National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

Volume 16 | Issue 3 | Spring 2020

The Tech We Take to Get Here

www.nasa.gov

Volume 16 • Issue 3 • Spring 2020

SPECIAL REPORT

The Tech We Take to Get Here

Under the Artemis banner, NASA will land the first woman and next man on the Moon in 2024, using innovative technologies to explore more of the lunar surface than ever before. Along with the agency's commercial and international partners, Goddard, too, is playing a role developing cross-cutting technologies that will support a more sustainable human presence on the Moon while enabling scientific measurements.

These crosscutting technologies span NASA's reach and include everything from in situ resource utilization and advanced communications, to more autonomous and intelligent instruments and in-space manufacturing techniques. Here, CuttingEdge highlights some of those technologies that could contribute to NASA's ultimate quest to land humans on Mars.

In Situ Resource Utilization Team Maps Lunar Harvesting Strategy

The Apollo 17 crew stayed on the Moon for slightly more than three days. Artemis mission planners envision a long-term base to build experience for a potential Mars landing by humans.

The scale and mass of long-term living arrangements, however, means NASA can't take everything it needs. Goddard scientists and engineers are working together, finding ways to identify, characterize, and use the resources that could sustain human habitation in these remote, inhospitable places. Their involvement spans the spectrum, everything from developing the needed technologies and working on special study teams, to housing

Continued on page 3

in this issue:

Spring 2020

About the Cover

Taken on April 7, 2020, this photo shows the "Super Pink Moon" that appeared larger and brighter than usual because the Moon was at its perigee, or the closest point to Earth in its elliptical orbit. Earth's natural satellite was just 221,772 miles (356,907 kilometers) from Earth, compared with its average distance of 238,855 miles (384,400 kilometers).

(Photo Credit: Ernest T. Wright/NASA)

SHARE this Issue Now!

You can now share this issue with your friends and colleagues via your own social-media channels. Click the Share button to begin.

SPECIAL REPORT

The Tech We Take to Get Here

important research-based databases of current or past planetary and lunar missions.

"Instead of having to bring all those physical resources with you, you can bring the technology to extract the resources. It's a massive savings to be able to derive some key resources you need from lunar materials," said Amy McAdam, research space scientist with Goddard's Planetary Environments Laboratory and co-leader of the agency's Lunar Water ISRU (In Situ Resource Utilization) Measurement Study (LWIMS), which she is leading with Julie Kleinhenz from the Glenn Research Center.

For Artemis, ISRU involves harvesting available materials on the Moon, such as ice to produce spacecraft fuel and drinking water, regolith to help build astronaut living quarters, and metals and oxides for construction materials. Scientists have identified signs of water in lunar polar regions, but the nature and extent of these resources are not fully understood.

Enabling Long-Term Presence

Producing usable resources from lunar materials will be an important milestone to enable a long-term presence, McAdam said.

The LWIMS team, a collaborative effort also involving the Kennedy Space Center, Johnson Space Center, the University of Maryland, the University of Arizona, North Star Imaging, Honeybee Robotics, and Silicon Audio, formed last summer. Chartered by the NASA ISRU System Capability Leadership Team, with support from three NASA mission directorates, the study group is charged with recommending an exploration plan.

The LWIMS team is divided into three groups, each tackling a different area of the project. The first group is defining the specific measurements needed to design ISRU systems. The second is evaluating information needed to create a predictive model of lunar water formation and distribution to determine if enough resources are available on the Moon for ISRU requirements. The third is identifying possible instruments and platforms to obtain lunar measurements to ultimately determine the quantity of resources available on the Moon.

The larger LWIMS team is currently synthesizing the findings of each group into a series of recommendations. The ultimate goal of LWIMS is to recommend an exploration plan that would provide

Continued on page 4

This European Space Agency visualization imagines a human habitat on the Moon shielded with lunar regolith.

enough information about available resources so that NASA can select a site on the Moon and design hardware for a pilot lunar ISRU plant in 2028.

This is an ISRU system concept for autonomous extraction of water from the Martian soil.

Using funding from Goddard's Internal Research and Development program and other NASA sources, Goddard and its partners, meanwhile, have been at the forefront of developing many technologies needed to collect information on these resources (see related story, page 5).

"Goddard is really in a unique position because we have a tremendous amount of experience in space missions. We're the largest collection of scientists engaged in Earth science, astrophysics, heliophysics, and planetary science," said Paul Mahaffy, principal investigator of the Curiosity rover's Sample Analysis at Mars experiment. "And so, the depth of our engineering and scientific skills is just tremendous."

In April 2020, NASA's Science Mission Directorate, Human Exploration and Operations Mission Directorate, and Space Technology Mission Directorate had planned a three-day Lunar Surface Science Workshop to help determine which science could be done by human crews on the lunar surface and how it could be achieved. McAdam, Mahaffy, and Goddard planetary scientists were set to attend to discuss possible Artemis approaches and lunar science in general. The workshop has since been postponed due to the mandatory telework status across NASA. The idea is to receive early community input on mission architectures. In many cases, data collected to address lunar science questions can also help inform ISRU needs.

"NASA decisionmakers will be listening very carefully to all of the advice because they have to decide where the funding is going to go to make some of these things happen," Mahaffy said. "So, they'd be looking at whom they think might be capable of pulling off some of these ambitious things, whether it's commercial entities, NASA centers, or universities. Then, they'll be trying to put together a program that will help us get to the goals of both science and exploration."

Cross-Disciplinary Efforts

For Mahaffy, preparation for the Artemis mission through ISRU is a great platform to enhance scientists' understanding of the Moon. Along with taking measurements that will indicate the availability and quality of lunar resources, the team will also measure the Moon's internal processes by sensing its response to impacts, monitoring geologic activity and temperature swings, studying dust and its charging, and tracking atmospheric radiation. All of these components factor into the preparation for placing humans on the Moon.

"There's still a lot to learn about the Moon," Mahaffy said. "If we're looking at a technology that might be telling us where resources are or understanding whether a particular area is good for resources, then also using that technology to learn as much as we can about the Moon is really important to us. Basically, we're trying to advance lunar science, not just going to the Moon to mine it, because it's really a place that we don't understand as well as we understand Earth."

"It's exciting times with the lunar exploration program being planned, and on the horizon, we're seeing the potential for substantial advances in lunar science as well," Mahaffy said. "So, understanding how exploration and science play together is critical. We're intending to support that from Goddard with the expertise that we have here." ❖

CONTACTS

Paul.R.Mahaffy@nasa.gov or 301.614.6379
Amy.Mcadam-1@nasa.gov or 301.614.6020

SPECIAL REPORT The Tech We Take to Get Here

ISRU Technologies Offer Cross-Disciplinary Uses

Many technologies pioneered by Goddard scientists and engineers for Earth science and planetary missions — some through the center's Internal Research and Development (IRAD) program — could become crucial components of NASA's Artemis program and in situ resource utilization. They are listed below:

Mass spectrometers, such as the instruments developed for the Sample Analysis at Mars experiment and the Lunar Atmosphere and Dust Environment Explorer, measure relevant species released from samples such as water, hydrogen, nitrogen, hydrogen sulfide, and organic molecules.

Pulsed Neutron Generator/Gamma-Ray Spectrometer, developed initially through IRAD funding more than a decade ago, are nearly ready for flight. For example, the Bulk Elemental Composition Analyzer (BECA) conceived by Goddard scientist Ann Parsons (CuttingEdge, Winter 2019, Page 6), sends a pulse of neutrons into the lunar surface to identify which elements are present. BECA is currently being funded by NASA's Development and Advancement of Lunar Instrumentation. Parsons is also contributing electronics and a pulsed neutron generator to the Dragonfly mission to Titan (CuttingEdge, Spring 2018, Page 16).

Lidar-based ranging and imaging, such as that implemented on Goddard's Lunar Reconnaissance Orbiter mission, maps the Moon's topography. Physical properties such as textures and grain sizes can also be inferred with these techniques and multi-wavelength laser systems can search for surface water.

Infrared spectrometers, like the Broadband Infrared Compact High-Resolution Explorer Spectrometer involving Goddard scientists (CuttingEdge, Summer 2015, Page 2), will measure liquid and vapor forms of water in ice, or those bound in minerals and other volatiles. These volatiles can be processed for use as rocket fuel or to support lunar habitats.

X-ray computed tomography, a technique that Goddard scientists are employing for different research efforts (CuttingEdge, Fall 2017, Page 16), images 3D structure and textures of lunar materials with a non-destructive method of analysis.

Raman spectroscopy is an IRAD-funded technology that scatters light off of a sample to measure the chemical composition. It uses lasers to take measurements without vaporizing the target.

Subsurface radars, such as the one advanced by Goddard engineer Rafael Rincon originally for Earth-science applications (CuttingEdge, Summer 2016, Page 9), can help scientists understand the likelihood that water is present in the first few meters of the surface. ❖

Volume 16 • Issue 3 • Spring 2020

SPECIAL REPORT — The Tech We Take to Get Here

Goddard Leverages Multi-Disciplinary Expertise to Create LunaNet

Lunar Communications and Navigation Architecture Designed for Flexibility

As NASA's crewed exploration missions journey to the Moon, Mars, and beyond, creating a robust communications and navigation architecture becomes paramount.

Goddard is leveraging the expertise of communications, navigation, science, and search and rescue engineers to develop a flexible and extensible lunar communications and navigation architecture called LunaNet.

Image Credit: Reese Patillo

With LunaNet in place, astronauts exploring the Moon will always have reliable access to critical network data.

"With the LunaNet architecture in place, space communications and navigation will be transformed, revolutionizing the network services that enable internetworked science and exploration at the Moon, while also paving the way for a future solar system internet," said Kendall Mauldin, a representative on the LunaNet System Engineering and Integration Task Force.

LunaNet serves as an open architecture network suite of services that could be hosted on any available platform. Individual companies, universities, businesses, and government partners could provide, expand, and build services for this network.

Internet Services in Space

Based on linked network assets, or nodes, LunaNet will enable networking services anywhere in the solar system, first at the Moon and then on planets farther in space. Each node will be capable of providing a combination of three standard service types: networking; positioning, navigation, and timing (PNT); and science utilization. Networking services will transfer data between nodes and the end user. PNT will offer velocity and position information, time synchronization, and astronaut search and rescue location services. Science utilization services will provide science measurements for situational alerts to ensure human and asset safety.

For example, if NASA's Solar Dynamics Observatory witnessed a solar flare — harsh, life-threatening radiation released from the Sun — LunaNet could send astronauts a warning and also direct them to the nearest shelter before the radiation reached them. This process will be transparent to end users, providing interconnectivity or opportunities for interconnectivity that were not previously available.

DTN Tapped

LunaNet will get this data to the end user through a networking capability known as Disruption Tolerant Networking (DTN), which will extend internet capabilities such as those on Earth to the harsh environment of space (CuttingEdge, Summer 2018, Page 16). Space communications are subject to frequent delays and the unavailability of contemporaneous end-to-end links results in the need for additional networking protocols. To mitigate this, DTN uses a store-and-forward approach. In the event of a disruption in communications between nodes, each node is capable of storing data until the next node becomes available, assuring delivery of data to the end user.

The LunaNet team has been refining the architecture since the proposal received positive responses in June 2019. In early 2020, the LunaNet team received Goddard Internal Research and Development (IRAD) funding.

Continued on page 7

SPECIAL REPORT

The Tech We Take to Get Here

IRAD Program Supports NetSI

Under the IRAD, the team is developing a prototype payload called the Network Services Instrument, or NetSI. Through DTN bundle protocol router functionality, NetSI will demonstrate LunaNet's networking services by storing and forwarding DTN bundles between a user platform component and available links, between two or more platform communications links, or by generating the bundles itself. The concept will initially be demonstrated in a Goddard lab prior to a flight demonstration, possibly on a high-altitude balloon.

The long-term goal is to provide a flight-instrument design based on commercially available components. This would assure that multiple flight platforms could take advantage of the technology and participate in the LunaNet architecture as either a network user or a network-services provider. NetSI provides the core functionality of a LunaNet Network node, and could be hosted on any available platform or location regardless of which organization provides the platform, whether it be NASA, a commercial partner, or academia.

NASA's push for commercialization encourages industry to cultivate the next round of LunaNet lunar-relay payloads, building up the interoperable system after the initial NetSI prototype.

"Internet" on the Moon

"Less than a year ago, LunaNet was a simple but powerful idea, brought forth by a small group of engineers," Mauldin said. "Now this idea has blossomed into a tangible architecture under the leadership of the Space Communications and Navigation program office at NASA Headquarters." Over the next few years, as NASA gears up to land astronauts on the Moon, the LunaNet team will create a terrestrial-like internet for the Moon, connecting assets and astronauts to home. ❖

CONTACTS

Kendall.D.Mauldin@nasa.gov or 301.286.8231
David.J.Israel@nasa.gov or 301.286.5294

First-of-its-Kind In-Space Manufacturing Technique to be Demonstrated

Large telescopes necessary for detecting and analyzing Earth-like planets in orbit around other stars or for peering back in time to observe the very early universe may not necessarily be built and assembled on the ground. In the future, NASA could construct them in space.

A Goddard engineer won a flight opportunity to show that an advanced thin-film manufacturing technique called atomic layer deposition, or ALD, could apply wavelength-specific reflective coatings on a sample — one of many steps in ultimately realizing the vision of constructing and assembling large telescopes in space.

"We think next-generation telescopes larger than 20 meters in diameter will be built and assembled in orbit," said Goddard engineer Vivek Dwivedi, an expert in ALD technology. "Instead of manufacturing the mirrors on the ground, why not print them in space? But you don't have a telescope mirror unless you coat it with a highly reflective material ideal for a particular wavelength. Our idea is to show that we could coat an optic in space using this technique, which we've used on the ground and understand the processes."

He and his collaborator, University of Maryland professor Raymond Adomaitis, will now have a chance to demonstrate the concept in space for the first time.

Blue Origins Flight Scheduled

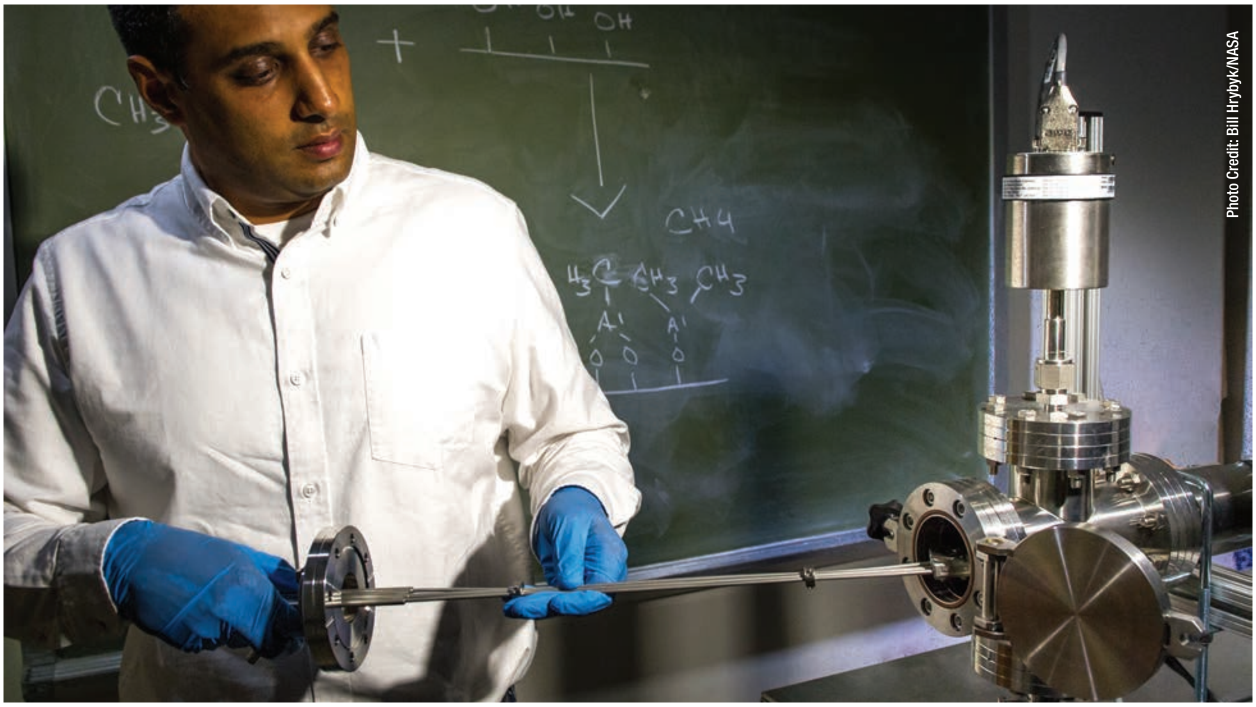
Recently, NASA's Space Technology Mission Directorate's Flight Opportunities Program selected Dwivedi and Adomaitis to fly a football-sized ALD chamber aboard a Blue Origins New Shepard launch vehicle. The launch will provide three minutes of microgravity, long enough for the team to apply a thin film of a well-known ALD material, alumina, on a two-inch silicon wafer. "Alumina is a bread-and-butter material in ALD applications," Dwivedi said. "It's been extensively researched."

Continued on page 8

Volume 16 • Issue 3 • Spring 2020

SPECIAL REPORT

The Tech We Take to Get Here



Goddard engineer Vivek Dwivedi won a flight opportunity to show that an advanced thin-film manufacturing technique called atomic layer deposition, or ALD, could apply wavelength-specific reflective coatings on a sample — the first time ALD will be tried in space.

Used ubiquitously by industry, ALD involves placing a substrate or sample inside an oven-like reactor chamber and pulsing different types of gases to create a smooth, highly uniform film whose layers are no thicker than a single atom. The beauty of ALD is that it can apply coatings to virtually anything, including three-dimensional objects.

ALD-Coated Samples in Space

Currently, ALD-coated samples are being exposed to plasma from an experiment pallet aboard the International Space Station. Dwivedi and Goddard technologist Mark Hasegawa created these samples to test whether indium tin oxide — an effective compound for dissipating electrical charges — might be applied to paints and other materials to prevent lunar dust from adhering to rovers, instruments, and spacesuits (CuttingEdge, Fall 2019, Page 8).

Moon dust adheres to virtually everything it touches due to its electrostatic charge and interactions with plasma. Mitigating this complicated interplay is considered one of NASA's thorniest challenges as the agency plans to establish a sustainable presence on the Moon under its Artemis program.

For in-space manufacturing, ALD offers a distinct advantage, Dwivedi said. ALD chambers scale to any size and can consistently apply smooth layers over very large areas.

Although Dwivedi and Adomaitis have built several ALD chambers using Goddard Internal Research and Development program funding, they decided to fly a chamber made of commercial off-the-shelf parts during the upcoming flight.

Dwivedi said he and Adomaitis conceived the idea about two years ago. A Goddard colleague, Franklin Robinson, secured a flight opportunity, also on a New Shepard launch vehicle, and proved a ground-breaking technology for effectively cooling tightly packed instrument electronics (CuttingEdge, Fall 2019, page 5).

"We worked very hard to get this opportunity," Dwivedi said. "Technologists like me spend 25 percent of the time advancing our technologies; the rest of the time we spend selling it. We can't wait to get the payload launched." ❖

CONTACT

Vivek.H.Dwivedi@nasa.gov or 301.286.3180

SPECIAL REPORT The Tech We Take to Get Here

Scientists Tapped to Mature More Rugged Seismometer System

NASA hasn't measured moonquakes since Apollo astronauts deployed a handful of measuring stations at various locations on the lunar surface and discovered, unexpectedly, that Earth's only natural satellite was far from seismically inactive.

If Goddard geophysicist Terry Hurford has his way, a next-generation, highly rugged seismometer that he is now developing with an Arizona State University partner will be one of the innovative new technologies and systems that NASA uses to explore the Moon in greater detail under its Artemis program. Called the Subsurface Lunar Investigation and Monitoring Experiment, or SUBLIME, the system's data will not only map the Moon's interior, from its regolith to its core, but also alert astronauts to seismic events.

NASA's Development and Advancement of Lunar Instrumentation, or DALI, is supporting the effort.

Rudimentary Understanding

Before Apollo, scientists were unaware of the Moon's quaking. From 1969 to 1977, instruments deployed as part of NASA's Apollo Lunar Surface Experiment Package, or ALSEP, recorded 12,000 seismic events, including meteor impacts and deep and shallow moonquakes, whose intensities ranged in magnitude from less than three to as high as five. In 1977, NASA turned off the ALSEP array. Although scientists are still mining ALSEP data, "our understanding of the Moon's interior remains rudimentary and is limited," Hurford said.

Learning more about the Moon's internal structure and providing an early-warning system for astronauts, therefore, are high priorities. "One of the key instruments would be a seismometer," he added, particularly one that is easily deployable, rugged, and relatively less expensive to build — performance criteria that SUBLIME is expected to satisfy.

Hurford and his team are specifically designing SUBLIME so that any NASA or commercial lander or rover system could deploy it, regardless of terrain and mission duration. The long-term goal is establishing a network of seismic stations.

Already relatively mature due to past investments from several NASA technology-development programs as well as Goddard's Internal Research and Development (IRAD) program, the pathfinding SUBLIME is expected to be nearly ready for deployment once its DALI funding ends in three years. Five other teams involving Goddard experts received DALI funding to advance other instruments, assuring that the center has a role to play in the agency's next era of exploration (CuttingEdge, Winter 2019, Page 5).

System Improvements

SUBLIME offers improvements over other systems, Hurford said. "There were several efforts to build planetary seismometers following the full deployment of the Apollo lunar network," he said. NASA eventually flew them on the Mars Viking mission, Venus Venera 13 and 14 missions, and now the Mars InSight mission, the agency's first mission dedicated to looking beneath the Martian surface.

The Apollo-era instruments were sensitive to tilt; therefore, astronauts had to position them. And while the Mars InSight instrument is the best-performing planetary seismometer to date, its sensor system is very large. A complex robotic arm must deploy the instrument.

SUBLIME is based on the Molecular Electronic Transducer, or MET, a technology Arizona State University is contributing. Used in terrestrial seismology, MET relies on a fluid that responds to seismic accelerations. The fluid flows through a sensing element that generates a measurable current, which provides highly precise ground-motion data.

The beauty of MET technology is that it's rugged and easily deployable. The SUBLIME unit will include three sensors oriented in different directions inside the instrument's housing. If the package tumbles and ends up on its side, for example, the orientation won't diminish SUBLIME's ability to gather data and locate the source of seismic activity. In other words, the instrument package doesn't

Continued on page 10

have to be positioned precisely to do its job. In addition, it has no moving parts and is easy to fabricate, Hurford said.

Goddard technologists helped improve the sensor's design to include additional seals and a better way to mount the sensors, Hurford said, adding that the goal under the DALI award is to mature the sensor's technology readiness level so that it can be proposed for flight.

But the center's most important contribution are the readout electronics, which feature an advanced, radiation-hardened application-specific integrated circuit, or ASIC, that minimizes the instrument's mass and power requirements. Developed by technologist Gerard Quilligan under multiple IRAD awards, the ASIC provides all housekeeping functions and converts the current detected by the MET sensor to a voltage reading and then digitizes it.

IRAD History

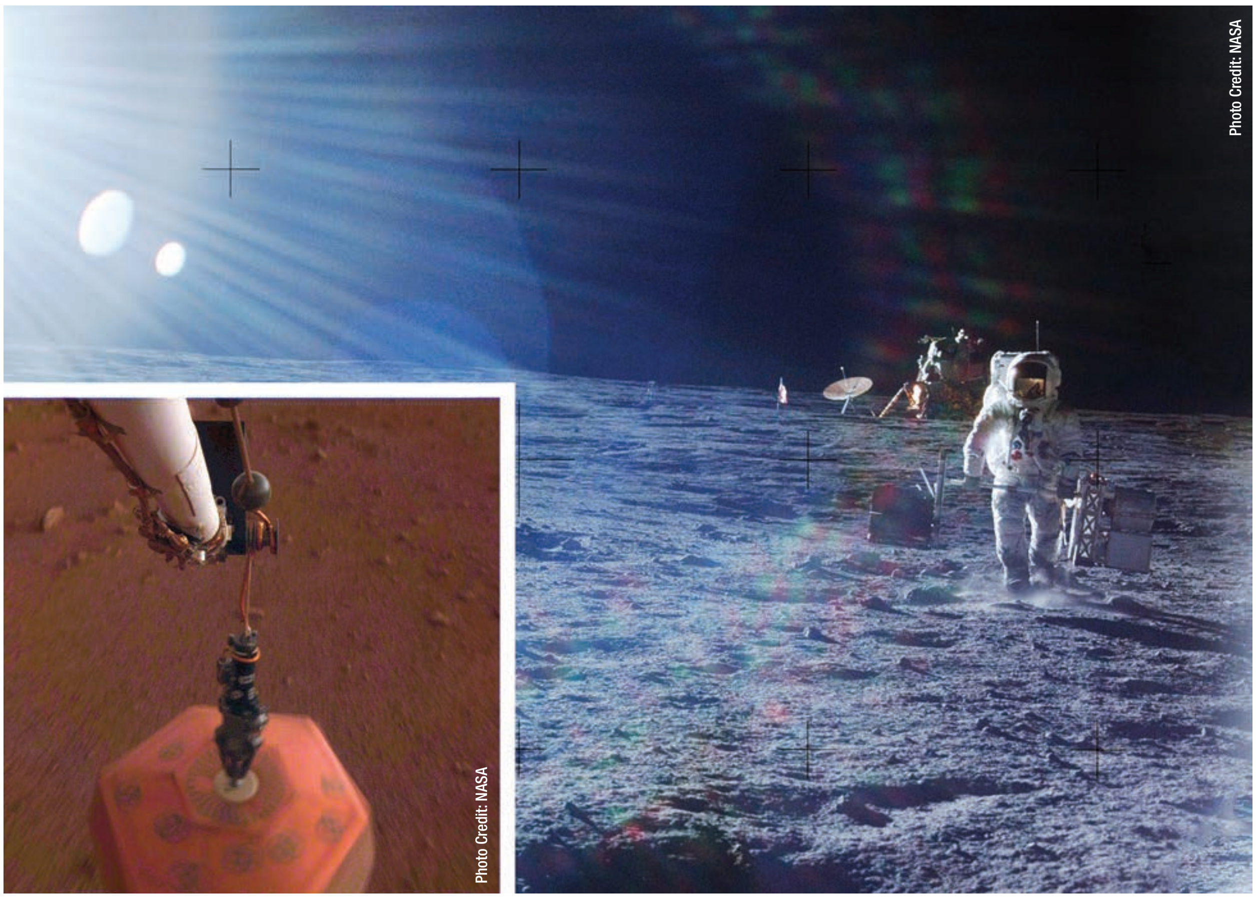
"That chip has a lot of history from past IRAD awards," Hurford said. "The sensor is vital, but it's not an instrument until you put it all together."

As a first-generation seismometer, SUBLIME will likely be used initially on short-duration deployments. But its design, which could be adapted for use on other planets and moons due to its ruggedness and sensitivity, enables long-term deployments needed to create a network of monitoring stations.

"Someday, I want to detect seismic activity on Europa, and SUBLIME is the first small step toward that goal," Hurford said. ❖

CONTACT

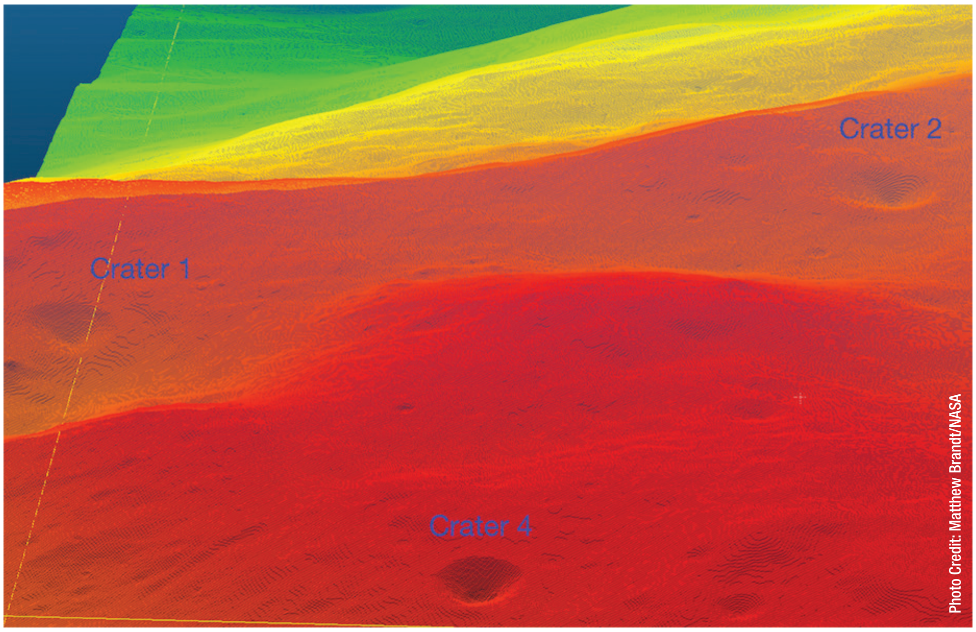
Terry.A.Hurford@nasa.gov or 301.286.4249



A next-generation seismometer could be deployed autonomously, unlike the systems shown here. Main photo: Apollo 12 astronaut Alan Bean carries the Apollo Lunar Surface Experiments Package to its deployment site on the Moon. The inset image on the left shows the deployment arm placing MarsInsight's seismometer system.

SPECIAL REPORT The Tech We Take to Get Here

Artificial Intelligence Applications Soar at Goddard



This is a simulated output from a deep learning algorithm. It shows craters detected near the Lowell Crater on the Moon. The algorithm was trained on terrain data from the Lunar Reconnaissance Orbiter.

Applications for artificial intelligence (AI) and machine learning are soaring at Goddard, just in time to power a new era of scientific discovery and human exploration beyond Earth orbit.

"A few years ago, we had only a few projects in this area," said Goddard Chief Technologist Peter Hughes. "This year, it just exploded. We had more than five times as many AI proposals through IRAD (Internal Reserch and Development). The capacity to do amazing science by applying these algorithms to scientific data is what really makes this exciting."

In addition to enhancing the analysis of scientific data, AI will power human exploration under NASA's Artemis program. Establishing a presence on the Moon, Mars, and other planets and their moons will require more advanced and intelligent technology to provide the greatest return. The new wave of robotic Moon landers, for example, will benefit from intelligent systems to analyze and prioritize data collection, navigate the lunar terrain, and assist astronauts. AI is also expected to power docking with the International Space Station, Lunar Gateway, and even other satellites.

Goddard leaders like Hughes and Mark Clampin, director of Goddard's Sciences and Exploration Directorate, are encouraging developers and scientists to share information to grow strategically in this area.

"A lot of what we're doing at Goddard is organic. It grew up on its own," Clampin said. "What's exciting is how we're using science to drive the development of computer code rather than using computers to try to do science. We have more grad students and post doctorates coming in now who are doing this in school and want to do it here, and that's good."

Machine learning, a big part of AI, involves teaching a computer to recognize patterns to perform a specific task or categorize data autonomously. Rather than performing a task or categorizing data based on explicit rules defined by a programmer, the machine learning model automatically learns rules or relationships from input data that are useful for the given task.

Pushing the Envelope

The more ambitious NASA's plans to explore the solar system, the more NASA's systems can benefit from artificial intelligence and machine learning, said Hanna Kerner, who researches machine learning applications for remote sensing and planetary exploration with the University of Maryland's Department of Geographical Sciences.

Kerner works on software the Mars Curiosity Rover uses to identify targets for follow-up analysis. Humans on Earth call the shots, she said, but AI

Continued on page 12

streamlines the decision making in the approximately 12 hours available between receiving images from the rover and uploading new instructions. With the Perseverance rover, formerly Mars 2020, that window narrows to five hours.

"We want to prioritize the targets for science planners that are most interesting to them based on what we've already seen on the surface," Kerner said. "A meteorite, for instance, might have a different shape, texture, and multispectral reflectance than native Mars rocks."

As NASA pushes into deep space, intelligent systems will be needed to prioritize which data they return to Earth and to guide in situ measurements and navigation. Radio communications lose efficiency over distance the same way a cellphone's signal loses bandwidth as it strays from the tower.

Capacity for the Future – Today

Goddard stands ready to accommodate artificial intelligence growth, said Dan Duffy, lead for the National Center for Climate Simulation (NCCS) at Goddard. "We're looking to support AI applications at all levels," he said. "You don't need to have a supercomputer-sized project. We are essentially the infrastructure for science."

In addition to higher computational capacity, the NCCS offers a curated collection of datasets, some with decades of observational data. ❖

CONTACT

Hkerner@umd.edu or 704.778.8648

Goddard R&D Supports Smart Machines for Lunar Exploration

When NASA returns to the Moon, intelligent machines will give astronauts advantages in harsh new environments, and Goddard's Internal Research and Development (IRAD) program is helping to pave the way for these smart systems (see related story, page 11).

Investigator Matthew Brandt, for example, is advancing a project called "Machine Learning for 3D Lunar Data Analysis." Under this effort, Brandt is developing a program capable of autonomously analyzing lunar terrain data and detecting hazards, much like how Waymo — a technology initially begun as the Google Self-Driving Car Project in 2009 — uses lidar to guide vehicles. Lidar generates a map of 3D data points on the terrain surface. This group of 3D data points is known as a "point cloud."

Specifically, Brandt fed 3D point cloud terrain data from the Lunar Reconnaissance Orbiter to a neural network to teach his algorithm to identify features on the Moon's surface. "The program can quickly tell you where the craters are or where drastic slopes are," Brandt said, "or other scientific targets we want to investigate."

Another IRAD Principal Investigator James MacKinnon works with a mass spectrometer similar to MOMA, the Mars Organic Molecule Analyzer, which can study materials and assess their chemical composition. Expected to launch with Perseverance (formerly known as Mars 2020) in July 2020, MOMA will look for organic compounds on Mars.

His project, "Towards Scientific Autonomy: Applying Machine Learning to MOMA Science Data," could teach rovers to independently choose which targets to analyze. The Perseverance version of MOMA needs a human to interpret data and adjust the position and intensity of the laser and provide other fine tuning.

"If we wanted to actually send a MOMA-like instrument to the outer worlds, such as Jupiter or Saturn, you just can't have a human in the loop," said MacKinnon. "The bandwidth is so much smaller that you can't get enough data back to make decisions about it, let alone control it." ❖

CONTACTS

Matthew.A.Brandt@nasa.gov or 301.286.1479
James.Mackinnon@nasa.gov or 301.286.4785

Pathfinding CubeSat Mission to Pick Up Where Dynamics Explorer Left Off

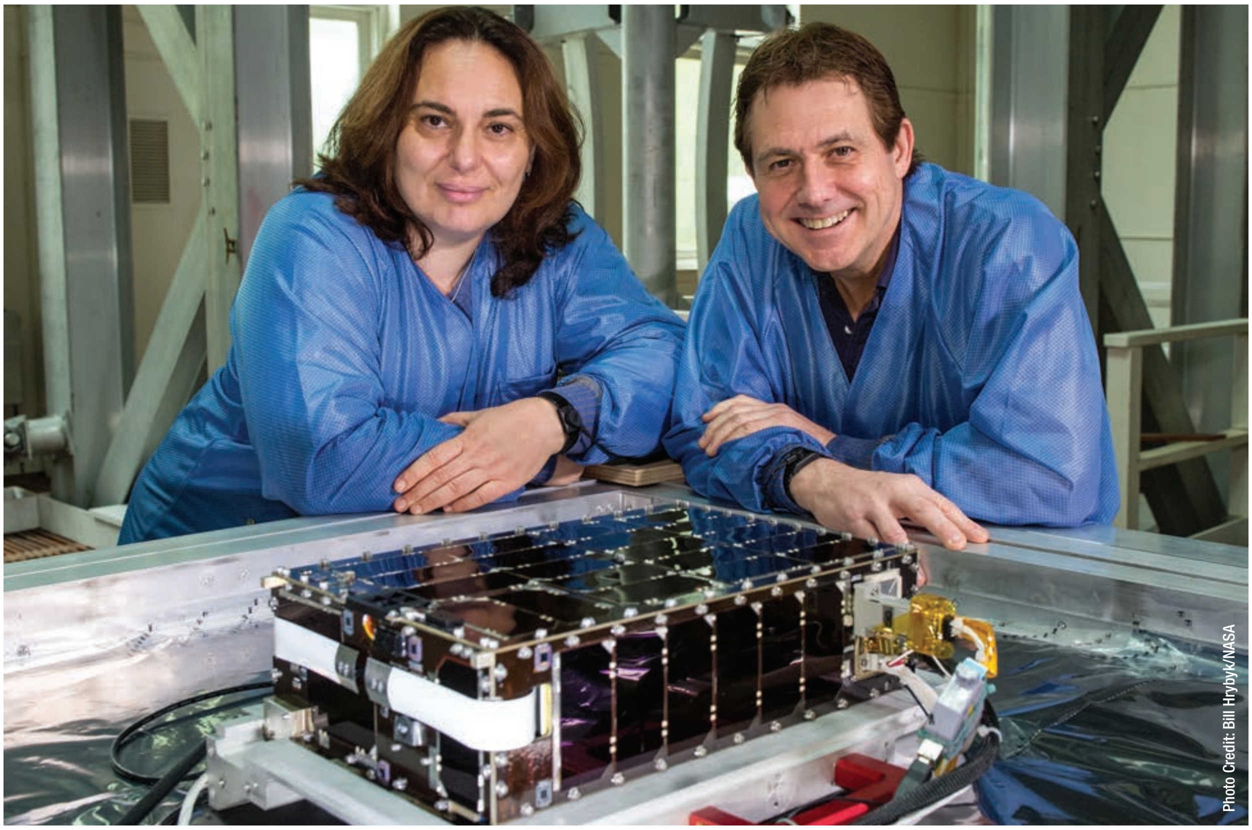


Photo Credit: Bill Hrybyk/NASA

Principal Investigator Efthyia Zesta and her team will study how Earth's upper atmospheric layers react to the ever-changing flow of solar energy into the magnetosphere with the Dione CubeSat mission. Goddard technologist Todd Bonalsky is providing the magnetometer system.

NASA has selected a new pathfinding CubeSat mission to gather data not collected since the agency flew the Dynamics Explorer in the early 1980s.

The new mission, called Dione after the ancient Greek goddess of the oracles, will carry four miniaturized instruments to study how Earth's upper atmospheric layers react to the ever-changing flow of solar energy into the magnetosphere — the magnetic field around Earth that deflects most of the particles that erupt from the Sun. The Earth's upper atmosphere is where most low-Earth-orbiting satellites reside, and their orbits are strongly affected by sudden density changes created by space weather.

Expected to launch in 2022, Dione will help give scientists insights into these physical processes — which contribute to atmospheric drag that causes low-Earth-orbiting satellites to prematurely reenter the atmosphere — and provide data needed to improve space weather forecasts.

"As more aspects of everyday lives depend on the predictable functioning of satellites in low-Earth orbit, the understanding and ability to forecast the impact of space weather on these assets has become a national security need," said mission Principal Investigator Eftyhia Zesta. "Measurements traditionally done by larger, more costly satellites must now be accomplished by thinking out of the box — or rather inside a CubeSat box. Dione will open the way for accomplishing exactly that."

The pathfinding Dione spacecraft is a prototype. It would complement the conceptual Geospace Dynamics Constellation, a mission proposed by the 2013 Heliophysics Decadal Survey, which, if developed, would gather similar data from multiple similarly equipped spacecraft, Zesta said. "Our team wants to show we can do this type of measurement with a CubeSat and eventually fly Dione-type spacecraft in a constellation," Zesta said.

Continued on page 14

Volume 16 • Issue 3 • Spring 2020

With a constellation, scientists could collect simultaneous, multi-point observations of Earth's ionosphere and thermosphere to learn more particularly how these upper atmospheric layers respond to energy dumped from the magnetosphere.

First Data Since the Dynamics Explorer

"It will provide the first set of energy input data and ionospheric-thermospheric responses measured from the same platform. We haven't gathered this type of specific data since NASA launched the Dynamics Explorer in 1981," said Zesta, whose team includes Deputy Principal Investigator Marilia Samara and Dione System Engineer Jaime Esper as well as a number of Goddard and university scientists providing the instruments. The Dynamics Explorer consisted of two satellites that investigated interactions between plasmas in the magnetosphere and those in Earth's ionosphere.

Dione will gather data not collected since NASA's dual-spacecraft Dynamics Explorer mission launched in the early 1980s.

Dione will accomplish these goals with distinct differences. Where the Dynamics Explorer gathered data maybe once every three orbits, Dione will collect measurements from successive orbits due to Dione's lower power requirements and miniaturized systems. It will also do this from a much smaller platform — a shoebox-sized, 6U platform that leverages experience gained from the Goddard-developed Dellingr spacecraft. A team of Goddard engineers and scientists specifically developed Dellingr to improve the reliability and robustness of these tiny spacecraft, but at a dramatically reduced cost (*CuttingEdge*, Summer 2017, Page 2).

Dellingr debuted in late 2017 when it deployed from the International Space Station. The platform has been baselined for other CubeSat missions and Goddard engineers have begun developing a new small-satellite architecture called MARES, short for Modular Architecture for Resilient Extensible SmallSat. This architecture would allow scientists to more reliably deploy smaller spacecraft in more distant, more hostile regions of space (*CuttingEdge*, Winter 2020, Page 10).

Densely Packed Platform

"This will be perhaps the most densely packed CubeSat ever flown," Esper added. "We're flying four science instruments and one engineering experiment in a 6U CubeSat. That's very unusual."

Three of the instruments will be provided by Goddard; all were developed with support from Goddard's Internal Research and Development program and all have either flown or are slated to fly during upcoming CubeSat or suborbital missions.

They include a flight-proven fluxgate magnetometer, which debuted on Dellingr's maiden flight, and the Ion-Neutral Mass Spectrometer (INMS), another instrument that flew on Dellingr as well as on a National Science Foundation-funded mission called ExoCube. On both Dellingr and ExoCube, the INMS was slated to measure the matter that creates atmospheric drag on satellites. Goddard's third contribution, the Dual Electrostatic Analyzer, will fly on Endurance, a pioneering CubeSat mission that will directly measure a particular component of Earth's electrical field generated in the ionosphere (*CuttingEdge*, Summer 2019, Page 5).

Utah State University and Virginia Tech are providing the fourth instrument, the Gridded Retarding Ion Distribution Sensor (GRIDS). GRIDS is designed to measure the distribution, motion, and velocity of ions and will fly on the Goddard-developed PetitSat mission scheduled to launch in 2021 (*CuttingEdge*, Spring 2017, page 22).

Zesta said she conceived the Dione concept several years ago while still working with the U.S. Air Force. "I came to NASA (in 2012) and the dream didn't die," Zesta said. ❖

CONTACT

Eftyhia.Zesta@nasa.gov or 301.286.6492

PROFILE IN EXCELLENCE

Twelfth Mission and Counting

Goddard Scientist Flies Technology on a Dozen High-Profile Missions

Scientists and engineers can spend their entire careers developing technologies and maybe, if they're lucky, fly them on a handful of missions. Goddard scientist and innovator Nikolaos Paschalidis must be an extraordinarily lucky man.

With the launch of the European Space Agency's Solar Orbiter in February, Paschalidis has contributed mission-enabling instruments, instrument subsystems, and spacecraft avionics to 12 high-profile missions — a number that doesn't include the three CubeSat missions for which he contributed instruments. And that number is still climbing, with additional missions in the development pipeline.

Paschalidis's technological innovations are set to fly on two large satellites and four CubeSat missions in the future. Even NASA's Gateway, a proposed outpost in lunar orbit, could benefit from Paschalidis's handiwork.

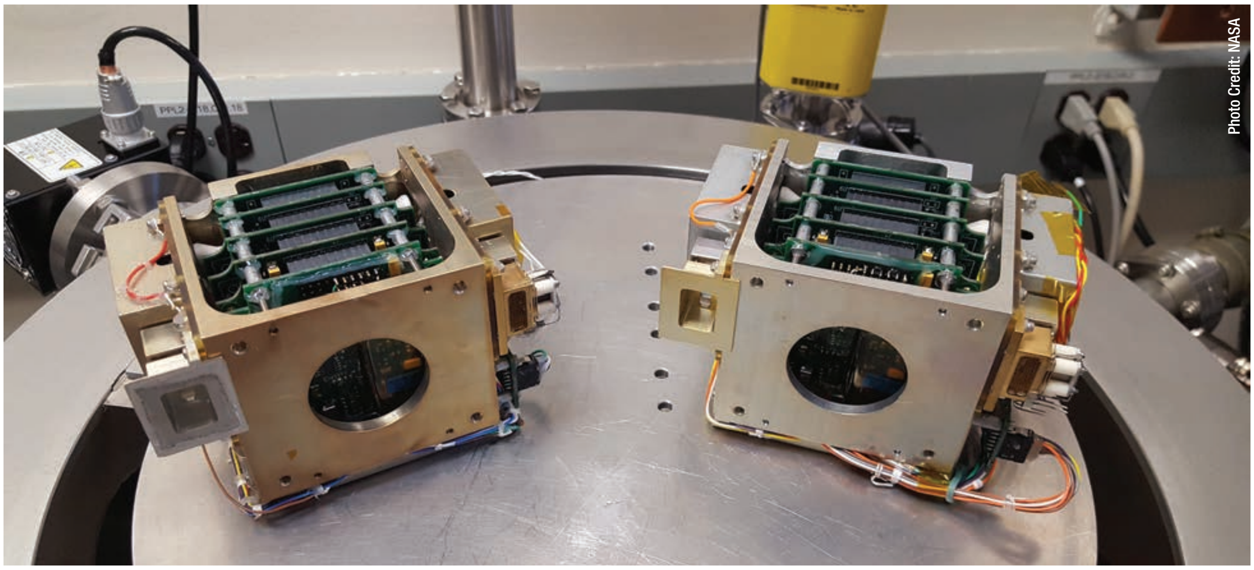
Difficult, Unusual Achievement

"Nick's achievement is very unusual and difficult, especially when you consider that these missions span the solar system," said Goddard Chief Technologist Peter Hughes, who recognized Paschalidis as his office's IRAD (Internal Research and Development) Innovator of the Year in 2015 (*CuttingEdge*, Winter 2016, Page 14). He also received the agency's Exceptional Technology Achievement Medal in 2016 for his contributions conceiving, building, and flying important technologies and instruments on both CubeSat and flagship missions. "I'm awed by his achievement," Hughes said.

The native of Greece, who worked for the Johns Hopkins University Applied Physics Laboratory before joining Goddard in 2011, made the study of the Sun and its influence on the solar system his life's work. But the 10 application-specific integrated circuits he created to measure time-of-flight, look angles, and energy down to a single photon have been used on a plethora of missions, including NASA's New Horizons, Juno, Van Allen Probes, Cassini, Parker Solar Probe, and Magnetospheric Multiscale missions, to name just a few. The European Space Agency and the Japan Aerospace Exploration Agency also employed his highly specialized computer chips to enable instruments on BepiColombo, which launched in 2018 to study the planet Mercury.

"What heartens me is that these technologies have been used continuously across the solar system: Sun, Earth, Moon, and all the planets, except Neptune, as well as the Kuiper Belt beyond Pluto," Paschalidis said. "This is a huge variation in extreme environments, literally fire, ice, and killing radiation." It also attests to their staying power during long-

Continued on page 16



The Ion-Neutral Mass Spectrometer, an instrument created by Nikolaos Paschalidis, and flight spare are shown here before they were delivered in preparation for the Dellingr launch.

duration missions. Cassini was active for nearly 20 years and New Horizons to Pluto is expected to remain active until 2021.

Paschalidis hasn't rested on his laurels since designing these integrated circuits more than 20 years ago. He's kept pace with new fabrication techniques, resulting in circuits that process data faster and consume less power and mass. He's also developed other system technologies, including detectors and collimators, which adjust the line-of-sight in telescopes, as well as other components that have resulted in more precise measurements.

Instruments NASA Needs

Following the tradition of conceiving and building technologies that NASA needs, Paschalidis more recently used IRAD support to create the miniaturized Ion-Neutral Mass Spectrometer, or INMS — the smallest instrument of its kind — which employs his ubiquitously used time-of-flight circuit. He and his team developed the instrument in less than a year — in of itself an accomplishment — to sample the densities of neutral and ionized gas species in Earth's upper atmosphere.

Paschalidis, who serves as the chief technologist for Goddard's Heliophysics Division, initially flew the instrument on the National Science Foundation's ExoCube, a CubeSat mission, and then again on the maiden flight of Goddard's Dellingr mission in 2017. He has since secured flight opportunities on the follow-on ExoCube 2 and PetitSat missions expected to launch in 2021, and more recently on Dione slated for a 2023 launch (see related story, page 13). This instrument offers important capabilities for other small satellite missions, particularly those involving a constellation of spacecraft, to study the structure and dynamics of Earth's ionosphere, he said.

With IRAD funding he has started developing a new instrument, called the HELio Energetic Neutral Atom, or HELENA, detector. It would provide the first-ever, unambiguous detection of solar energetic neutral atoms (ENAs) erupting from the Sun. ENAs are a key component in the sequence of space weather events that can be life threatening to humans living and working in space and disruptive to terrestrial power grids and communications systems.

Currently baselined for a proposed CubeSat mission called the Science-Enabling Technologies for Heliophysics, or SETH (*CuttingEdge*, Winter 2020, Page 4), HELENA offers stand-alone applications — particularly for astronauts living on the Moon and those traveling to Mars. A HELENA-type detector could be used to warn astronauts of potential space-radiation threats, giving them time to take cover.

"In a time of rapid technological change, it's difficult keeping certain technologies, unless they have something unique to offer," Paschalidis said, reflecting on his decades-long career as a scientist with a background in electrical engineering. "Providing new science measurements through cross-disciplinary capabilities is how I want to define my work at NASA." ❖

Novel Technology Sets the Stage for a New Way to Monitor Earth

The team creating a first-of-its-kind lidar capability include (from left to right): Erwan Mazarico, Jeffrey Chen, Guangning Yang, Hui Li, Travis Wise, David Harding, Jon Ranson, and Mark Stephen.

Goddard engineers and scientists partnered to create a small satellite concept — believed to be the first of its kind — that would employ just one lidar, a miniaturized spectrometer, and artificial intelligence to strategically monitor changes on Earth.

The Concurrent Artificially Intelligent Spectrometry and Adaptive Lidar System, or CASALS for short, would use a space-based lidar system to create 3D images that would help monitor, for the first time from one tiny satellite, the heights of forests, ice on land and sea, and clouds and aerosols. Equipped with machine-learning algorithms, CASALS would be able to identify when it's over a forest or ice sheet and autonomously adjust its lidar to obtain relevant, detailed information.

The idea was conceived about a year ago when Goddard engineers Guangning Yang and Jeffrey Chen walked into scientist David Harding's office and said, "Hey, we have this idea and wonder if it would help Earth sciences," they recalled. After elaborating on their plans, "a light bulb went off in my head," Harding said. "It's a 'Swiss army knife' to solve many science needs."

In addition to its advanced lidar technologies, CASALS is expected to fly a miniaturized spectrometer, MiniSpec, developed with funding from both Goddard's Internal Research and Development program and NASA's Earth Science Technology Office (*CuttingEdge*, Winter 2020, Page 12). MiniSpec combines and miniaturizes two sensors to monitor the health of trees, among other vegetation.

Lidar and Spectrometry

CASALS combines hyperspectral imaging with capabilities inspired by NASA's two current lidar missions — the Global Ecosystem Dynamics Investigation (GEDI) and the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2). With GEDI, scientists can measure the height of trees to better understand how they absorb and emit carbon dioxide into the atmosphere (*CuttingEdge*, Winter 2019, Page 14). With ICESat-2, scientists can see how quickly ice sheets melt and investigate how this affects sea-level rise.

Lidar is a surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital three-dimensional representations of the target.

However, CASALS aims to combine, shrink, and even improve GEDI and ICESat-2's lidar capabilities

Continued on page 18

and fly them on a single spacecraft. Its advanced lidar system and spectrometer not only determine changes in forest and ice heights, but also gleans information about forest health and what causes ice sheets to grow or shrink in thickness.

Though CASALS borrows elements from both ICESat-2 and GEDI's lidar, its lidar beams aren't in fixed positions. Instead, by rapidly tuning the wavelength of the laser and using a grating, the beams can be directed to different locations. As a result, by scanning a narrow range of wavelengths, the instrument can map a whole swath on the ground in three dimensions.

The CASALS concept is expected to use machine learning to allow it to autonomously scan Earth with a laser beam to study elevations of both ice and forests.

"The CASALS effort is an intriguing approach to high-spatial resolution, multi-beam altimetry," said Matt McGill, deputy director of Goddard's Earth Science Division. "The CASALS approach is a very different way to address the measurement and holds great promise for measurements of surface topography, vegetation canopy, and ice sheet altimetry."

With support from various technology-funding programs, Yang and his team proved their scanning concept in laboratory testing. The team is now building a brassboard, or experimental version of the instrument, to be tested outside the laboratory and eventually in space.

"We think the ecology and polar science communities will be excited by the opportunity to continue and improve upon ICESat-2 and GEDI in a single mission," Harding said. GEDI and ICESat-2 launched in the latter half of 2018.

Making Decisions in Orbit

CASALS will analyze MiniSpec data while in orbit to make autonomous decisions about where to point the trailing laser footprint and how to process the data based on artificial-intelligence machine-learning training.

First, MiniSpec uses visible and shortwave infrared detectors to image a 55-mile-wide swath of Earth's surface. It locates clouds and then the system steers the beam to cloud-free areas. MiniSpec images help target the lidar beams, using the wavelength tuning, on features of interest such as locations of foliage loss due to insect infestations or rapid ice sheet melting indicated by telltale features like melt ponds and lakes. Over time, CASALS could see if forest growth is stunted by insect damage and could measure how much the ice sheet shrinks due to melting.

CASALS relies on machine-learning algorithms to make decisions based on a set of hierarchical rules. These rules consider how important the feature is for scientific research, how much data was previously collected in the area, and if there are any special demands for the area, such as a wildfire, flood, or other events.

The team is training CASALS's software using data gathered from the Land, Vegetation and Ice Sensor (LVIS) campaigns. LVIS, developed at Goddard, is an airborne wide-swath imaging lidar that collects surface topography and 3D structure data. LVIS collects data over many types of vegetation and ice sheets. "Incorporating machine learning will help the system make smart decisions while operating," Harding said.

Beyond Earth

CASALS technology is driven by science applications that even extend beyond Earth. The system could be adapted to study the surface of the Moon or Mars, said Erwan Mazarico, a planetary scientist on the Goddard-based team. In fact, the instrument might be able to obtain even higher-resolution data of the Moon or other planets since they lack Earth's atmosphere, Mazarico said.

"CASALS will allow us to do so much more than before," Mazarico said. ❖

CONTACT

Guangning.Yang-1@nasa.gov or 301.614.6806

Another Blacker-than-Black Technology Pursued for Planet-Finding Missions

Goddard Technologists Develop Pupil Mask for a Testbed

More than a work of art, the etched black silicon pupil masks are designed to absorb straylight in coronagraphs.

Having already pioneered the use of carbon nanotubes as a promising light-suppression technology needed to detect and image Earth-like planets in orbit around nearby stars, Goddard technologists are now experimenting with another emerging, equally effective technique for absorbing straylight.

Led by scientist Ron Shiri, the team is investigating patterned, etched black silicon for use in next-generation pupil masks, important components in internal coronagraphs that block bright starlight to create a dark zone to reveal the relatively faint planets in orbit around their host stars. Even with multiple coronagraphic masks, starlight can still diffract off the edges of the instrument's optical components, making it difficult to completely block the light.

Honing Light-Suppression Capabilities

To overcome the challenge — likened to trying to photograph a firefly circling a streetlight from thousands of miles away — Goddard engineers have advanced carbon-nanotube coatings. They are now honing their expertise in etched black silicon — a development that could assure Goddard's role in providing light-suppression solutions for next-generation planet-finding observatories.

Both carbon nanotubes and etched black silicon work the same way, but are created with completely different manufacturing processes. Both, for example, rely on very black, tightly packed nano-sized tubes or spikes. The color black is important because it naturally absorbs light. However, the tiny gaps between the structures make these technologies particularly effective because they literally trap light. Once ensnared, the light cannot escape or continue reflecting off surfaces and interfering with the light that scientists want to measure.

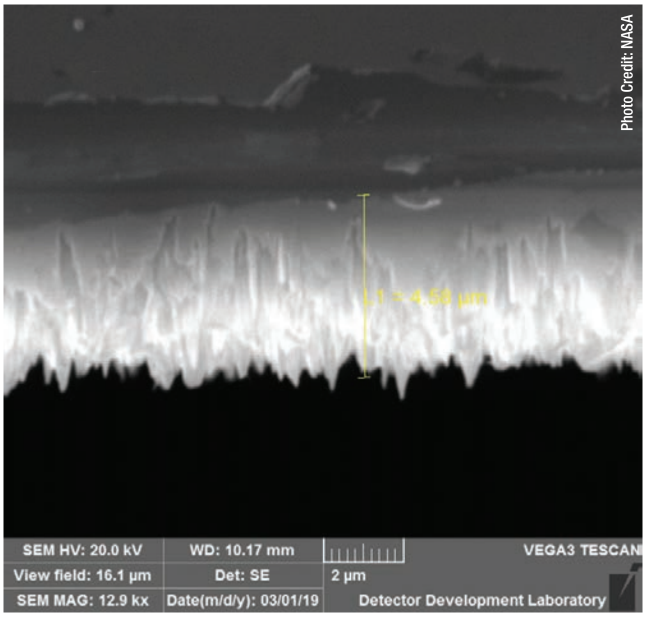
"We know the carbon-nanotube technology. That technique is unique to Goddard," Shiri said.

Continued on page 20

However, he learned about the black silicon technology nearly a decade ago in a paper published by Jet Propulsion Laboratory researchers who are also advancing the technique. "We're working on nanometer-scale technologies and black silicon is one such capability."

Samples Created for Testing

With support from Goddard's Internal Research and Development program, Shiri and detector engineer Christine Jhabvala produced a patterned black silicon mask for the High-contrast Imager for Complex Aperture Telescope, a testbed at the Space Telescope Science Institute in Baltimore. This facility is designed to evaluate different coronagraphic approaches primarily for the conceptual Large Ultraviolet/Optical/Infrared Surveyor.



This image, taken with a scanning electron microscope, shows the shag-like structures that trap stray light in etched black silicon wafers. Goddard technologists are pursuing this technology for next-generation telescopes.

In addition, Shiri and his team prepared four, one-inch black silicon masks and three sets of carbon-nanotube-coated metallic wafers for testing aboard the International Space Station. These samples launched in early March 2020 as part of MISSE-13 (Materials International Space Station Experiment), which investigates the effects of long-term exposure of materials in the harsh space environment. While in low-Earth orbit, these wafers will be exposed to atomic oxygen to assess the wafers' degradation and optical performance.

Although both carbon-nanotube coatings and etched black silicon work similarly, they are developed with different processes. Carbon-nanotube coatings, which under a microscope look like a black shag rug, are grown on substrates through various deposition processes requiring high heat. The snowflake-like patterns on black silicon are etched and require a cryogenic environment to be produced.

The first step in the process is determining which snowflake-like design would work best at capturing wayward light. Once designed, Jhabvala uses a laser-based lithography system to apply a layer of highly reflective aluminum to create the pattern on a precisely polished silicon wafer. With another machine, called the Cryogenic Deep Reactive Ion Etcher, Jhabvala then etches tiny spikes in the non-reflective areas where the straylight will be absorbed. The etcher operates at a frosty -184 degrees Fahrenheit — the temperature at which the etching process turns the silicon black.

Same Performance in Visible Light

The end result is a mask that absorbs the unwanted light and transmits the wanted light ultimately to its final destination — a detector.

Initial tests indicate that the patterned, etched silicon wafers perform as well as carbon nanotubes in absorbing visible light — the targeted wavelength. However, "the team is investigating the cryogenic etching process to optimize black silicon for infrared and submillimeter wavelengths," Shiri said. "Carbon-nanotube coatings aren't as effective in these regimes," Jhabvala said.

"The maturation of black silicon etching has a broad impact on many instrument and components," Shiri said, adding that research is continuing. "Having the ability to absorb light from the visible to the submillimeter wavelengths will certainly be useful for next-generation astrophysics and other sciences." ❖

CONTACTS

Christine.A.Jhabvala@nasa.gov or 301.286.8694
Ron.Shiri@nasa.gov or 301.286.3383

Cutting edge Goddard's Emerging Technologies

CuttingEdge is published quarterly by the Office of the Chief Technologist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The publication covers emerging technologies that Goddard is pursuing to help NASA achieve its mission and goals. Editor: Lori Keesey, ljkeesey@reagan.com; contributors: Karl Hille, Karl.B.Hille@nasa.gov; Elizabeth Goldbaum, Elizabeth.F.Goldbaum@nasa.gov; Katherine Schauer, Katherine.E.Schauer@nasa.gov; Madison Arnold, Madison.C.Arnold@nasa.gov; and Mariah Cox, Mariah.Cox@nasa.gov.

Publication Number: NP-2020-3-530-GSFC