uploading all the databases they can get their hands on, and they take people through the cosmos," Kuchner added. "Well, I'm not going to build a planetarium in my office, but I can put on a headset and I'm there."

Realizing a Vision

The discovery realized a vision for Goddard Chief Technologist Peter Hughes, who saw the potential of VR to aid in scientific discovery when he began supporting Grubb's VR project more than three years ago under the center's Internal Research and Development (IRAD) program and NASA's Center Innovation Fund *(CuttingEdge, Summer 2017, Page 18).* "All of our technologies enable the scientific exploration of our universe in some way," Hughes said. "For us, scientific discovery is one of the most compelling reasons to develop an AR/VR capability."

Scientific discovery, however, isn't the only beneficiary, Grubb stressed.

The VR and augmented reality (AR) worlds can help engineers across NASA and beyond, Grubb said, explaining that VR puts the viewer inside a simulated world, while AR overlays computer-generated information onto the real world. Since the first "viable" headsets came on the market in 2016, Grubb said his team began developing solutions, like the star-tracking world Kuchner and Higashio explored, as well as virtual hands-on applications for engineers working on next-generation exploration and satellite servicing missions.

Engineering Applications

Grubb's VR/AR team is now working to realize the first intra-agency virtual reality meetups, or design reviews, as well as supporting missions directly. His clients include the Satellite Servicing Capabilities Division's Restore-L mission, a robotic spacecraft equipped with tools, technologies, and techniques needed to extend satellites' lifespans, the Wide Field Infrared Survey Telescope mission, and various planetary science projects.

"The hardware is here; the support is here," Grubb said. "The software is lagging, as well as conventions on how to interact with the virtual world. You don't have simple conventions like pinch and zoom or how every mouse works the same when you right click or left click."

That's where Grubb's team comes in, he said. To overcome these usability issues, the team created a framework called the Mixed Reality Engineering Toolkit (MRET) and is training groups on how to work with it. Funded by IRAD, MRET assists in science-data analysis and is enabling VR-based engineering design, from concept designs for CubeSats to simulated hardware integration and testing for full-fledged missions and in-orbit visualizations like the one for Restore-L.

For engineers and mission and spacecraft designers, VR offers cost savings in the design/build phase before they build physical mockups, Grubb said. "You still have to build mockups, but you can work out a lot of the iterations before you move to

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Proposed SETH Mission Could Pave the Way for SmallSat Firsts

NASA to Announce Winner of Mission Competition by End of 2020

Photo Credit: Chris Gunn/NASA

Principal Investigator Antti Pulkkinen (right) won Phase-A funding to advance a new SmallSat concept that would demonstrate optical communications technologies and an instrument, now being developed by scientist Nikolaos Paschalidis (left), that could serve as a harmful-radiation, early-warning system for astronauts.

NASA already has big plans for transmitting gigabytes of data using lasers, but so far that ambition has been confined to near-Earth or larger deep-space missions.

That could change with a proposed small-satellite mission specifically designed to demonstrate miniaturized optical communications technologies capable of handling large data rates from deep space and a new instrument that could serve as a harmful-radiation, early-warning system for astronauts.

The agency's Heliophysics Division chose the Science-Enabling Technologies for Heliophysics, or SETH, for Phase-A funding under its first-ever mission solicitation dedicated exclusively to demonstrating and maturing technologies needed in the future. If selected over another mission concept that also received Phase-A funding, SETH would fly as a secondary payload on NASA's Interstellar Mapping and Acceleration Probe (IMAP) set to launch in 2024. NASA is expected to choose between the two by the end of 2020.

"We're very excited," said SETH Principal Investigator Antti Pulkkinen, who is leading a team comprised of experts from Goddard, the Jet Propulsion Laboratory (JPL), Lowell Observatory, Fibertek Inc., and City University of New York. "We will demonstrate unprecedented high data rates using optical communications and a novel science capability that could also potentially save the lives of astronauts living beyond low-Earth orbit — all from one small-satellite platform. This solicitation is a first for NASA's Heliophysics Division. I think SETH is also paving the way for a number of firsts."

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Optical Communications via a Small Satellite

Although NASA is now developing the Laser Communications Relay Demonstration to validate an optical or laser communications system in geosynchronous orbit, SETH would be the first deep-space mission equipped with miniaturized, less-complex space and ground terminals capable of a hundred-fold increase in data rates over traditional radio communications. The demonstration would occur well past geosynchronous orbit at a distance of about 10-20 million miles from Earth.

"We are unique compared with other optical communications efforts. We would be the first deep-space SmallSat that will send data over laser light," Pulkkinen said. Although partner JPL is participating in the Deep Space Optical Communications demonstration, its flight terminal — the device that embeds data onto the optical light and transmits to ground stations — is "far too large for SmallSats and CubeSats," Pulkkinen said. "Another very exciting feature of our mission is beaconless optical communications and optical-ranging experiments that have far-reaching implications for all space communications."

SETH Science-Enabling Technologies for Heliophysics

Image Credit: NASA

SETH's technology, once proven, could reduce the burden on NASA's Deep Space Network and provide scientists with a more robust means to more efficiently transmit and receive copious amounts of data from deep-space small satellites.

SETH's technologies, once proven, could ease the burden on NASA's future deep-space missions by reducing spacecraft size, weight, and power consumption, which would lower overall mission costs.

In addition, these technologies could ease the burden on NASA's Deep Space Network and provide scientists with a more robust means to more efficiently transmit and receive copious amounts of data from deep-space SmallSats. Such a capability would support the deployment of constellations of SmallSats capable of gathering multi-point, simultaneous measurements across the heliosphere. "Radio-based communications systems aren't adequate enough for our next-generation science," Pulkkinen said.

HELENA Offers New Insights

Another SETH first is a new instrument, called the HELio Energetic Neutral Atom (HELENA) detector. Developed by Goddard scientist Nikolaos Paschalidis with Goddard Internal Research and Development program funding, HELENA would provide the first-ever, unambiguous detection of solar energetic neutral atoms (ENAs) erupting from the Sun. ENAs are a key component in a sequence of space weather events that can be life-threatening to humans living and working beyond Earth's protective magnetic shield and disruptive to terrestrial power grids and communications systems.

During coronal mass ejections (CMEs), for example, the Sun ejects large clouds of plasma and accompanying magnetic field that travel across the solar system. ENAs contained in these eruptions follow a straight line and arrive before the more massive amounts of potentially life-threatening charged particles whose trajectories follow the arched path of the Sun's magnetic field lines. The 2012 Heliophysics Decadal Survey recognized the critical role that ENAs could play as an early-warning system alerting astronauts to a potentially life-threatening event — if ENAs could be detected.

Designed to detect ENAs, HELENA could be deployed as a detector to warn astronauts of potential space-radiation threats, which would give them time to take cover, Paschalidis said. This is important, especially as NASA sets to return humans to the Moon and beyond under its Artemis and Gateway programs.

HELENA would also provide important scientific data. Pointing toward the Sun, the instrument would not only sense and image these energetic neutral atoms, but also separate them from the associated hard X-rays and solar energetic charged particles. The separation would give scientists a more comprehensive view of the evolution of space weather — from its birth with a solar flare, through its explosive evolution in the solar corona, to its propagation across the solar system, Paschalidis said.

If NASA selects SETH and launches the mission in 2024, HELENA's new remote-sensing capability would coincide and add extra value to data gathered by NASA's Parker Solar Probe, which launched in 2018 to obtain the closest-ever observations of the Sun. Parker is expected to operate beyond 2024, Paschalidis said. "HELENA will also benefit Solar

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Great Observatory Science from a Balloon?

New Technologies Could Enable More Powerful Far-Infrared Observations

Scientist Al Kogut has found a way to do Hubble Space Telescope-class science from a relatively inexpensive scientific balloon and is well on the way to proving the concept.

Principal Investigator Al Kogut (foreground) operates the computer during the demonstration of BOBCAT technologies. Also pictured are Nick Bellis (middle) and University of Maryland-College Park graduate student Sam Denker.

If he succeeds, the technology he's developing under the Balloon-borne Cryogenic Telescope Testbed (BOBCAT) effort could prove potentially revolutionary for cosmologists and other scientists who need to collect far-infrared light to observe the very distant universe and study the formation and evolution of the universe. At this particular wavelength, scientists can detect 98 percent of all photons emitted after the Big Bang.

"Of course, it's best to go into space, but space observatories are expensive," Kogut said. "With less-expensive balloons, you can go to the top of the atmosphere, which is nearly as good as what you would detect in space."

With support from Goddard's Internal Research and Development program, Kogut is developing ultra-lightweight dewar technologies to enable Great Observatory science from a balloon. Even NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA), an aircraft-borne telescope that operates at an altitude of 45,000 feet — well below a balloon's float altitude of 133,000 feet — is adversely affected by atmospheric emissions. These emissions create noise in the data, which then requires longer observing times.

"If you could put a cold telescope on a balloon, you could get rid of the foreground emissions and improve sensitivity by a factor of 100,000," said Kogut, who has developed balloon-borne telescope apertures measuring just 20 inches in diameter, considerably smaller than the desired 10- to 13-foot telescopes he would eventually like to fly. "Theoretically, we could gather more science in one night than we could during the entire SOFIA program."

Tricky Business

But obtaining far-infrared light, especially on a balloon with a telescope equipped with an 8-foot or larger light-collecting mirror, isn't as simple as it might seem. It's tricky.

For one, these wavelengths are difficult to collect. Heat generated by the telescope and light emitted by the atmosphere overwhelm the weak far-infrared signal. Therefore, these observatories, including those flown in space, must be cooled to a frosty –442 degrees Fahrenheit.

Scientists achieve these super-cold temperatures by placing the telescope inside a dewar and cooling the container with cryogenic fluids, such as nitrogen and helium. However, conventional dewars capable of accommodating a large Hubble-style primary mirror would weigh about 11,000 pounds because their walls must be thick to withstand atmospheric pressure at sea level. As a result, the balloon and its payload would struggle to get off the ground.

BOBCAT tackles those challenges.

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The successful BOBCAT balloon mission paves the way for additional test flights in 2020. This closeup was taken before the flight in 2019.

In August 2019, Kogut and his team demonstrated important BOBCAT technologies — primarily that they could pump cryogenic fluids into the dewar once the balloon reached its observing altitude — thereby proving his concept isn't as far-fetched as some might believe.

During a balloon launch from Fort Sumner, New Mexico, the team loaded the ballooon's gondola with electronics, a conventional test dewar, which launched warm, and lightweight storage containers holding the liquid nitrogen and helium.

Shortly before the balloon reached its float altitude, the team pumped liquid nitrogen to pre-cool the test dewar and then, once the balloon lofted to about 133,000 feet, transferred about 30 liters of liquid helium to cool the container to the desired temperature. Because nitrogen flash freezes and helium becomes superfluid at certain pressures, which would adversely affect the dewar's ability to cool to super-cold temperatures, Kogut and his team also needed to show that the transfer could occur in a near-vacuum.

"Full Success"

"The flight achieved full success," Kogut said. "This represented the first remote transfer of either liquid nitrogen or liquid helium at float altitudes and demonstrated that potential problems related to the transfer at float altitudes can be mitigated."

The successful transfer was critical to the concept, he added. "We can't fill an ultra-lightweight dewar on the ground since the thin vacuum walls can't withstand 15 pounds-per-square-inch atmospheric pressure at sea level."

The successful demonstration paves the way for another later this year, but this time, Kogut plans to transfer the cryogenic fluids into the ultra-lightweight test dewar now being built by Goddard engineers. According to Kogut, the dewar's stainless-steel walls are just slightly thicker than a beer can's. The goal is to compare its performance to the standard dewar flown in 2019.

While BOBCAT can demonstrate ultra-lightweight dewars, Goddard engineers don't have the manufacturing facilities to fabricate a 10- to 13-foot dewar that could accommodate a large-aperture cold telescope. As a result, NASA has awarded a Small Business Innovation Research grant to Quest Thermal Group LLC, a Colorado-based company specializing in the development of advanced thermal-insulation systems. The company's job is to develop manufacturing techniques for a 10-foot or larger dewar.

"This effort eliminates the concerns about the technological maturity of flying large-aperture telescopes on a balloon," Kogut said. "BOBCAT technologies could be a game-changer." ❖

This image shows BOBCAT hardware used to demonstrate the successful transfer of cryogenic fluids into a dewar during a balloon demonstration in August 2019. The shot was taken when the balloon reached its float altitude of 133,000 feet.

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Snow Days

NASA Launches In-Depth Snow Study — First in 30 Years

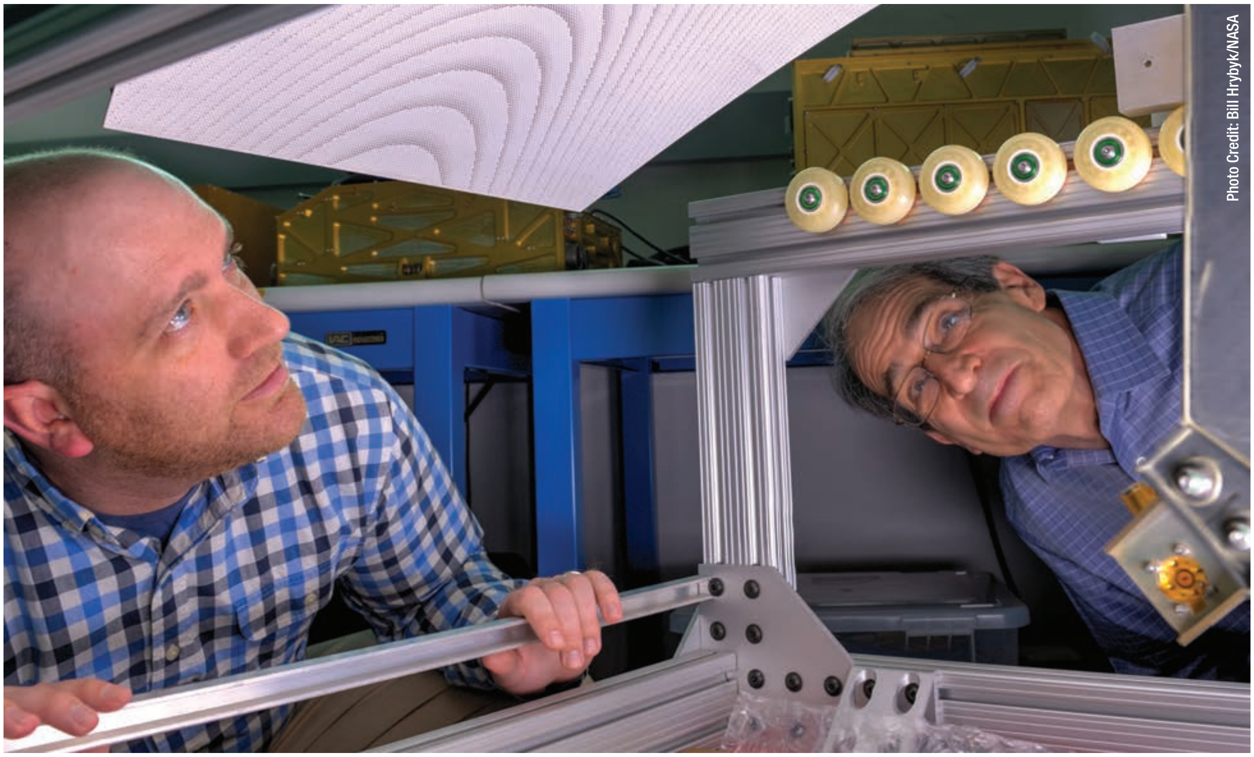

Photo Credit: Bill Hrybyk/NASA

Gerry Heymsfield (right) and John Yorks are looking at the Cloud Radar System W-band reflect array antenna that was built as a subscale prototype for the ACE radar under a NASA technology-development project. The technology is flying on an agency-funded aircraft campaign to measure snow.

The last time NASA carried out an in-depth study of winter storms in the heavily populated Northeast, the Berlin Wall had just come down and George H. W. Bush occupied the White House.

That changed in mid-January when a team led by University of Washington researcher Lynn McMurdie began a six-week campaign to better understand how snow bands form and evolve.

The team began deploying a suite of complementary, tried-and-true remote-sensing and in-situ instruments aboard two NASA research aircraft flying at different altitudes — one above the storm and the other within it. With this data, scientists want to get a greater understanding of these poorly understood processes, improve snowfall measurement from space, and further forecasters' ability to predict snowfall accumulation.

"Technology has improved dramatically over the past 30 years," said Gerry Heymsfield, a Goddard scientist and deputy principal investigator of the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms, or IMPACTS, mission funded by NASA's Earth Venture-Suborbital Program. "Now is an ideal time to conduct a well-equipped study."

"Improving snowstorm prediction and expected accumulation, obviously, is of interest to virtually everyone," added Scott Braun, a Goddard scientist serving as the IMPACTS science team lead. According to statistics, snowstorms cost as much as $300-$700 million per snow-shutdown day, cause about 211,000 vehicle crashes, 67,000 injuries, and 730 fatalities annually, primarily in the Northeast and Midwest. Ten percent of power outages are attributable to snowstorms and flight cancellations are nearly two times more frequent during the winter months.

"IMPACTS is measuring conditions contributing to snowfall in winter storms. It will provide data that will improve our weather models and eventually allow people to plan for these events," said Goddard scientist John Yorks, the other IMPACTS deputy principal investigator. "What's important about IMPACTS is the breadth and heritage of its instruments as well as its promise to help us with future space-based mission planning."

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Goddard's Contributions to IMPACTS

The HIWRAP dual-frequency Doppler radar is one of five instruments that Goddard contributed to the snow mission that is now underway.

Many of the instruments that Goddard is contributing to NASA's first in-depth snow campaign in more than a generation trace their heritage to initial support from Goddard's research-and-development programs. Here is a snapshot of what's flying on the ER-2, which simulates what a satellite might detect from space.

The **Cloud Radar System (CRS),** which Goddard scientists originally developed more than 20 years ago, is a W-band Doppler, nadir-pointing radar that measures the velocity and reflectivity of clouds and light precipitation. About six years ago, Goddard engineer Matthew McLinden completely rebuilt CRS, adding a solid-state transmitter and new antenna *(CuttingEdge, Summer 2014, Page 9).*

Developed by scientist Matt McGill, the **Cloud Physics Lidar** made its debut in 2001 during a campaign to study biomass burning in southern Africa. Since then, it has proven to be an essential player for measuring aerosols and the optical properties of clouds across multiple wavelengths. McGill used Internal Research and Development program funding to develop an instrument version that could operate autonomously on unmanned aerial vehicles *(Goddard Tech Trends, Winter 2007, Page 7).*

Goddard originally created the **Conical Scanning Millimeter-wave Imaging Radiometer** to calibrate sensors for the Defense Department's Meteorological Satellite Program. This instrument pioneered the use of the submillimeter-wavelength bands to sense ice clouds *(CuttingEdge, Fall 2016, Page 13).*

The **ER-2 X-Band Doppler Radar** also developed by engineer Lihua Li with Goddard R&D support, is an X-band Doppler scanning radar that first flew in 2012. It measures 3-D cloud and precipitation structure, horizontal wind vectors, and ocean surface winds *(CuttingEdge, Summer 2014, Page 9).*

In 2005, IMPACTS Deputy Principal Investigator Gerry Heymsfiled started working on the **High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP),** a dual-frequency Ku- and Ka-band, dual-beam conically scanning radar originally designed for the Global Hawk platform *(CuttingEdge, Summer 2013, Page 6).* After its first flight in 2010, Heymsfield used R&D funds to further advance HIWRAP's radar technology, which he tested during NASA's Hurricane and Severe Storm Sentinel mission.

The Hawkeye probe, which Goddard developed with support from NASA's Small Business Innovative Research program, also is flying on the P-3 aircraft, along with 10 other instruments. It measures small snow and ice particles. ❖

Snow Days, *continued from page 8*

Campaign Now Underway

IMPACTS — the first campaign of its kind in about three decades — began its first six-week deployment on January 15, covering about 400,000 square miles from the Washington, D.C., area northward into New England, an area that is home to about 100 million people. The team plans a jaunt into the Midwest should the Northeast not be experiencing an event during the scheduled campaign, but as Braun said, "there are always storms of one kind or another." Subsequent flights are scheduled for 2021 and 2022.

During the campaign, which is based at the Wallops Flight Facility, the NASA P-3 is flying at altitudes of up to 25,000 feet to penetrate the storms and collect in-situ data on temperature, humidity, and winds as well as the phase, shape, numbers, and sizes of ice particles. To do this, the P-3 is carrying 11 instruments provided by the University of North Dakota, Goddard, the Langley Research Center, the National Center for Atmospheric Research, and the University of Colorado.

At the same time, an ER-2 aircraft takes off from Hunter Army Airfield in Savannah, Georgia. Flying at an altitude of 65,000 feet, it gathers measurements with six different types of radar, lidar, and microwave instruments all tuned to different frequencies ideal for gathering snow measurements. Goddard provided five of those heritage instruments, all developed over the years with R&D support for various precipitation-measurement campaigns (see instrument list, page 9).

"What the IMPACTS team brings is a range of instruments and experience," said Matt McGill, a Goddard scientist who developed one of the ER-2 instruments, which has also proven its mettle in several aircraft campaigns. "The scientific and societal benefits of IMPACTS will be substantial. Many of the instruments have heritage in Goddard IRAD (Internal Research and Development program) and ESTO (Earth Science Technology Office) funding, and it is pleasing to see these sensors adopted for such significant research. We can't wait to get the results." ❖

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An Architecture for SmallSat Off Roading

Goddard engineers are taking a page from automakers' playbooks: they are developing a SmallSat architecture that would give scientists different options for venturing off the paved roads in low-Earth orbit for off-road experiences in more hostile regions in space.

The effort, formerly known as DellingrX, is now dubbed Modular Architecture for a Resilient Extensible SmallSat, or MARES for short. It is a follow-on to Goddard's Dellingr mission, which a tiger team developed to show that tiny CubeSat platforms could be robust and cost effective, yet capable of gathering NASA-quality science *(CuttingEdge, Fall 2014, Page 4).*

The initial breadloaf-sized Dellingr spacecraft and its suite of miniaturized instruments launched in late 2017 into a relatively benign low-Earth orbit and proved that the goal was doable.

Ratcheting Efforts

Now Goddard engineers are ratcheting up their efforts — focusing on providing an easily adaptable, highly modular SmallSat platform that would allow scientists to more reliably deploy smaller spacecraft in more distant, more hostile regions in space.

MARES targets everything from 6U CubeSats that weigh about 16 pounds to larger, 400-pound SmallSats that can be deployed from the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA). ESPA is a device that takes advantage of excess launch capacity by mounting up to six ESPA-class, secondary payloads below the primary spacecraft on a rocket.

At the core of MARES spacecraft, regardless of size, are radiation-hardened technologies that would overcome the problems associated with gathering science on smaller, less-expensive platforms not specifically hardened against the effects of radiation, which can cause electronics to latch up and fail, among other consequences.

"MARES is more than a CubeSat," said Michael Johnson, chief technologist of Goddard's Applied Engineering Directorate. "We're developing an ar-

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chitecture, much like how automakers design an auto platform that buyers can equip differently based on their needs. MARES is capabilities driven, with an emphasis on reliability, scalability, and high-performance processing."

Robin Ripley (left), Colby Goodloe (center), and James Fraction (right) are part of the team developing the new MARES SmallSat architecture. They are holding Goddard-developed electronic cards that users can use to customize their spacecraft.

Core Capabilities

As a comprehensive architecture, MARES brings together multiple Goddard- and industry-developed technologies. One of the most important Goddard-developed technologies is a more robust, radiation-hardened command and data handling system.

This system combines two previously developed capabilities. Specifically, it unites the Goddard-developed Modular Unified Space Technology (MUSTANG) — a miniaturized avionics system comprised of mix-and-match electronic cards that act as the brains and central nervous system of the spacecraft *(CuttingEdge, Winter 2017, Page 5)* — with SpaceCube, a radiation-tolerant, very fast flight processor now being used in multiple missions to quickly crunch large amounts of data *(CuttingEdge, Fall 2017, Page 14).*

Although SpaceCube and MUSTANG are already relatively small, MARES shrinks these two powerful technologies down to a 1U CubeSat form factor, aerospace-speak for a system that measures just four inches on each side.

Because this system is literally made up of electronic cards, users can modify their spacecraft by plugging in other capabilities now being advanced through Goddard's Internal Research and Development program. For instance, if they need GPS navigation, they can customize their MARES architecture to include a NavCube card, a navigation technology that combines the processing power of SpaceCube with Goddard's highly successful Navigator GPS, which acquires GPS navigational signals in weak-signal areas.

In the future, MARES could even include an emerging optical-navigation technology that would autonomously guide a spacecraft using images captured by the spacecraft.

The beauty of MARES is that a user may want all that the architecture offers or just one component, said Robin Ripley, MARES systems engineer. "The key is that it's reconfigurable. You can customize without designing things from scratch. You can choose which capabilities you need."

"What we're offering is an integrated solution," Ripley continued. "It's great for very small missions with a limited number of instruments, but a large amount of data. It's also good for constellations of spacecraft."

Filling a Need

The architecture appears to be filling a need, particularly the gap between low-Earth-orbiting CubeSats and more expensive, yet reliable SmallSats.

GTOSat, which will study the radiation belts that encircle Earth in geostationary transfer orbit, was the first to adopt the architecture. The GTOSat team needed to make sure its CubeSat could withstand the onslaught of charged particles that can destroy electronics and ultimately end missions — a requirement that dissuaded them from using commercial components and systems *(CuttingEdge, Spring 2018, Page 11).*

Once the architecture is mature, the goal is to license it to private industry, Johnson said. "The goal was to show you could cost efficiently enable new science in a challenging spaceflight environment with SmallSat platforms." ❖

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A Tiny New Instrument Employs New Techniques and Technology to Monitor Flora from Space

The creators of a tiny new instrument that "speaks for the trees" include (from left to right): Manal Khreishi, Jon Ranson, and Joe Howard. Not pictured are Jacqueline LeMoigne (Earth Science Technology Office), Phil Dabney, Fred Huemmrich (University of Maryland-Baltimore County), and Ray Ohl.

Just like Dr. Seuss's Lorax, a tiny new instrument aims to "speak for the trees, for the trees have no tongues."

This instrument, which is now being developed by a team led by Goddard scientist Jon Ranson, combines and miniaturizes two sensors to monitor the health of trees, among other vegetation — information needed by forest and water managers. NASA's Earth Science Technology Office (ESTO) and Goddard's Internal Research and Development (IRAD) program are co-funding the development of MiniSpec, short for miniaturized spectrometer.

"As the climate changes, plants' environments also change," said Ranson, who collaborated with Goddard researchers Joe Howard and Phil Dabney to make MiniSpec's design small and capable of doing cutting-edge science. "We're trying to understand what's happening to these vegetated ecosystems."

The eventual goal is to put a MiniSpec onto multiple small satellites so that scientists can observe plants at different times of the day, while keeping overall costs lower than they would be for a large satellite mission.

In the near future, MiniSpec will be incorporated into an IRAD- and ESTO-funded project led by Goddard engineer Guangning Yang and Goddard scientist David Harding. The Concurrent Artificially intelligent Spectrometry and Adaptive Lidar System will find new ways to combine measuring capabilities into one instrument to better understand both ice and vegetation.

Measuring Light and Shadow

Most operating satellites measure plants once a day, and often in the morning when there's less stress on the plants, Ranson said. MiniSpec aims to measure plants both in the morning and in the early afternoon, when they're often facing harsher sunlight, warmer temperatures, and less moisture.

To do this, MiniSpec has two parts: one that measures light and the other that measures shadows. As its spectrometer determines how plants reflect sunlight, its camera takes a look at how plants create shadows.

"Plants reflect sunlight in different wavelengths depending on how well they're functioning," Ranson said. For instance, they absorb certain wavelengths, or colors, which they need for photo-

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synthesis, while reflecting colors they don't need, like the color green. "This is why we see plants as green," Ranson said.

Once in orbit, MiniSpec could see how and when leaves' colors change over time to note anything unusual. "Many indications of health or stress can be seen with this kind of instrument," said Randolph Wynne, a Virginia Tech professor who advised Ranson. "For example, when a plant is stressed by receiving too much light, it responds by slightly changing pigment concentrations. We can look at different colors to pinpoint issues with chlorophyll, water, soils, or something else," he added.

Freeform Optical Systems

To make MiniSpec small enough to fit on a small satellite, the team miniaturized a spectrometer using freeform optics.

In a free-form optical system, the surface shape of the mirrors can take any form and even fit with smaller configurations. Instead of the usual arrangement of lenses and mirrors, "we designed a specialized surface of the mirrors to reflect the incoming light, or light passing through the spectrometer," Ranson said, adding that the team capitalized on previous IRAD-funded studies that showed free-form optics were necessary to reduce the instrument's size. In fact, using free-form optics reduces the volume by 50 times, Ranson said.

While MiniSpec monitors light, it simultaneously uses a small camera to measure the three-dimensional structure of plants, like how they are physically arranged in space. Knowing how tall a plant is and how it's holding its leaves can help determine how much light is available to the plant for photosynthesis. "Understanding plant structure enables us to estimate the amount of shadows present in the scene and improve measurement accuracy," Ranson said.

"This combination hasn't been done before from space," Wynne said. "We can look at underperforming areas and note any opportunities for early intervention and management."

Managing Vegetation

MiniSpec could help forest specialists, among other decision makers, better contain diseases, like the Oak Wilt fungus. Oak Wilt is one of many diseases currently hitting trees at a higher rate than previously recorded, said Jeannine Cavender-Bares, a professor at the University of Minnesota who also advised Ranson. Oaks are the most abundant trees in the U.S. and Mexico and contribute at least $22 billion every year to the U.S. economy, Cavender-Bares said. Not only do they produce wood products, they also store greenhouse gasses and filter air pollutants.

Photo Credit: Ray Ohl/NASA

MiniSpec combines two miniaturized sensors to monitor the health of trees, among other vegetation — information needed by forest and water managers.

As a disease like Oak Wilt progresses, a spectrometer can pick up on changes in physiology, leaf chemistry, and color due to wilting from the spread of the fungus that blocks water transport in the tree, as well as other stressors. "Having eyes in the skies is really critical for keeping up with the disease," she said.

In addition to catching diseases as soon as they appear, MiniSpec can also illuminate how forests take up carbon, shedding light on how they possibly mitigate the impact of climate change. "Just because you have trees there doesn't mean they're doing what you expect," Wynne said. "If we can really understand, on a management scale, where these forests are productive and how well they're photosynthesizing, that's incredibly powerful at a really important time," he said. ❖

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X-Ray Navigation is Ready for the Next Level

SEXTANT Experiment Ends; Proves Potentially Revolutionary Navigation Technology

Photo Credit: Rebecca Roth/NASA

Goddard engineer Munther Hassouneh is a member of a team further enhancing X-ray navigation technologies initially proven from an experiment aboard the International Space Station. In 2019, the team delivered Goddard's XNAV Laboratory Testbed (XLT) to the Johnson Space Center's Integrated Power Avionics and Software system, which helps mature avionics systems for human spaceflight.

Having proven the possibility of navigating throughout the solar system and beyond using X-ray signals from rapidly spinning neutron stars, Goddard engineers are further enhancing the technology and laying the groundwork to ultimately build an operational X-ray navigation, or XNAV, system.

Goddard's XNAV team, led by Jason Mitchell, Munther Hassouneh, and Luke Winternitz, recently wrapped up its work with the Station Explorer for X-ray Timing and Navigation Technology (SEXTANT), a technology demonstration attached to the Neutron Star Interior Composition Explorer (NICER) mission onboard the International Space Station.

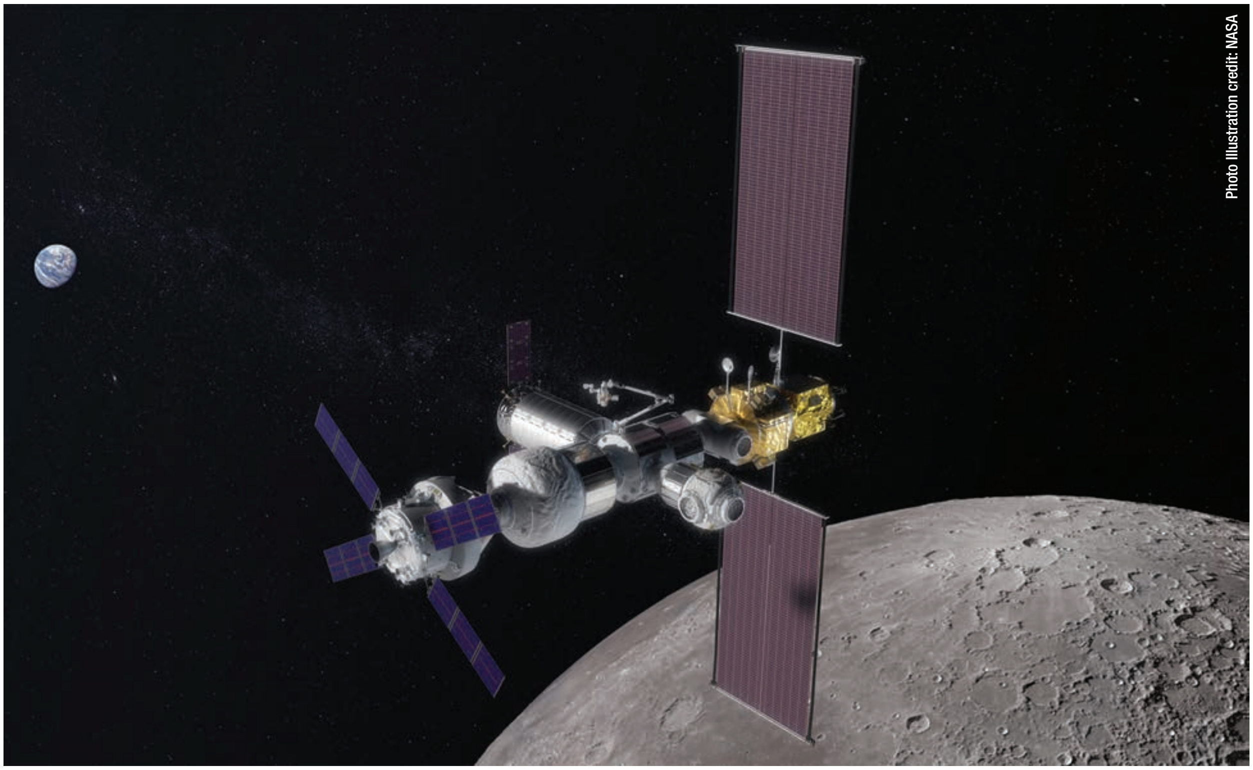
The results of this two-year experiment funded by NASA's Space Technology Mission Directorate, with early funding from Goddard's Internal Research and Development (IRAD) program, paves the way for using pulsars as beacons for a future GPS-like system to enable spacecraft navigation.

In particular, SEXTANT showed that millisecond pulsars could be used to accurately determine the location of an object moving at thousands of miles per hour in space — similar to how the Global Positioning System, widely known as GPS, provides positioning, navigation, and timing services to users on Earth with its constellation of 24 operating satellites (CuttingEdge, Winter 2018, Page 2).

Although NICER studied all types of neutron stars as an attached payload on the station, SEXTANT focused on pulsars, highly magnetized rotating neutron stars that emit beams of radiation from their poles and are seen as flashes of light when they sweep across our line of sight. With these predictable pulsations, pulsars can provide high-precision timing information. SEXTANT's onboard algorithms used these signals to autonomously stitch together real-time navigational solutions.

"SEXTANT made a successful demonstration of real-time onboard XNAV in a challenging on-orbit environment, and its results suggest you could travel for years and maintain an accuracy of tens of kilometers for location," SEXTANT Project Manager Mitchell said. "Compared to GPS that provides navigational solutions in near Earth, that's not competitive, but when you're exploring the solar system that's pretty accurate."

Continued on page 15



Goddard's SEXTANT team developed a navigation simulation that predicted promising performance levels for a miniaturized SEXTANT-like system for NASA's Lunar Gateway, a planned orbital platform near the Moon that will provide access to more of the lunar surface than ever before.

"The next stage is turning it into an operational system," Mitchell said, adding that the team is now analyzing SEXTANT data to continue refining their potential. "There's a ton of data from that mission that we can still work with," Winternitz added.

"The initial IRAD investment in XNAV has given us a completely new autonomous navigation technology for crewed and robotic exploration of deep space. This incredible success is a testament to the vision, commitment, and value of Goddard's IRAD program."

– SEXTANT Project Manager Jason Mitchell

In the meantime, the team is working with NASA's Johnson Space Center to further implement XNAV. In 2019, the team delivered Goddard's XNAV Laboratory Testbed (XLT) to the Johnson Space Center's Integrated Power Avionics and Software system, which helps mature avionics systems for human spaceflight. The XLT combines the Modulated X-ray Source, a device the team created to test SEXTANT technologies and algorithms, with a commercial silicon drift detector similar to those used on NICER. The stand-alone XTL simulates an XNAV system in a manner analogous to the use of a GPS signal simulator for a GPS receiver.

The team also developed a navigation simulation that predicted promising performance levels for a miniaturized SEXTANT-like system for NASA's Lunar Gateway, a planned orbital platform near the Moon that will provide access to more of the lunar surface than ever before. The team published the simulation results at a conference sponsored by the American Astronautical Society in 2019.

Moon-bound CubeSat

Additionally, XNAV may be employed on CubeX, a Moon-bound CubeSat mission that will study the Moon's lower crust and mantle in the X-ray spectrum. CubeX is a concept developed by the Smithsonian Astrophysical Observatory and Harvard University.

"The initial IRAD investment in XNAV has given us a completely new autonomous navigation technology for crewed and robotic exploration of deep space," Mitchell said. "This incredible success is a testament to the vision, commitment, and value of Goddard's IRAD program." ❖

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Reality, *continued from page 3*

the physical model," he said. "It's not really sexy to the average person to talk about cable routing, but to an engineer, being able to do that in a virtual environment and know how much cabling you need and what the route looks like, that's very exciting."

In a mockup of the Restore-L spacecraft, for example, Grubb showed how the VR simulation would allow an engineer to "draw" the cable path through the instruments and components, and the software provides the cable length to follow that path. Tool paths to build, repair, and service hardware can also be worked out virtually.

In addition, Grubb's team worked with a team from the Langley Research Center this past summer to work out issues interacting with visualizations over NASA communication networks. This year, they plan to have people at both locations able to fully interact with the visualization. "We'll be in the same environment and when we point at or manipulate something in the environment, they'll be able to see that," Grubb said.

Photo Credit: Chris Gunn/NASA

Augmented Science — a Better Future

For Kuchner and Higashio, the idea of being able to present their findings within a shared VR world was exciting. And like Grubb, Kuchner believes VR headsets will be a more common science tool in the future. "Why shouldn't that be a research tool that's on the desk of every astrophysicist," he said. "I think it's just a matter of time before this becomes commonplace." ❖

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Seth Mission, *continued from page 5*

Orbiter to be launched in Feb 2020 and several upcoming solar missions," he added.

"With one instrument, we will be able to get information about three physical parameters and get access to significant new information about charged-particle acceleration," Pulkkinen added. "New observations would ultimately result in improved prediction of hazardous solar energetic particles."

Competing with Solar Cruiser

SETH has competition.

Also vying for a chance to fly as a secondary payload on NASA's IMAP is the Marshall Space Flight Center's proposed Solar Cruiser. Central to this proposal is the demonstration of an 18,000-square-foot solar sail, which would show the ability to use solar radiation as a propulsion system. Its second technology is a coronagraph capable of simultaneous measurements of the Sun's magnetic field and speed of coronal mass ejections.

According to NASA officials, both SETH and Solar Cruiser were chosen for Phase-A funding because they support the agency's heliophysics program, which seeks to better understand the nature of space throughout the solar system and how it changes in response to the Sun's constant outpouring of energy and particles.

"By focusing on SmallSats and capitalizing on the cost savings of sharing a launch, we can test and advance cutting-edge technologies at a reasonable price," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate. "We are leading the charge in using this innovative solution to test new mission paradigms and technologies and, in turn, to reap great rewards researching our neighborhood in space." ❖

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Cutting edge Goddard's Emerging Technologies

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