National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

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Giving Machines Human-Like Brains

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Machines with Brains

Goddard Researchers Leverage Artificial Intelligence as NASA Launches a New Era of Exploration

NASA plans to establish a permanent presence on the Moon and continue exploring beyond. Getting there will involve the use of robots and instruments equipped with faster, less error-prone, human-like brains, Goddard experts said.

Goddard researchers are working to make that happen through the exploitation of artificial intelligence (AI) and, more specifically, machine learning, where computer processors employ algorithms or computer models that allow the machine to think and learn from data, like a human, but more accurately. The machines, in other words, do the initial analysis.

Machine learning has been implemented on space-rated computers, which are tougher but slower than commercial computers, and Goddard is investing more resources into developing this emerging AI technology with plans to test on Earth-observing CubeSats.

"I came to Goddard 30 years ago to work on AI, where it is has been done in pockets, but now applications are exploding," said Goddard Chief Technologist Peter Hughes, who sponsored a conference on intelligent machines in 2018.

Addressing Challenges

Future probes to the Moon, Mars, and beyond will face two big technical challenges: sending back enough data to verify their findings and being able to analyze data in the field to tell what would be interesting to human controllers, said Michael Johnson, chief technologist for the Center's Engineering and Technology Directorate.

NASA is currently planning to augment its radio-based communications networks with optical communications, which can transmit 10 to 100 times as much data and allow future exploration missions to communicate more efficiently. However, AI-enhanced explorers could help reduce the communications load by allowing future robotic explorers to pick and choose what to pass along (see related story, page 4).

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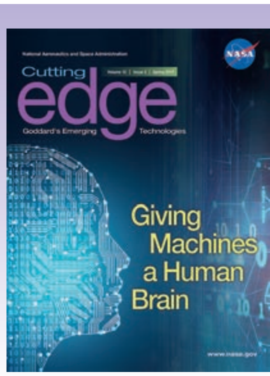

About the Cover

In this issue, CuttingEdge revisits technologists' efforts to infuse space-based instruments with algorithms that allow them to think like a human. Such an advance would free up communications networks, among many other benefits.

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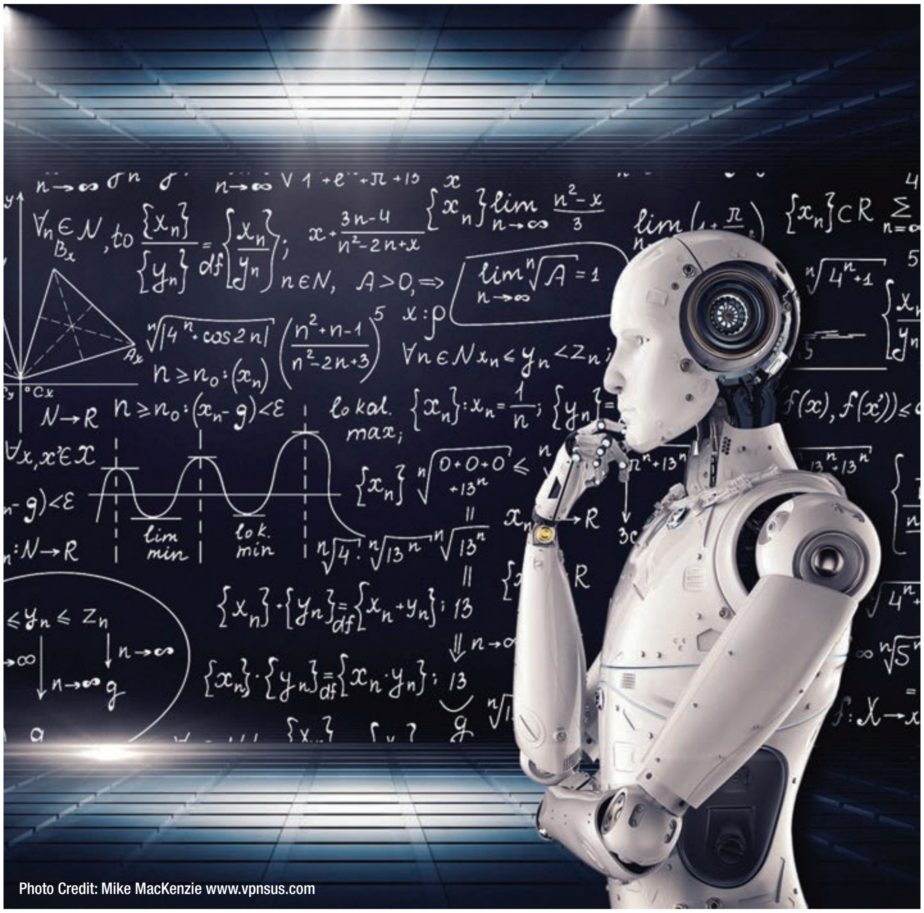
"For a spacecraft in deep space, the communications channel is narrow and long," Johnson said. It's expensive to put humans in space, but with artificial intelligence, "we can leverage the advancements made in AI to do what would be otherwise impossible" he said. "Sensors and detectors are becoming more capable and the software can enable the spacecraft to make decisions about what they see and what they send back."



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Even here around Earth, SmallSat and CubeSat platforms offer proving grounds to try new things with lower risk, Johnson said. These developments can be tailored to more forward-looking capabilities that, once proven, can transform the mission capabilities of future space explorers.

"You have to have confidence that it's going to work before you put it on a high-cost, high-profile mission," Johnson said.

Much of the groundwork for neural networks and machine learning is being laid in the private sector, he said. These companies are investing billions of dollars in advanced algorithms and specialized processors. "We're working collaboratively with industry and academia to leverage what they have and tailor it to our applications," he said.

Experimentation with Space-Rated Computers

Meanwhile at Goddard, Computer Engineer James MacKinnon has shown that AI functions can operate on space-rated computers. These hardened machines lag generations behind what's on a typical desktop due to requirements that they not fail and can endure the high-radiation environment of space.

He's made significant gains working with computers like those that run the Moderate Resolution Imaging Spectroradiometer, or MODIS, instrument on NASA's Terra and Aqua satellites by uploading algorithms on these missions to tackle new AI-capable problem-solving challenges. He uploaded algorithms to see if these machines could identify wildfires (*CuttingEdge*, Fall 2018, Page 9).

"If we could fly enough sensors, NASA could detect fires anywhere on Earth within 20 to 30 minutes of ignition," MacKinnon said. "Sensors keep getting smaller and better, but your downlink is static or deteriorating over time. If you can process that data, and just send back the interesting data, you could just beam back a list of locations where fires are instead of all of the thermal imagery from a continent," he said.

Newer generations of space computers won't be as restrictive as the MODIS processors he worked on, but the knowledge he's gained is still useful.

"Once you have developed the capability, the product you have is a library," MacKinnon said. "You input a set of data to which you have known answers. The machine learns the task. Your output is a model that can be repurposed to similar tasks or adapted to new tasks."❖

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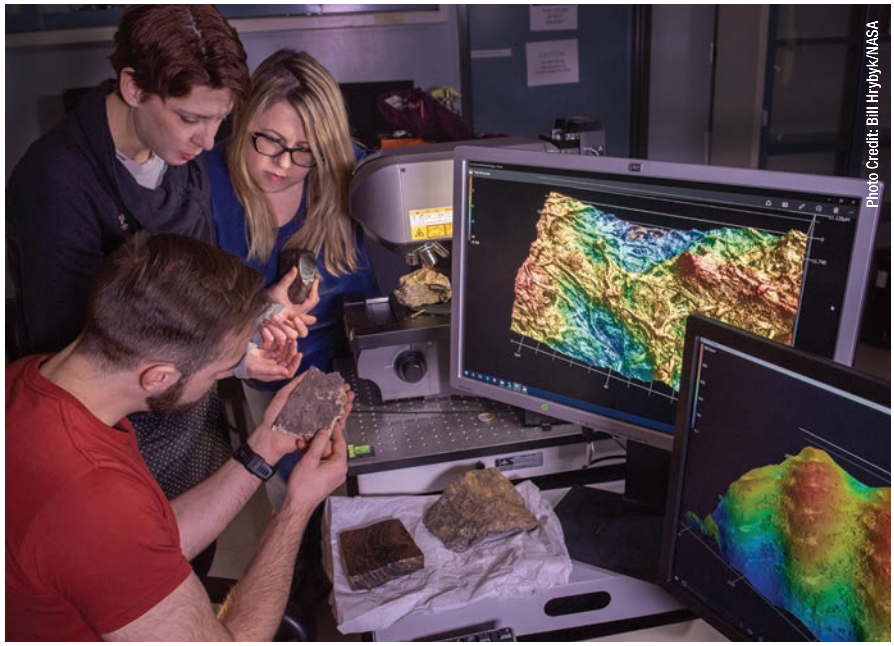
Goddard Team Teaches Algorithms to Identify Life

If you've seen dental plaque or pond scum, you've met a biofilm. Among the oldest forms of life on Earth, these ubiquitous, slimy buildups of bacteria grow on nearly everything exposed to moisture and leave behind common tell-tale textures and structures identifying them as living or once-living organisms.



An interdisciplinary team of Goddard researchers, including Ryan Kent, Heather Graham, and Burcu Kosar who are pictured here, are harnessing the power of machine learning to identify textural patterns unique to life. The pilot project is funded by Goddard's Internal Research and Development program.

Without training and sophisticated microscopes, however, these biofilms can be difficult to identify and easily confused with textures produced by non-biological and geological processes.

A team of Goddard engineers and scientists has launched a pilot project teaching algorithms to autonomously recognize and classify biofabrics, textures on rocks created by living organisms. The idea would be to equip a rover with these sophisticated imaging and data-analysis technologies and allow the instruments to decide in real-time which rocks to sample in the search for life, regardless of how primitive, on the Moon or Mars.

The multidisciplinary project, led by Goddard materials engineer Ryan Kent, is harnessing the power of machine learning — considered a subset of artificial intelligence — where computer processors are equipped with algorithms that, like humans, learn from data, but faster, more accurately, and with less intrinsic bias.

Used ubiquitously by all types of industries, including credit card companies searching for potentially fraudulent transactions, machine learning gives processors the ability to search for patterns and find relationships in data with little or no prompting from humans.

Goddard researchers have begun investigating ways NASA could benefit from machine-learning techniques (see related story, page 2) and assist in NASA's new era of human exploration. Their projects run the gamut, everything from how machine learning could help in making real-time crop forecasts or locating wildfires and floods to identifying instrument anomalies (CuttingEdge, Fall 2018, Page 9).

Other NASA researchers are tapping into these techniques to help identify hazardous Martian and lunar terrain, but no one is applying artificial intelligence to identify biofabrics in the field, said Heather Graham, a University of Maryland researcher who works at Goddard's Astrobiology Analytical Laboratory and is the brainchild behind the project.

The possibility that these organisms might live or had once lived beneath or on the surface of Mars is possible. NASA missions discovered gullies and lake beds, indicating that water once existed on this dry, hostile world. The presence of water is a prerequisite for life, at least on Earth. If life took form, their fossilized textures could be present on the surfaces of rocks. It's even possible that life could have survived on Mars below the surface, judging from some microbes on Earth that thrive miles underground.

But verifying their existence is a challenge.

"It can take a couple hours to receive images taken by a Mars rover, even longer for more distant objects," Graham said, adding that researchers

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examine these images to determine whether to sample it. "Our idea of equipping a rover with sophisticated imaging and machine-learning technologies would give it some autonomy that would speed up our sampling cadence. This approach could be very, very useful."

Teaching the Algorithms

Teaching algorithms to identify biofabrics begins first with a laser confocal microscope, a powerful tool that provides high-resolution, high-contrast images of three-dimensional objects. Recently acquired by Goddard's Materials Branch, the microscope is typically used to analyze materials used in spaceflight applications. While rock scanning wasn't the reason Goddard bought the tool, it fits the bill for this project due to its ability to acquire small-scale structure.

Kent scans rocks known to contain biofabrics and other textures left by life as well as those that don't. Machine-learning expert Burcu Kosar and her colleague, Tim McClanahan, plan to take those high-resolution images and feed them into commercially available machine-leaning algorithms or models already used for feature recognition.

"This is a huge, huge task. It's data hungry," Kosar said, adding that the more images she and McClanahan feed into the algorithms, the greater the chance of developing a highly accurate classifying system that a rover could use to identify potential lifeforms. "The goal is to create a functional classifier, combined with a good imager on a rover."

The project is now being supported by Goddard's Internal Research and Development program and is a follow-on to an effort Kent initially started in 2018 under the Goddard Fellows Innovation Challenge, another R&D program.

"What we did was take a few preliminary studies to determine if we could see different textures on rocks. We could see them," Kent said. "This is an extension of that effort. With the IRAD, we're taking tons of images and feeding them into the machine-learning algorithms to see if they can identify a difference. This technology holds a lot of promise." ❖

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GPS on the Moon

Goddard Team Leads Development of Lunar GPS Receiver

A satellite-based navigation system used by an estimated four billion people worldwide could be used to pilot in and around lunar orbit.

A Goddard team is developing a lunar GPS receiver that could provide autonomous navigation for the Orion spacecraft, the lunar-orbiting command outpost, Gateway, and future lunar landing missions using signals provided by the U.S. military's 24 to 32 operational Global Positioning System (GPS) satellites operating about 12,550 miles above Earth's surface.

Such a capability would ease the load on NASA's communications networks and free up bandwidth for data transmission, among many other advantages. Just as important, the use of GPS signals would reduce risks and open up opportunities for commercial and international partners who are expected to play a sizeable role in the NASA-led effort to establish a sustainable human presence on and around the Moon and ultimately extend human presence to Mars and beyond.

"What we're trying to do is use existing Earth-based infrastructure for navigational purposes, instead of building new infrastructure around the Moon," said Goddard engineer and Principal Investigator Munther Hassouneh.

Extending GPS-based navigation as far as the Moon, which at its most distant point is 225,623 miles from Earth, shouldn't be difficult, team members said.

"The point is we're using infrastructure that was built for surface navigation," said Jason Mitchell, chief technologist for Goddard's Mission Engineering and Systems Analysis Division. "Its use for higher-altitude navigation has already been established. In fact, we're already nearly halfway to the Moon."

Navigator GPS Heritage

The lunar GPS receiver is partially based on the Goddard-developed Navigator GPS, which engineers began developing in the early 2000s specifi-

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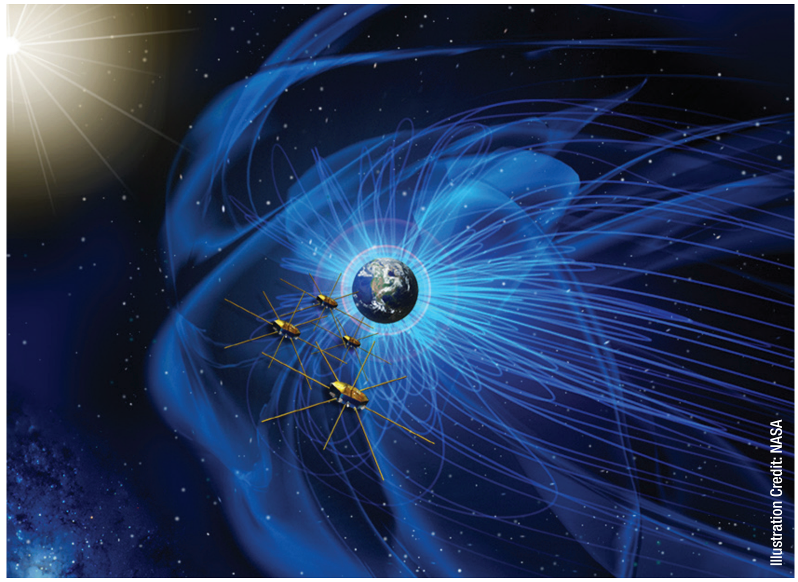
cally for NASA's Magnetospheric Multiscale (MMS) mission (CuttingEdge, Spring 2015, Page 2). The goal was to build a receiver and associated algorithms that could quickly acquire and track GPS radiowaves even in weak-signal areas.

Navigator is now considered an enabling technology for this first-ever mission to study magnetic reconnection.

Without Navigator GPS, the four identically equipped MMS spacecraft couldn't fly in their tight formation in a highly elliptic orbit that now reaches apogee distances of 115,000 miles from Earth's center — far above the GPS constellation and about halfway to the Moon.



This artist's concept of NASA's Magnetospheric Multiscale mission consists of four identically equipped observatories. They rely on Navigator GPS to maintain an exacting orbit that is at its highest point nearly halfway to the Moon. Navigator's developers are now developing a lunar GPS receiver, an evolution of MMS's Navigator.

"NASA has been pushing high-altitude GPS technology for years," said Luke Winternitz, the MMS Navigator receiver system architect. "GPS around the Moon is the next frontier."

Technology Enhancements Required

Extending the use of GPS to the Moon will require some enhancements over MMS's GPS system, including a high-gain antenna, an enhanced clock, and updated electronics.

The team said it's addressing those challenges — thanks to Goddard's years-long investment in important enabling technologies, particularly in the area of miniaturization.

"Goddard's IRAD (Internal Research and Development) program has positioned us to solve some of the problems associated with using GPS in and around the Moon," Mitchell said, adding that a smaller, more robust GPS receiver could support the navigational needs of SmallSats, including the DellingrX platform Goddard engineers are now developing.

The team's current lunar GPS receiver concept is based on NavCube, a new capability created from the merger of MMS's Navigator GPS and SpaceCube, a reconfigurable, very fast flight computer platform that has proven its mettle on several high-profile missions, including the Robotic Refueling Mission 3 (CuttingEdge, Fall 2016, Page 4). The more powerful NavCube will be demonstrated on the International Space Station, where it is also expected to operate NASA's planned demonstration of X-ray communications in space (CuttingEdge, Winter 2019, Page 9).

Other enhancements include the replacement of the system's GPS radio-frequency (RF) card with an IRAD-developed application-specific integrated circuit, better known as an ASIC. This ASIC — whose job is to condition the GPS signal prior to digital processing — will help further reduce the receiver's size and weight, while using less power. Meanwhile, another IRAD researcher, Victor Marrero-Fontanez, is working on a high-gain, wide-band GPS antenna that would improve the received GPS signal and extend its use for orbit determination at lunar distances.

Earlier this year, the team published promising GPS-based navigation performance predictions for the NASA Lunar Gateway using computer simulations of the lunar NavCube GPS system. By the end of this year, the team plans to complete the lunar NavCube hardware prototype.

"NASA and our partners are returning to the Moon for good," Mitchell said. "NASA will need autonomous navigation afforded through a capability such as ours. We've developed all the enabling technologies to make this happen. We've spun these technology webs to accomplish multiple goals." ❖

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Creating the World's Largest Scientific Instrument

Goddard Scientist Receives Patent for Innovative Technique to Measure GICs

A NASA expert in space-weather phenomena has won a patent for an idea that, if fully implemented, would create the world's largest scientific instrument for detecting a condition that has caused power outages in the past.

Sean Blake (left), a post-doctoral student from Ireland, and Todd Bonalsky (right), a Goddard instrument engineer, are testing two stations set to deploy beneath power lines operated by the Southern Company in Alabama.

Goddard scientist Antti Pulkkinen and his team have started implementing the idea, installing scientific stations equipped with commercial fluxgate magnetometers and compact command-and-control computers beneath high-voltage power transmission lines operated by Dominion Virginia Power and American Electric Power in Ohio.

The team is getting ready to install additional stations — equipped with second-generation equipment — beneath lines operated by the Southern Company in Alabama. All participating stations include reference stations positioned up to two miles from the power lines.

The project represents the first time NASA has used high-voltage power lines as a tool to map large-scale geomagnetically induced currents, or GICs, caused by severe space weather. During solar storms, violent changes occur in near-space, which then are sensed by the transmission lines, essentially making them antennae.

"Win-Win" Situation

"It's a win-win for everyone involved," Pulkkinen said, referring to the project that he began investigating five years ago with R&D funding (CuttingEdge, Spring 2014, Page 3). His patent covers the general idea, not specific instruments, he added.

The project gives power companies data about GICs, while offering scientists an opportunity to "reverse engineer" the data to learn more about what happens in Earth's upper atmosphere when severe space weather is taking place.

GICs typically occur one-to-three days after the Sun unleashes a coronal mass ejection, a gigantic bubble of charged particles that can carry up to 10 billion tons of matter. These bubbles accelerate to several million miles per hour as they race across space. If a blob of material slams into Earth's near-space atmosphere, the impact causes Earth's magnetosphere — and electric currents within it — to fluctuate.

These variations induce electric currents that can flow through any large-scale conductive structure, including power lines, oil and gas pipelines, undersea communications cables, telephone networks, and railways.

An extreme example of a GIC was the great magnetic storm of March 1989. Rapid variations in the geomagnetic field led to intensely induced electric fields at Earth's surface, which caused currents to flow through conducting structures — in this case, the Canadian Hydro-Quebec power grid. The excess current collapsed the transmission systems, causing the loss of electric power to more than six million people.

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Mission-Saving Instrument Secures New Flight Opportunity; Slated for Significant Upgrade

A miniaturized fluxgate magnetometer that helped stop the Dellingr spacecraft from a potentially mission-ending spin has secured a flight aboard a NASA CubeSat mission — NASA's first with Brazil — and is now undergoing a significant upgrade that would benefit both space- and ground-based data collection.

Developed exclusively with support from Goddard's Internal Research and Development Program (IRAD), the miniaturized fluxgate magnetometer proved that scientists could reduce the size of these powerful instruments and gather scientifically useful magnetic-field measurements from small platforms sometimes no larger than a shoebox, said Principal Investigator Todd Bonalsky.

The instrument made its debut as one of two magnetometers aboard the Dellingr mission, created at Goddard to improve the reliability and resiliency of CubeSat platforms. Shortly after its launch in 2017, the Dellingr spacecraft began to spin, crippling communication and preventing one of the mission's miniaturized mass spectrometers from collecting usable data. To slow down the tumbling, mission controllers wrote and uploaded new software and used Bonalsky's miniaturized fluxgate magnetometer as an attitude sensor to provide the data needed to activate Dellingr's torquers and help stabilize the spinning (*CuttingEdge*, Fall 2018, Page 5). Dellingr is now collecting useful data.

The same instrument has also flown on a couple sounding rocket missions and will gather data on the Scintillation Prediction Observations Research Task, or SPORT, mission expected to launch in 2020. The objective of this joint NASA partnership with the Brazilian National Institute for Space Research is understanding the conditions in Earth's ionosphere that lead to scintillation, which can compromise GPS and other transmissions from low-Earth orbit.

Perhaps more exciting, though, are efforts to develop a self-calibrating, miniaturized magnetometer. It could fly on CubeSats and sounding rockets, but also be used as a ground-based instrument for NASA's first-ever effort to use high-voltage power lines as a super-scale antenna for gathering measurements about geomagnetically induced currents (see related story, page 7).

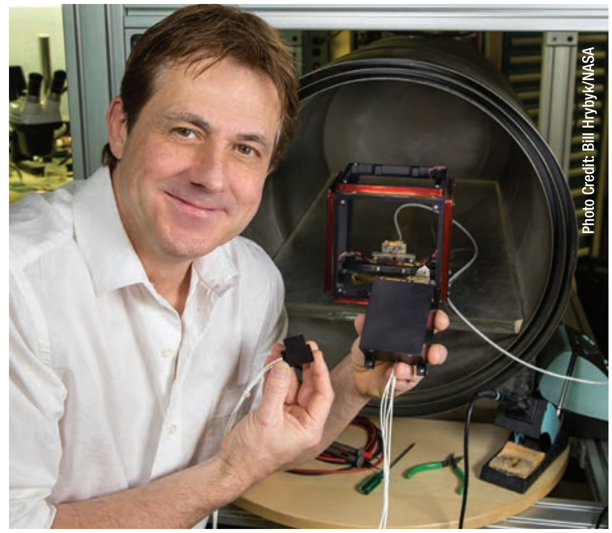
Photo Credit: Bill Hrybyk/NASA

Principal Investigator Todd Bonalsky developed a miniaturized fluxgate magnetometer, which debuted on the Dellingr mission and is slated to fly aboard SPORT. He is now upgrading the instrument so that it can self-calibrate.

With funding from Goddard's FY19 IRAD program, Bonalsky is continuing an effort he began two years ago to combine the flight-proven miniaturized fluxgate magnetometer that can measure both a magnetic field's magnitude and direction, with an optically pumped atomic magnetometer. With the marriage of the two types, Bonalsky said he would create a self-calibrating instrument.

"Our miniaturized fluxgate system, which has been so successful on Dellingr and other flight programs, is prone to drift over long periods of time due to wide and repeated temperature variations," Bonalsky said. However, atomic magnetometers, which can only measure the magnetic field's magnitude, not its direction, could maintain the fluxgate's calibration because they aren't prone to drift.

"A self-calibrating fluxgate magnetometer would be very valuable to us," said Antti Pulkkinen, the Goddard scientist spearheading the power-grid study. "We could put them in the ground and literally walk away without worrying about whether they are properly calibrated. They would do it themselves," Bonalsky added. "I want to put them in the field!" ❖

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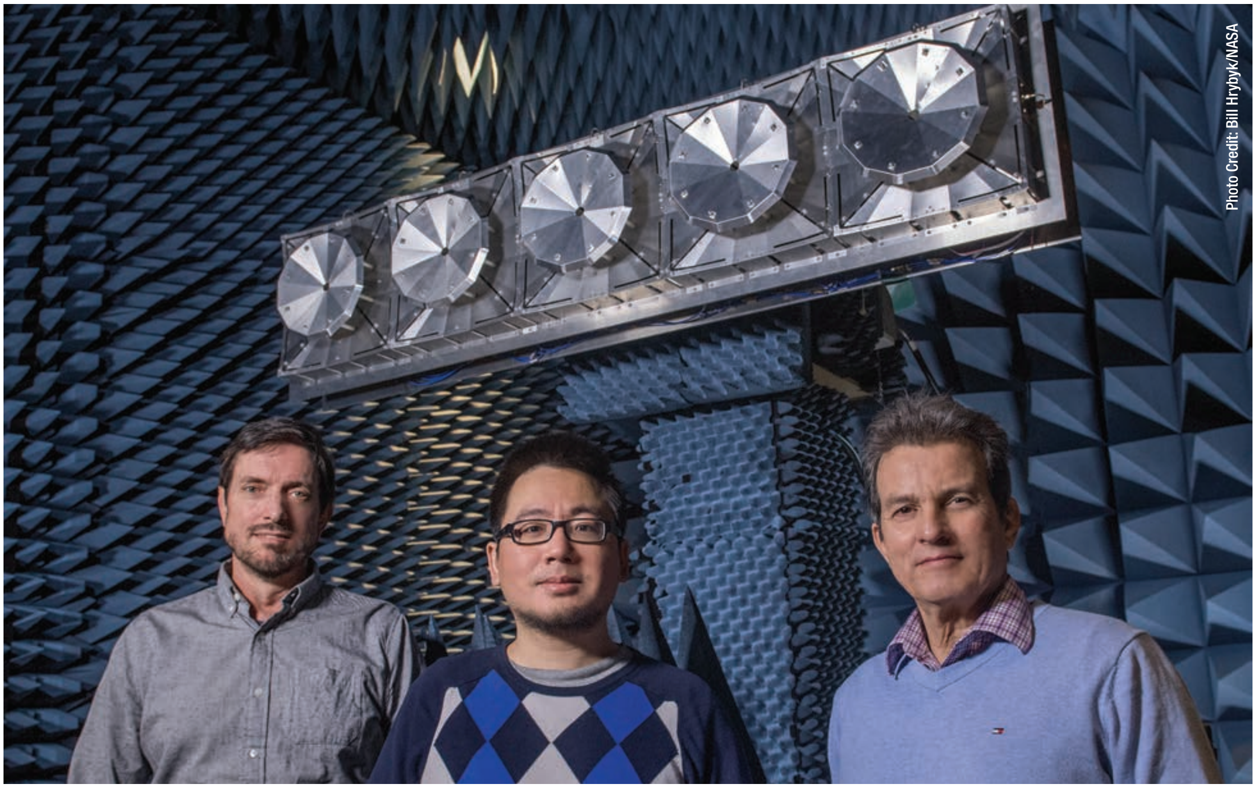
What Lurks Beneath the Surface?

NASA Closer to Discovering What Lies Beneath the Surfaces of Airless Planetary Bodies



In this picture, Goddard technologists Cornelis Du Toit (left), Daniel Lu (center), and Rafael Rincon (right) stand before a prototype antenna subarray for Space Exploration Synthetic Aperture Radar. The team successfully tested the technology at Goddard's Electro-Magnetic Anechoic Chamber.

NASA is a step closer to eventually discovering what lies up to 32 feet or 10 meters beneath the surfaces of Mars, the Moon, or any airless body in the solar system — a region roughly the length of a three-story building.

Goddard engineer Rafael Rincon and University of Arizona scientist Lynn Carter are using NASA technology-development funding to mature the Space Exploration Synthetic Aperture Radar, or SESAR. It would be capable of gathering meter-scale images of ice deposits, lava flows, caves, natural resources, and fluvial channels that lie buried beneath the surfaces of planets, moons, and other small bodies.

Current NASA instruments can probe the surface or tens to hundreds of miles inside the interior. However, near-surface regions targeted by SESAR remain hidden from view with current spaceflight instruments, said Rincon, who, along with Carter, created the instrument concept.

"Our instrument will bridge the gap in these observations," Rincon said. "In fact, synthetic aperture radar technology, which we employ in our instrument, is the only remote-sensing technique capable of penetrating meters into the surface while still providing high-resolution images."

With this radar data, scientists could obtain greater insights into how volcanism, cratering, and fluvial activity and other geologic processes shaped these bodies. They could determine how surface regolith — that is, the layer of dust, soil, broken rock, and other materials — developed over time. And they could locate regions potentially hospitable to life, search for safe havens for astronauts to take cover in case of an emergency, and measure the extent and depth of ice deposits or potential sources of water.

With funding from NASA's Maturation of Instruments for Solar System Exploration program, Rincon, Carter, and their team will build an instrument prototype and then test it in Goddard's Electro-Magnetic Anechoic Chamber, which simulates conditions found in space. The goal, Rincon said, is to mature the instrument to the point where it could be proposed for a future mission once the funding ends in three years.

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A Serendipitous Discovery

New Instrument for Measuring Ozone Created

Goddard research scientist Tom Hanisco set out to build an instrument capable of measuring a short-lived chemical that cleanses the atmosphere of methane — a potent greenhouse gas — but found instead that his technique outshined the best commercial instruments at detecting ozone, a regulated greenhouse gas that also poses significant risks to humans with respiratory ailments.

His serendipitous discovery has led to the filing of a patent application for an instrument he now calls the Rapid Ozone Experiment, or ROZE, and a berth aboard a NASA research aircraft, which will be carrying out a wildfire-related field campaign this summer.

"Research and development are never wasted," Hanisco said. "When we started this development effort, ozone was the farthest thing from our minds."

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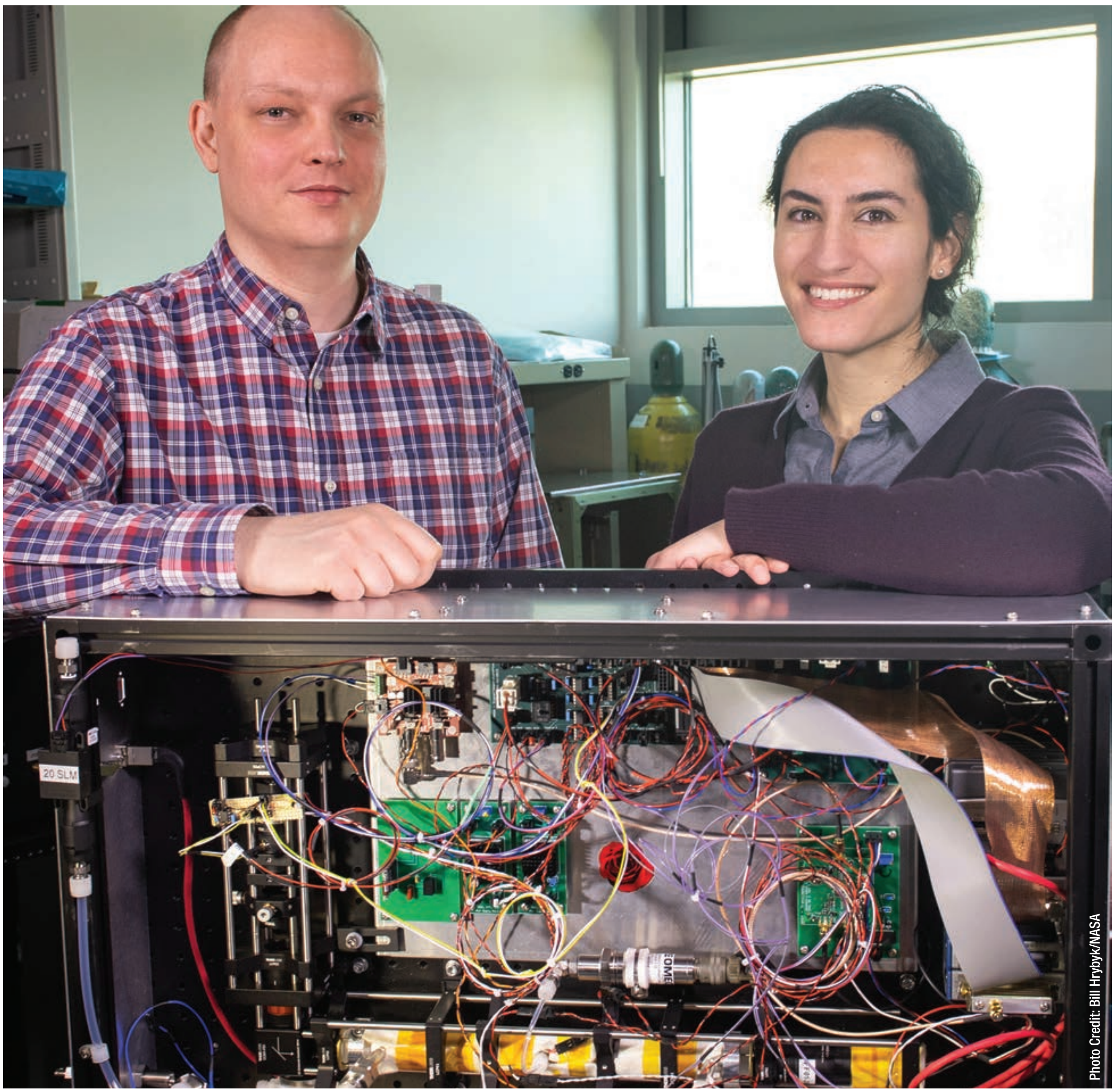

In pursuit of an instrument that could detect a methane-cleansing chemical in the atmosphere, a Goddard team discovered that its instrument was highly sensitive to ozone, a tropospheric pollutant. Here, Goddard instrument engineer Andrew Swanson and scientist Reem Hannun are shown with the instrument now slated for an aircraft campaign this summer.

Good and Bad Ozone

While stratospheric ozone protects life on Earth from harmful ultraviolet radiation, it's harmful in the troposphere, exacerbating respiratory diseases that kill hundreds of thousands of people each year. Not emitted directly, tropospheric ozone is created by chemical reactions between oxides of nitrogen and volatile organic compounds. This happens when pollutants emitted by cars, power plants, industrial boilers, and other sources react chemically in the presence of sunlight.

As a result, the Environmental Protection Agency in the U.S. regulates ozone levels and penalizes cities when levels exceed accepted levels.

ROZE Vital to Municipalities

ROZE, which Hanisco believes municipalities could use to monitor ozone levels and help in determining how much is deposited on the surface, is a version of a prototype instrument he initially developed to measure hydroxyl, or OH (CuttingEdge, Summer 2018, Page 6).

Hydroxyl is produced in nature by reactions initiated by ultraviolet light from the Sun. During this reaction, ozone is disassociated to produce an oxygen atom, which reacts with water to produce the OH radical. Although short-lived and highly reactive, OH is nature's detergent: it cleanses the atmosphere of methane, a devastatingly powerful greenhouse gas that is more effective than carbon dioxide at absorbing heat.

To better measure hydroxyl, Hanisco incorporated a tried-and-true measurement technique called gas filter correlation spectroscopy. Hanisco's idea was to fill a cavity with hydroxyl produced by the instrument. Once filled, the hydroxyl would block all the light at wavelengths hydroxyl absorbed. When he turned off the cavity to prevent hydroxyl from filling it, the instrument would then measure all the light affected by hydroxyl. The difference between the two measurements would be proportional to the abundance of hydroxyl in a column.

In testing, however, the team encountered difficulties photolyzing water to produce hydroxyl. Instead, an air leak produced ozone, which is made up of three oxygen atoms. "Ozone interfered, but we did a few quick numbers to see actually how much ozone we could see. As it turned out, the instrument was supersensitive to this molecule," Hanisco said.

With some tweaking, Hanisco and his colleague, Reem Hannun, were able to improve the instrument's sensitivity to ozone. It is now 100 times more precise than the best commercially manufactured optical instrument, Hanisco said, adding that his instrument is easy to build and relatively inexpensive.

"Research and development are never wasted. When we started this development effort, ozone was the farthest thing from our minds."

– Goddard Research Scientist Tom Hanisco

Patent Filed; Aircraft Campaign on the Horizon

Hanisco has filed a patent application and now plans to fly the instrument on an aircraft campaign called FIREX-AQ, short for Fire Influence on Regional to Global Environments Experiment-Air Quality. The campaign, to be conducted aboard a DC-8 aircraft in July-August, will measure trace gases and aerosol emissions caused by wildfires and prescribed fires in California, Nevada, and Oregon. Although gathering ozone measurements isn't a focus of FIREX-AQ, the flight opportunity gives Hanisco and his team a chance to operate ROZE under flight conditions.

Already ROZE has generated interest among researchers at government agencies and universities. Due to its high sensitivity and fast sampling rates, they believe it could fill a vital niche in ozone monitoring. Current instruments are effective at measuring overall background levels, but aren't adept at revealing how much gets deposited at ground levels, where it can harm humans and even plants if they absorb too much.

Knowing deposition rates is important to municipalities and states, particularly if an area falls into non-attainment and is penalized. "EPA has models that can predict how much ozone will form," Hannun said. "But these models don't really know how fast it's being deposited. If we don't know the rate, we can't accurately model how ozone moves from one area to the next, or how long it will stick around once formed."

As for creating an instrument sensitive to hydroxyl, Hanisco hasn't given up. He submitted a patent for that concept, too, and plans to further develop the technology. "Even if you don't win, ultimately you do win. That was certainly the case here," Hanisco said. ❖

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Team Develops New Instrument for Gathering Difficult-to-Obtain Snow Water Equivalent Measurements

NASA is good at measuring the spatial extent of snow cover, but isn't as effective at determining how much water is stored in the snowpack — a difficult-to-measure parameter that ultimately affects 1.2 billion people worldwide who rely on seasonal snowpack and glaciers for their fresh water.

A team led by Goddard scientist Batu Osmanoglu, however, has built a first-of-its-kind microwave instrument that recently proved successful at remotely sensing snowpack conditions that would reveal snow water equivalent, or SWE, which is critical for understanding the world's water resources and the impact that climate change may have on them.

Goddard technician Stephen Seufert stands inside Goddard's Electro-Magnetic Anechoic Chamber, where technicians tested the SWESARR instrument and its unique antenna.

Partially as a result of that demonstration late last year aboard a Twin Otter research aircraft over the Grand Mesa in Colorado, the Snow Water Equivalent Synthetic Aperture Radar and Radiometer, or SWESARR, has secured a berth on NASA's next SnowEx campaign in the winter of 2019-2020.

The Goddard-managed SnowEx effort is a multi-year airborne and ground-based campaign aimed at determining which suite of instruments is most effective at gathering observations. These observations are fed into sophisticated computer algorithms to estimate SWE. The goal is to ultimately fly these instruments aboard a remote-sensing satellite for global measurements.

A Winning Concept

The SWESARR team, which began developing the instrument about nine years ago with funding from NASA's Earth Science Technology Office and Goddard's Internal Research and Development program, thinks it may have a winner in the agency's quest to understand how much water is stored in terrestrial snow.

"SWESARR went out and collected data on the first flight," said Goddard engineer and SWESARR co-developer Paul Racette, referring to the technology demonstration. "That impressed me. It's not easy building an instrument and having it work the first time it goes out."

Remote-sensing instruments, which typically passively receive or actively bounce microwave, visible, or infrared light and combine them using algorithms to interpret the returning signals, don't work consistently in all snow-covered environments.

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A new Goddard-developed instrument will fly on NASA's SnowEx mission centered around the Grand Mesa, Colorado, this summer. The area was chosen due to its varying forest cover.

Forests and complex topography, among other conditions, complicate these interpretations.

Radar instruments, which actively pulse microwave radiation to the surface, are sensitive to snow properties and may provide a relevant means for accurately monitoring SWE over extensive areas. However, radar microwave radiation is lost when the snow gets wet or too deep. Lidar, which transmits visible light to targeted areas below, can obtain depth levels even in forested areas, but can't see through clouds. And radiometers, which passively listen to microwave signals arising from the surface, are sensitive to all types of snow, even in forested areas, but their measurements are coarse in spatial scale and therefore lack detail.

What makes SWESARR different is the fact that it carries an active, dual-polarization radar tuned to three specific microwave frequencies — Ku-High, Ku-Low, and X-band — and a passive radiometer sensitive to the Ka-band, K-band, and X-band. This broad spectral window — ideal for gathering snow-related measurements — gives SWESARR higher sensitivity than other instruments, Osmanoglu said.

"Some microwave frequencies are better for certain types of snow and not good for others. This broad spectral range gives us a large range of snow depths for measuring SWE accurately," he said.

When operating, SWESARR's radar fires 3,000 pulses per second, alternating over its three microwave bands. As with radar instruments used by weather forecasters, SWESARR transmits both horizontally and vertically polarized signals. These perpendicular fields bounce off the surface and back to SWESARR's antenna, providing a more detailed two-dimensional picture of the snow cover. These observations vary according to the presence of snow, its depth, grain size, and the presence of vegetation. They are then fed into sophisticated algorithms to derive SWE.

The radiometer, which listens for horizontal polarized microwave signals arising from the surface, doesn't begin collecting data until the radar stops. "It's a highly choreographed dance," Osmanoglu added.

Another advantage is the fact that SWESARR's two instruments share the same antenna. "SWESARR is the only instrument using the same antenna for this purpose," Osmanoglu said, adding that the resulting co-located data reveal greater insights about e snowpack and ultimately how much water it contains.

SnowEx Campaign and Space Beyond

SWESARR is scheduled to fly, along with other microwave and optical instruments, on the next SnowEx campaign later this year over the Grand Mesa, Colorado — selected because of its varying forest cover. The campaign will involve a variety of research aircraft, including the Twin Otter upon which SWESARR will fly. Ultimately, however, SWESARR's developers believe the instrument would be a candidate for a spaceborne mission that would gather information about the global cryosphere.

"We created an instrument that NASA didn't have in its toolbox," said Rafael Rincon, the SWESARR lead engineer. "With limited time and funding, we proved its functionality. Nothing about this instrument would prevent it from flying in space. It's an amazing success story." ❖

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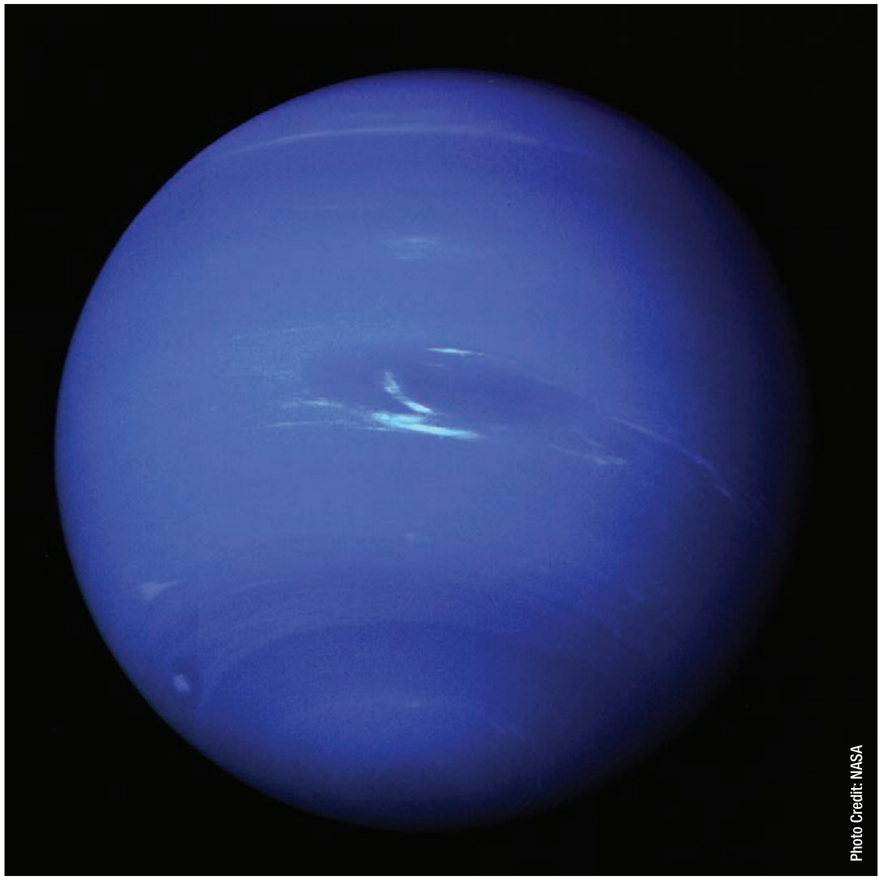
Taking the Plunge into the Ice Giants

Next-Generation Instrument Advanced to Study the Atmospheres of Uranus and Neptune

Much has changed technologically since NASA's Galileo mission dropped a probe into Jupiter's atmosphere to investigate, among other things, the heat engine driving the gas giant's atmospheric circulation.

A Goddard scientist and his team are taking advantage of those advances to mature a smaller, more capable net flux radiometer. This type of instrument tells scientists where heating and cooling occurs in a planet's atmosphere and defines the roles of solar and internal heat sources that contribute to atmospheric motions. The next-generation radiometer is specifically being developed to study the atmospheres of Uranus or Neptune, but could be used to study an object with an atmosphere.



NASA's Voyager 2 spacecraft gave humanity its first glimpse of Neptune and its moon, Triton, in the summer of 1989. This image, taken at a range of 4.4 million miles from the planet, shows the Great Dark Spot and its companion bright smudge. These clouds were seen to persist for as long as Voyager's cameras could resolve them.

Of all the planets in the solar system, only Uranus and Neptune — called the ice giants because they are composed mostly of ices — remain relatively unexplored. While Voyager 2 snapped photos of the seventh and eighth planets, it did not obtain the breathtaking details that the Galileo and Cassini missions gathered about Jupiter and Saturn. Even far-flung Pluto scored a close-up look with the New Horizons mission in 2015.

Discoveries Remain

A lot remains to be discovered, said Shahid Aslam, who is leading the team developing the next-generation instrument, an effort funded by NASA's Planetary Instrument Concepts for the Advancement of Solar System Observations, or PICASSO, program.

Scientists do know that both Uranus and Neptune host a slushy mantle of water, ammonia, and methane ices, while their atmospheres consist of molecular hydrogen, helium, and methane gas. However, differences exist in these cold outer Jovian worlds.

As temperatures fall below -333.7 degrees Fahrenheit, ammonia gas freezes into ice crystals and drops out of the atmospheres of both planets. Methane — a blue-colored gas — becomes dominant.

While the amount of atmospheric methane is similar in both planets, they look different. Uranus appears as a hazy blue-green, while Neptune takes on a much deeper color blue. Some unknown atmospheric constituent is thought to contribute to Neptune's deeper blue color, Aslam said.

Also, Uranus lacks internal heat. Consequently, its clouds are cold and don't billow above the top haze layer. Neptune, on the other hand, radiates as much energy as it receives from the Sun. This internal energy gives Neptune an active, dynamic atmosphere, distinguished by dark belts and bright clouds of methane ice and cyclonic storms.

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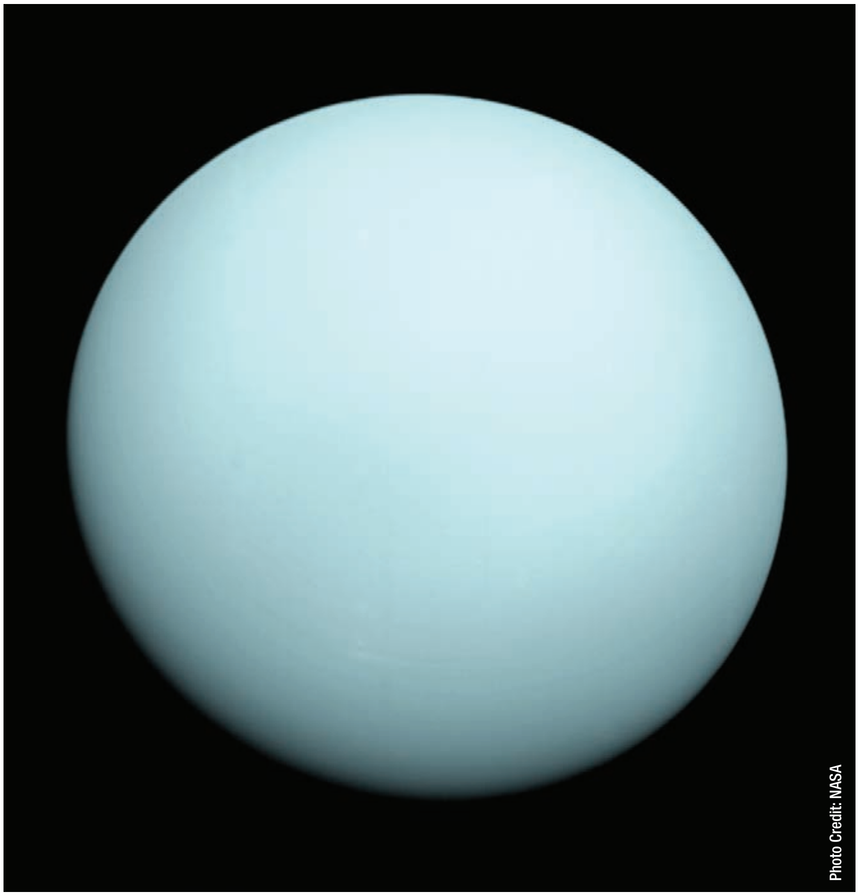
Because NASA has never flown a dedicated mission to the ice giants, details of the physics driving these atmospheric conditions remain elusive, Aslam said.

New Instrument Holds Promise

He believes the new instrument could provide answers.

It's a successor to a similar type instrument that gathered data about Jupiter's atmospheric conditions before being crushed by Jupiter's atmospheric pressure in December 1995. During that perilous, 58-minute ride deep into the planet's atmosphere, Galileo's net flux radiometer — one of several mounted inside the probe — measured radiation that reached the planet from the Sun above as well as the thermal radiation or heat generated by the planet itself below. These top and bottom measurements helped scientists calculate the difference between the two — a measurement called net flux.



This is an image of the planet Uranus taken by the spacecraft Voyager 2, which flew closely past the seventh planet from the Sun in January 1986.

In addition to providing details about atmospheric heating and cooling, net flux data reveal information about cloud layers and their chemical composition. "Actually, you can learn a lot from net flux data, especially sources and sinks of planetary radiation," Aslam said.

Like its predecessor, Aslam's instrument would take a suicidal plunge through the atmospheres of either Uranus or Neptune. But as it made its descent, it would gather information about these poorly understood regions with greater accuracy and efficiency, Aslam said.

"Available materials, filters, electronic detectors, flight computing, and data management and processing have all improved. Frankly, we have better technology all the way around. It's clear that the time is now to develop the next generation of this instrument for future atmospheric entry probes," he said.

New or Improved Components

Instead of using pyroelectric detectors employed on Galileo, for example, Aslam is eyeing the use of thermopile sensors, which convert heat or infrared wavelengths or heat into electrical signals. The advantage is that thermopile circuitry is less susceptible to disturbances and electrical noise.

Aslam's team is also adding two additional infrared channels to measure heat, bringing the total to seven, and two additional viewing angles with which to gather these wavelengths and help model light scattering. When light scatters in one field of view due to interactions with aerosols and ice particles, the scattering can contaminate measurements in another field of view. This gives scientists a skewed picture of what's happening when they analyze the data.

Furthermore, the instrument's tighter field of view will reveal greater detail about the planet's cloud decks and atmospheric layers as the instrument makes its descent. Just as important, the instrument is smaller and its sensors employ modern application-specific integrated circuits (ASICs) that support fast data sampling, Aslam said. ❖

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Scientific Instrument,

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Regulatory Requirements

Due to their threat to power grids, the Federal Energy Regulatory Commission will require power companies to mitigate GICs. Mitigation can include postponing the maintenance of critical lines and injecting reserve power into the system to allow power companies to "weather the solar storms," Pulkinnen said.

"Solar storms propagate across various regions of the geospace," said Todd Bonalsky, a Goddard instrument engineer and co-investigator. "If an event were to hit Oregon, for example, you could watch the storm propagating across the country through these measurements. With the data, you can predict which states are likely to be most affected."

Pulkkinen wants to install stations beneath the lines of as many power companies as he can recruit. "With the industry and science need for stations, this project offers a nice mutual benefit," Pulkkinen said. "In essence, we're tapping into a very large antenna to learn more about GICs and associated space physical phenomena." ❖

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Legacy System

Rincon said he is confident of the team's ultimate success.

SESAR is based on the L-Band Digital Beamforming Synthetic Aperture Radar, or DBSAR, which Rincon developed more than a decade ago. L-band is a microwave frequency range used for aircraft surveillance, telecommunications, and Earth remote sensing.

DBSAR demonstrated for the first time the ability to simultaneously synthesize multiple L-Band radar beams directed at targets below and then produce two-dimensional, high-resolution images of very large surface areas from the returning signals. Prior to its development, conventional synthetic aperture radar systems could only gather high-resolution data along a narrow swath on one side of the flight track.

Taking the technique one step further, Rincon and a colleague then adapted the same general approach to tune the system to the P-band — a lower microwave frequency ideal for piercing forest canopies and measuring biomass (CuttingEdge, Summer 2016, Page 9). The end result was an instrument called EcoSAR, which obtained unprecedented two-and three-dimensional fine-scale measurements of the biomass during its debut flight aboard a P-3 research aircraft in 2013.

Like EcoSAR, SESAR will operate in the P-band, which, as EcoSAR demonstrated, can penetrate meters of structure. However, the team had to first overcome two major design challenges: the power required to steer the beams and the mass of the antenna. "We've successfully resolved both," Rincon said.

With research and development funding, the team created a more efficient subsystem for steering the antenna, which must be relatively large to capture the P-band signal. In testing, the subsystem proved it could reduce power consumption by a factor of five compared with more conventional steering technologies.

Because the antenna must be large, it's inherently heavy. To reduce its mass, the team constructed the antenna array with lightweight, structurally strong materials. It, too, was successfully tested at Goddard's Electro-Magnetic Anechoic Chamber in March 2019. With the new funding, the team will further mature the instrument, aiming to reduce power consumption by a factor of 10, which would help assure the instrument's readiness for a future mission, Rincon said. ❖

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Cutting edge Goddard's Emerging Technologies

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