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Goddard's Emerging Technologies

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A New Dawn for CubeSat Reliability

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Dellingr Set to Launch in August

R&D-Funded CubeSat Purposely Designed to Improve the Reliability of Small Satellites

They named their new-fangled CubeSat after the mythological Norse god of the dawn. Now, just days from launch, Goddard scientists and engineers are confident Dellingr will live up to its name and inaugurate a new era for scientists wanting to use small, highly reliable satellites to carry out important, and in some cases, never-before-tried science.

The shoebox-sized spacecraft — the brainchild of Michael Johnson, the chief technologist of Goddard's Applied Engineering and Technology Directorate, and scientists with the center's Heliophysics Science Division — is set to launch in August aboard a SpaceX Falcon 9 rocket to the International Space Station where it will be deployed later into a low-Earth orbit.

Purposely designed to be relatively inexpensive and more reliable than current CubeSat platforms, the six-unit, or 6U, Dellingr will demonstrate the vigor of its design, while gathering NASA-quality data about the sun's influence on Earth's upper atmosphere using a suite of miniaturized instruments and components (see related story, page 4).

Funded partially by Goddard's Internal Research and Development program, the Dellingr effort began in 2014 in response to growing interest among NASA and other government scientists who wanted to use CubeSat platforms to carry out scientific investigations. Originally created by the California Polytechnic State University in 1999 for educational purposes, the university-class platform quickly gained popularity among universities and others interested in giving students hands-on experience building satellites or gathering scientific data.

Continued on page 3

in this issue:

Summer 2017

About the Cover

Chuck Clegett, Larry Kepko, and Michael Johnson are part of a team that purposely developed the Dellingr 6U CubeSat to be more reliable than the models commonly used today. The spacecraft, which is carrying three heliophysics-related payloads, among other technologies, will be launched to the International Space Station in August aboard a SpaceX Falcon 9 rocket. The bus already has been baselined for future CubeSat missions.

Photo Credit: Bill Hrybyk/NASA

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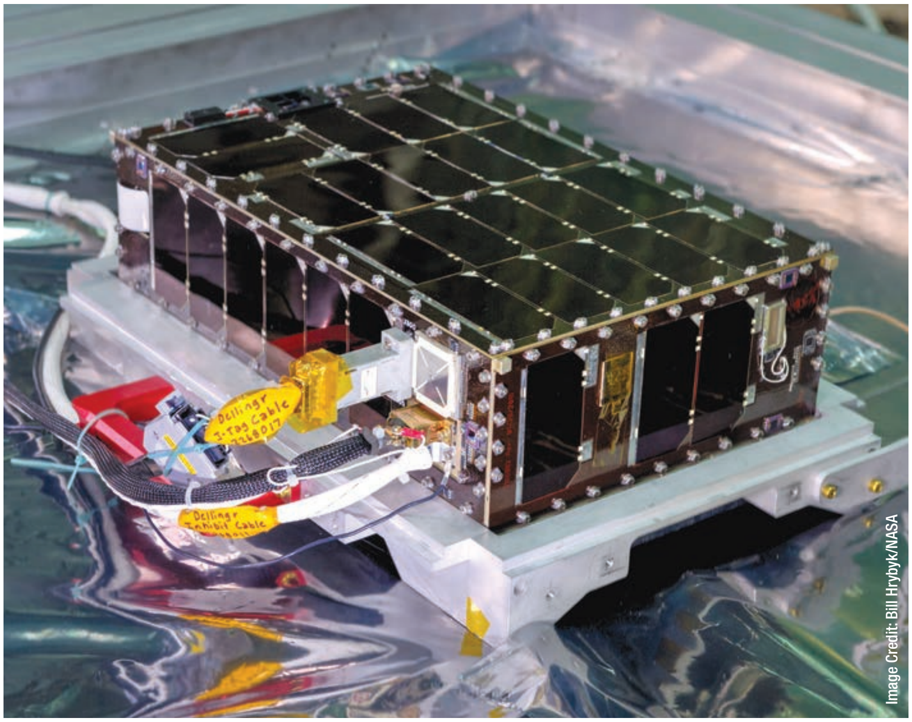
In addition to their low cost, CubeSats offered scientists the potential to fly swarms of these tiny platforms around Earth or other solar system bodies to gather simultaneous, multi-point observations — an observing technique not financially feasible with larger, more traditional spacecraft. Although they fulfilled their original academic purpose, scientists soon discovered that despite their huge potential for enabling new types of observations, the university-class CubeSat did not completely satisfy their needs.



The Dellingr spacecraft is a 6U CubeSat and is shown here at Goddard's magnetic calibration facility where it underwent testing. It is scheduled for an August 1 launch to the International Space Station where it will be deployed into a low-Earth orbit.

"A Reliability Issue"

"It was a reliability issue," Johnson said. "While adequate, university-class CubeSats weren't consistent with what we wanted to do. We had different expectations," he added, referring to the experience of Goddard scientist and Heliophysics Division Chief Technologist Nikolaos Paschalidis. He, along with his team, developed the world's smallest Ion Neutral Mass Spectrometer for the National Science Foundation's 3U ExoCube 1 mission that launched last year.

Soon after the spacecraft's launch, mission operators realized ExoCube-1 wasn't communicating properly, delaying the commissioning of important spacecraft functions. After about six months, Paschalidis finally confirmed his instrument's basic functionality, but the mission abruptly ended due to computer problems. Using lessons learned, the foundation plans to launch a follow-on ExoCube-2 in 2018.

"ExoCube-1 still achieved a lot by validating many functions of the 3U bus and demonstrating the basic functionality of my instrument. However, the experience put a strong emphasis on the need for a robust bus and a complete mission-operations scenario," said Paschalidis, who is flying an improved version of his instrument on Dellingr. "A successful Dellingr mission will give NASA the basis for a reliable bus and mission capability to enable a plethora of future missions."

Road to Success Bumpy

Although the team believes it ultimately will succeed in its pathfinding mission, the road to launch wasn't always smooth.

Within months of starting Dellingr, the team discovered that building a reliable, 6U CubeSat with just $1 million in funding — the project's stated objectives — was easier said than done. Although the team wanted to keep down costs largely by using commercially available subsystems, it discovered that these components didn't always play well together or work as advertised, requiring additional engineering and technician effort. These glitches extended schedules well past the one-year goal and drove up costs.

They also quickly learned that they would have to change the way they managed CubeSat missions to keep them affordable. So even though they missed their cost target, the lessons learned and knowledge acquired during development were well worth the additional costs, Johnson said.

"It's a new way of doing things," said Project Manager Chuck Clagett. "We were applying old ways of doing things to an emerging capability and it didn't work very well."

Continued on page 4

Lessons Learned

From the exercise, the team found a better balance between management and testing requirements and the critical need for more mission-enabling technologies, including CubeSat-specific software, Clagett said.

Just as important, the team learned the true cost of a CubeSat mission, said Goddard heliophysicist Eftyhia Zesta, who is the lead project investigator for the Dellingr magnetometers. The university-class, $1-million CubeSat, developed with less rigorous design and system-engineering practices, isn't a realistic cost for highly reliable CubeSat missions, she said.

NASA Already Benefiting

While Dellingr's developers await launch, they are heartened that NASA already is benefiting from their two-and-a-half-year effort to change the CubeSat paradigm.

Johnson, along with other experts, initiated the Goddard Modular SmallSat Architecture, or GMSA (CuttingEdge, Winter 2017, Page 7). Its goal is to develop overarching system designs and technologies to dramatically reduce small-satellite mission risks without significantly increasing the platforms' cost. As part of this effort, technologists now are developing avionics systems, command-and-data-handling systems, batteries, and other technologies that either can make or break a mission. The lessons learned are being applied to a second-generation Dellingr bus, which the team will make available to anyone who wants to use it.

The group was further buoyed when NASA selected a Goddard team to develop the Plasma Enhancements in The Ionosphere-Thermosphere Satellite, or petitSat, which will study Earth's ionosphere using the second-generation Dellingr bus (CuttingEdge, Spring 2017, Page 22). "We had high confidence in petitSat's costs because of the Dellingr experience," said Larry Kepko, a Goddard scientist who is now heading NASA Science Mission Directorate's small satellite initiative.

"We know how to build large satellite buses," Kepko continued. "All of our satellite buses last forever. We wanted to do the same thing with CubeSats, but without burdening the platform and driving up costs and extending schedules. We endeavored to take our engineering knowledge and best practices to give small satellites the same level of reliability as our larger spacecraft. We endeavored to transition CubeSats from an educational to a science tool. I think we did that with Dellingr." ❖

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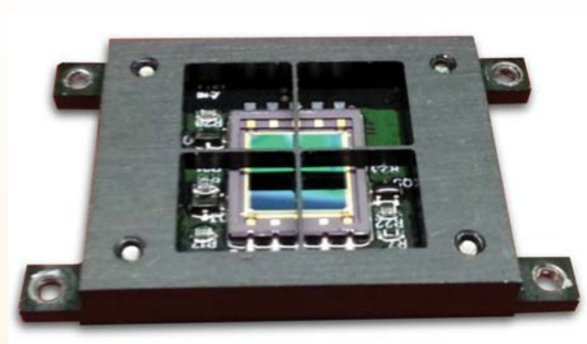
R&D-Funded Technologies Showcased on Dellingr's Debut Flight

Along for the ride on Dellingr's maiden journey is a suite of miniaturized Goddard-developed technologies — one no larger than a fingernail — that in many cases already have proven their mettle in suborbital or space demonstrations, boosting confidence that they will perform as designed once in orbit.

All, including three heliophysics-related instruments, a miniature release mechanism, a sun sensor, and a passive thermal-control system, trace their development to seed funding provided through various NASA and Goddard R&D programs.



The Goddard Fine Sun Sensor, created with Goddard Internal Research and Development program funding, will provide orientation data for Dellingr's instruments.

Ion-Neutral Mass Spectrometer

The Ion-Neutral Mass Spectrometer, developed by Principal Investigator Nikolaos Paschalidis and his team in less than a year, is a complicated instrument designed to sample the densities of neutral and ionized atom species in the atmosphere (CuttingEdge, Fall 2015, Page 18). During the Dellingr mission, it will measure the equatorial ionosphere.

Like a bulldozer scooping up dirt as it moves, the instrument catches particles as the satellite speeds

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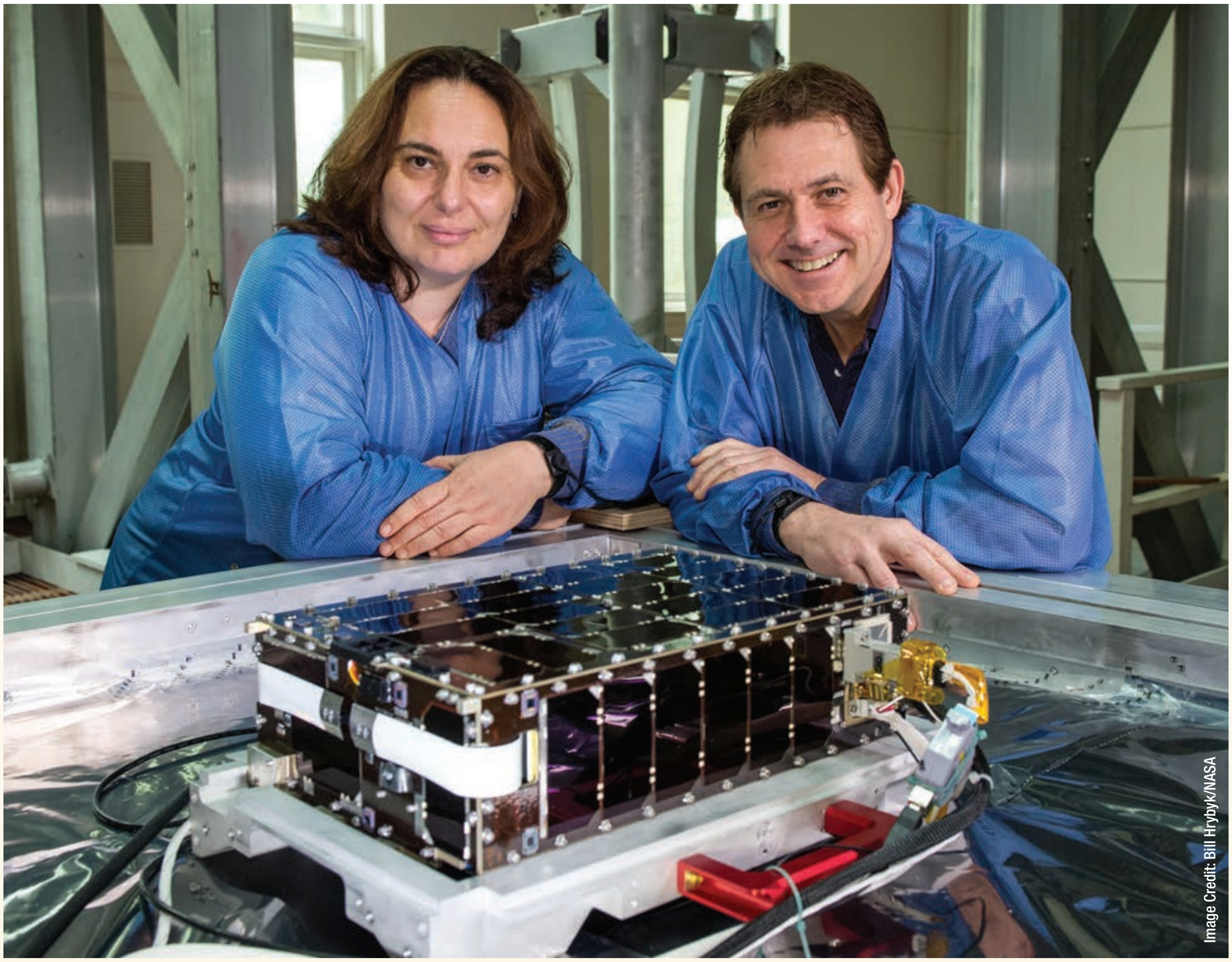


Principal Investigators Eftyhia Zesta and Todd Bonalsky created boom and no-boom magnetometer systems for Dellingr. They are pictured here in Goddard's magnetic calibration facility during Dellingr's magnetic testing.

along at nearly five miles per second. Once inside the instrument, the particles are accelerated to about the same energy. They zoom through two electrically gated time-of-flight systems, one that measures ions and the other neutrals, which must be converted into ions before they enter the main instrument. By counting each set at the final detectors, researchers can easily calculate how many of each type are present.

The team initially flew the instrument on the National Science Foundation-funded CubeSat mission. Although the instrument gathered "beautiful" ion-composition counts of hydrogen, helium, and oxygen, the CubeSat bus proved unreliable and the mission was aborted six months after launch, Paschalidis said.

"The immediate plan with Dellingr is to extensively prove the instrument's functionality. Assuming all goes well, we want to collect as much data as possible, calibrate for spacecraft attitude and location, analyze the data, and plot ion and neutral composition and densities as a function of orbit. This by itself is a unique data set," Paschalidis added.

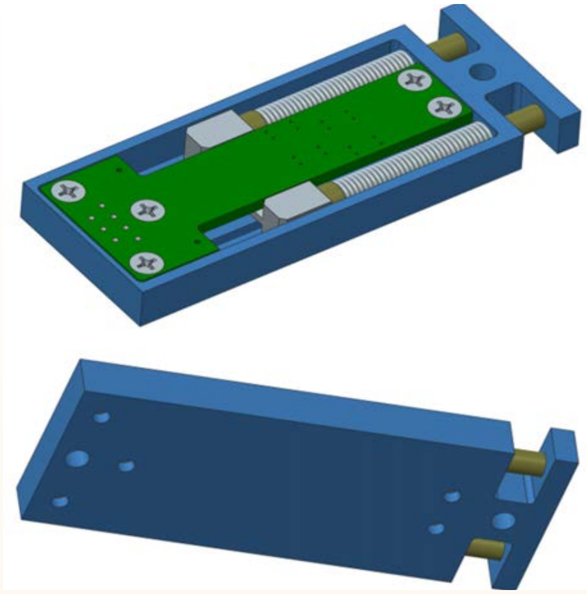
Boom and No-Boom Magnetometer Systems

Two miniaturized magnetometer systems, developed by Principal Investigators Eftyhia Zesta and Todd Bonalsky, also were successfully demonstrated earlier this year aboard a sounding-rocket mission from Poker Flats, Alaska. On Dellingr, these instruments are expected to show a dramatic improvement in the accuracy and precision of miniaturized magnetometers used to measure magnetic fields. The instruments use a never-before-tried technique involving boom and no-boom systems.

Included in this observing technique is one

Continued on page 6

Volume 13 • Issue 4 • Summer 2017



This is an engineering drawing of the Diminutive Assembly for Nanosatellite Deployables, or DANY, that stows and releases antennas, solar panels, magnetometer booms, and even sunshades on CubeSats.

thumbnail-sized magnetometer positioned it at the end of a deployable boom and a couple sensors positioned inside Dellingr. The purpose of the internal sensors is measuring the magnetic fields, or “noise,” generated by the spacecraft’s torquers, solar panels, motors, and other hardware. Sophisticated algorithms that Zesta’s team created then will analyze the external and internal magnetometer data to subtract spacecraft-generated noise from the actual science data.

“CubeSats, like any spacecraft, will be noisy; they are magnetically unclean,” Zesta explained, adding that to avoid the problem in more traditional spacecraft, the magnetometer is placed at the end of a long boom. “Even with a one-meter (three-foot) boom — unless there is a magnetic cleanliness program — you will need to use algorithms to get rid of bus noise. Algorithms are the only way to get scientific value from your data.”

In comparison, the Dellingr boom is only about 22-inches long and it is not magnetically clean, Zesta said. “We absolutely needed to develop noise-cancellation algorithms if we wanted to get any useful science data.”

The Diminutive DANY

Deploying the magnetometer boom and UHF antenna is a miniaturized device called the Diminutive Assembly for Nanosatellite Deployables, or DANY (CuttingEdge, Spring 2014, Page 10). Created by technologist Luis Santos, DANY operates much like a car-door latch. Affixed to the exterior of Dellingr, it holds the boom and antenna in place during launch and then, upon command, applies a current that activates a heating element, which weakens a plastic device holding the retaining pins. Once Dellingr reaches its intended obit, the satellite activates the heating element and the deployables will swing open to begin operations.

Goddard Fine Sun Sensor

Another R&D-funded technology making Dellingr’s debut flight is the Goddard Fine Sun Sensor, or GFSS, designed specifically for CubeSats. The panel-mountable device will gather digital data orienting onboard instruments to the sun. As with the other Dellingr instruments, improvements are afoot. Principal Investigator Zachary Peterson is taking lessons learned from the Dellingr effort to improve GFSS’s accuracy and lower its power consumption. Other flight opportunities are planned.

Thermal-Control Technology

In addition to gathering or enabling the collection of scientific data, Dellingr will demonstrate technol-

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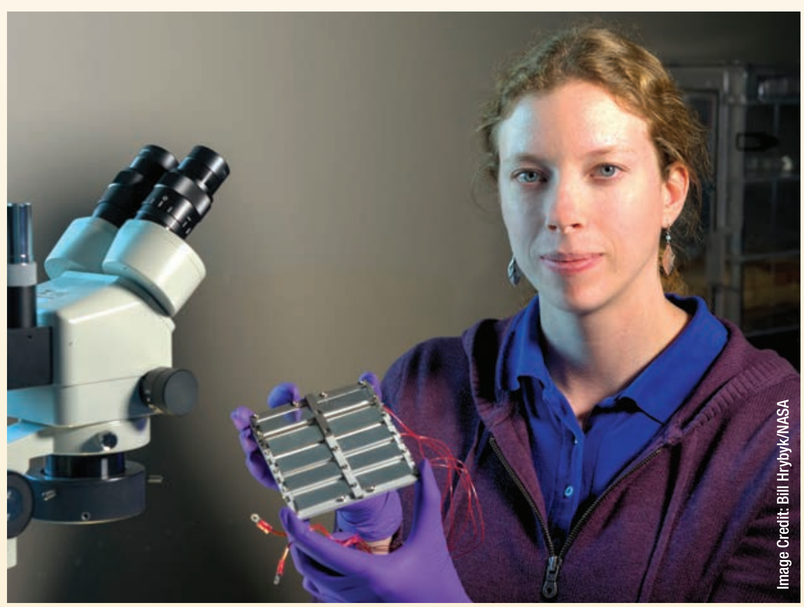

Principal Investigator Allison Evans has repurposed an old thermal-control technology specifically for the CubeSat platform.

ogy. Principal Investigator Allison Evans is miniaturizing an older thermal-control technology that requires no electronics and consists of louvers that open or close, much like venetian blinds, depending on whether heat needs to be conserved or shed (CuttingEdge, Spring 2016, Page 9). During the flight, she wants to prove the louvers will operate as expected in a space environment.

> *"Even with a one-meter (three-foot) boom — unless there is a magnetic cleanliness program — you will need to use algorithms to get rid of bus noise. Algorithms are the only way to get scientific value from your data."*
>
> ***– Eftyhia Zesta, lead magnetometer principal investigator***

As designed, the device consists of front and back plates, flaps, and springs. The back plate is painted with a white, highly emissive paint and the front plate and flaps are made of aluminum, which aren't as emissive. The bimetallic springs do all the work. They are made of two different types of metal. Attached to the highly emissive back plate, the springs uncurl if one of the metals gets too hot, forcing the flaps to open. When the spring cools down, it reverts to its original shape and the flaps close.

For the Dellingr demonstration, Evans is flying just one flap/spring combination to help mature the technology in preparation for future missions where the miniature thermal louvers would be an integrated part of the thermal design. "A mission with a temperature-sensitive instrument or a component that sheds significant amounts of heat only occasionally would be a good candidate for this technology," she said. ❖

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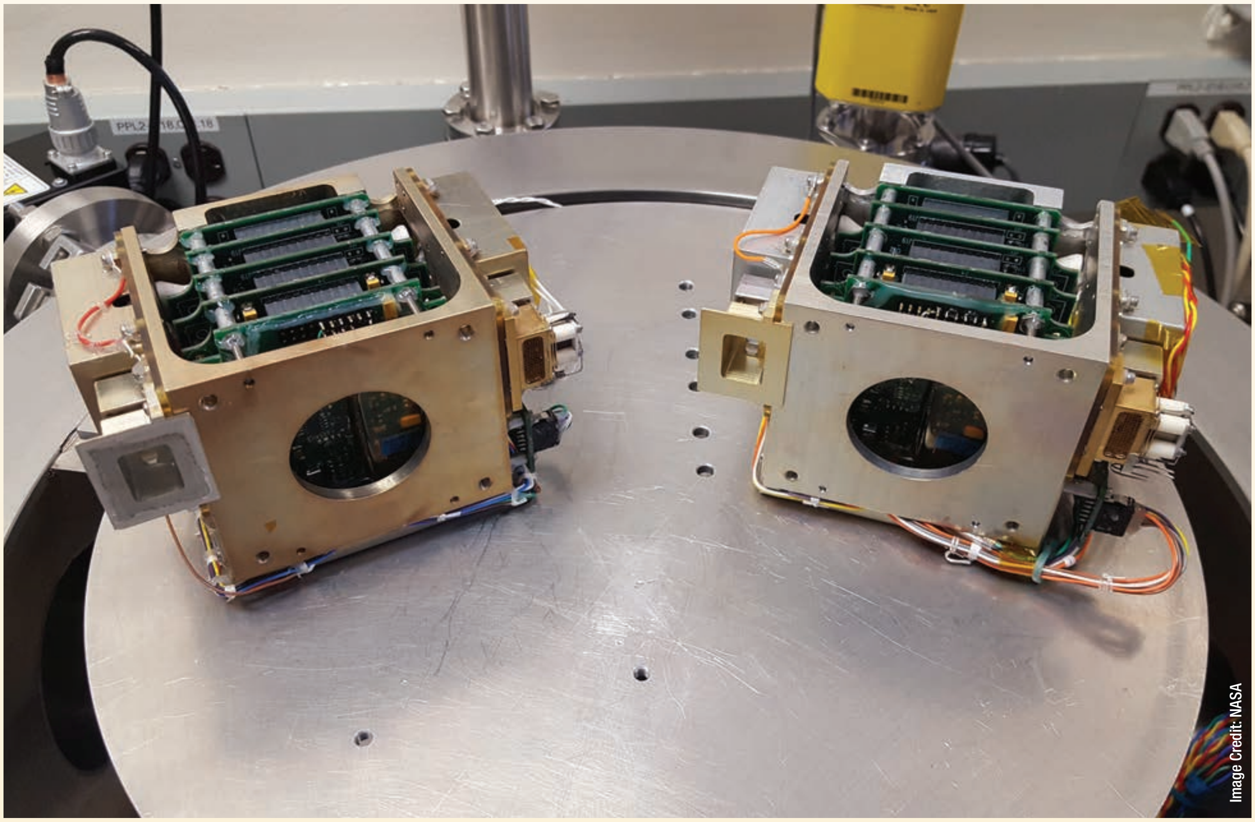
Image Credit: NASA

The Ion-Neutral Mass Spectrometer and flight spare are shown here before they were delivered in preparation for the Dellingr launch.

Volume 13 • Issue 4 • Summer 2017

NASA Team Passes Major Technological Milestone for Characterizing Exoplanets

R&D-Supported PISCES Enables Never-Before-Achieved Deep Contrast Between a Star and Exoplanet

NASA researchers say they have passed a major milestone in their quest to mature more powerful tools for directly detecting and analyzing the atmospheres of giant planets outside the solar system — one of the observational goals of NASA's proposed Wide-Field Infrared Space Telescope, also known as WFIRST.

In tests conducted at the Jet Propulsion Laboratory's (JPL's) High-Contrast Imaging Testbed — one of the world's most advanced testbeds of its kind — researchers created what they call a region of very deep contrast between a simulated star and its planet. They also demonstrated the ability to detect and analyze the planet's faint light over a relatively large portion of the visible to near-infrared wavelength band.

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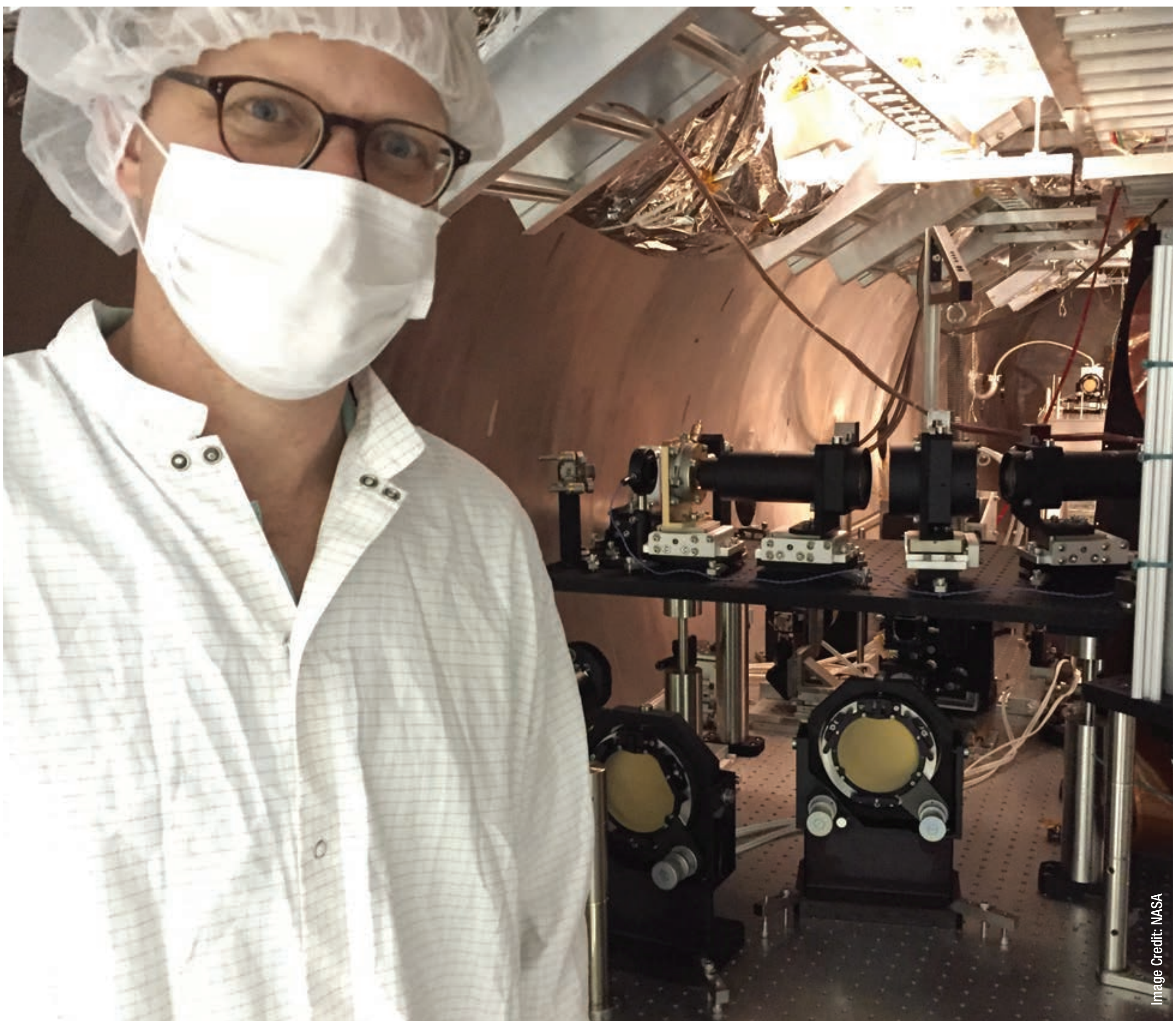
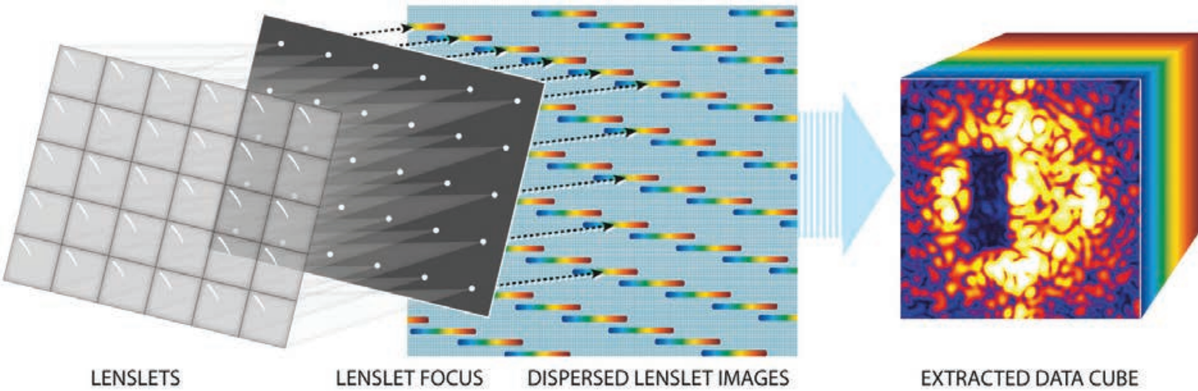


Instrument Scientist Michael McElwain and his team developed an integral field spectrograph called PISCES. The tabletop-sized instrument now is installed at a Jet Propulsion Laboratory facility to test light-suppression technologies for a planned follow-on to the James Webb Space Telescope. Goddard team members include Qian Gong, Tyler Groff, Jorge Llop, Avi Mandell, Maxime Rizzo, Prabal Saxena, and Neil Zimmerman. JPL team members include Eric Cady and Camilo Mejia Prada.



This graphic shows the lenslet array in the PISCES instrument and how it creates micro-spectra for the light that passes through each of the tiny lenses.

A Goddard-developed instrument — the Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies, or PISCES — played an important role in the demonstration, showing that it could separate light of one or more Jupiter-sized exoplanets by its wavelength (color) and record this at every position around a star (*CuttingEdge*, Summer 2016, Page 19).

To appreciate the researchers' milestone, it's important to understand the challenge itself.

The light from these planets is exceedingly faint — fainter than their host stars by a factor of 100 million or more, and from our perspective on Earth, these planets appear quite close to their stars. With a conventional imaging camera, the planet's light is lost in the glare of the star. However, with a coronagraph — a device that suppresses the glare and creates a dark zone around a star — the faint light of an exoplanet can be revealed.

Working in concert with the coronagraph, an integral field spectrograph, or IFS, such as PISCES, would be able to separate the exoplanet's light by its wavelength and record the data, revealing details about the planet's physical properties, including the chemical composition and structure of its atmosphere.

During the test, the Goddard-JPL team maintained a very deep contrast over 18 percent of the coronagraph's wavelength band — a record that bodes well for future missions like WFIRST, which has baselined a coronagraph and an IFS-type instrument on the mission. (To put this in perspective, the human eye can see the full visible spectrum of colors, from blue to red, which corresponds to a 50 percent bandpass. In comparison, a laser pointer has one single color, which is much smaller than one percent.)

Never-Before Achieved Contrast

"Achieving a contrast this deep over such a broad band has never been done before and was one of our goals. Ideally, we would like to observe the entire spectrum of the planet — in other words, see all its colors at once — but that's not yet possible with current coronagraphic technologies. Eighteen percent, as demonstrated by PISCES, is the current state of the art," said Goddard scientist and PISCES Instrument Scientist Michael McElwain. In comparison, JPL's laboratory coronagraph maintained the same level of dark contrast over 10 percent of the optical-wavelength bands before the commissioning of the table-top PISCES last year.

"We are not done yet and are still trying to get to higher contrasts, but the 100 million-to-one over 18 percent of the optical wavelength band is an important and significant milestone," said Maxime Rizzo, a postdoctoral student who is working with McElwain and his team to advance PISCES. "With the increased bandpass, we can get many colors at once. This enables us to identify more molecules in the atmospheres and get a big picture."

A Little Different

PISCES, which McElwain developed with funding from Goddard's Internal Research and Development program and the prestigious Nancy Grace Roman Technology Fellowship, separates light a little differently than more traditional spectrographs.

As an IFS-type device, PISCES takes a coronagraphic image and samples it with a micro-lens array made up of more than 5,800 tiny glass segments no larger than the width of three human hairs. The micro-lens creates an array of "spots" that is then dispersed by a prism and finally

Continued on page 15

Volume 13 • Issue 4 • Summer 2017

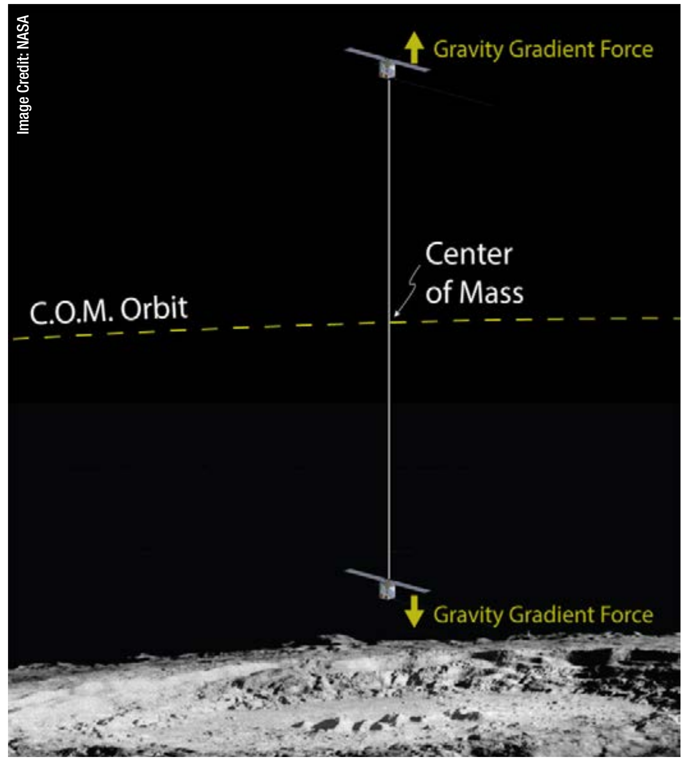
Hanging by a Tether

Team Wins NASA Funding to Advance Dual-CubeSat Mission to Study Lunar Swirls

A novel mission concept involving two CubeSats connected by a thin, miles-long tether could help scientists understand how the moon got its mysterious "tattoos" — swirling patterns of light and dark found at more than 100 locations across the lunar surface.

NASA's Planetary Science Deep Space SmallSat Studies, or PSDS3, program recently selected a Goddard team led by Principal Investigator Timothy Stubbs to develop a mission concept called the Bi-sat Observations of the Lunar Atmosphere above Swirls, or BOLAS. The study could lead to the first tethered planetary CubeSat mission, Stubbs said.

"This is an exciting concept," said Michael Collier, a BOLAS co-investigator who received an FY15 Internal Research and Development program award to study tether-based missions for gathering difficult-to-obtain lunar measurements. "Candidly, I think it's groundbreaking. Tethered satellites are a very natural approach for targeting lunar science."



This artist's drawing shows how two CubeSats, connected by a miles-long tether, would gather measurements on the moon.

Two 12U CubeSats

As currently conceived, the mission would involve two 12-unit, or 12U, CubeSats, whose individual units would measure just four inches on a side. Once the pair reached a low-maintenance, quasi-stable orbit about 62 miles above the moon's surface, the two would separate. Connected by a 112-mile-long thin tether, the top satellite would climb 118 miles above the surface, while the lower, nearly identical twin would plunge to an altitude of about six miles above the surface.

"The tension in the tether keeps the CubeSats in vertical alignment as they orbit," Stubbs said. "The configuration, with the center-of-mass in a quasi-stable orbit, should enable the lower CubeSat to fly for long durations at low altitudes."

Without a tether system, a comparable low-altitude mission would need prohibitive amounts of fuel to maintain its orbit. NASA's Lunar Reconnaissance Orbiter, or LRO, for example, flew in a circular orbit 31 miles above the surface early in its mission. If NASA hadn't executed propulsive maneuvers to maintain this orbit, the spacecraft would have smashed into the surface.

This is due to the large concentrations of mass lurking on the lunar surface. These "mascons" change the gravity field and can either pull the spacecraft or push them off course, dooming them to mission-ending collision.

"For planetary objects that lack an atmosphere, tethering is an innovative approach to the technical challenge of low-altitude measurements using minimal propellant," Collier said, adding that a CubeSat couldn't carry the amount of fuel needed to carry out periodic station-keeping maneuvers.

Spectrometers, Imagers Planned

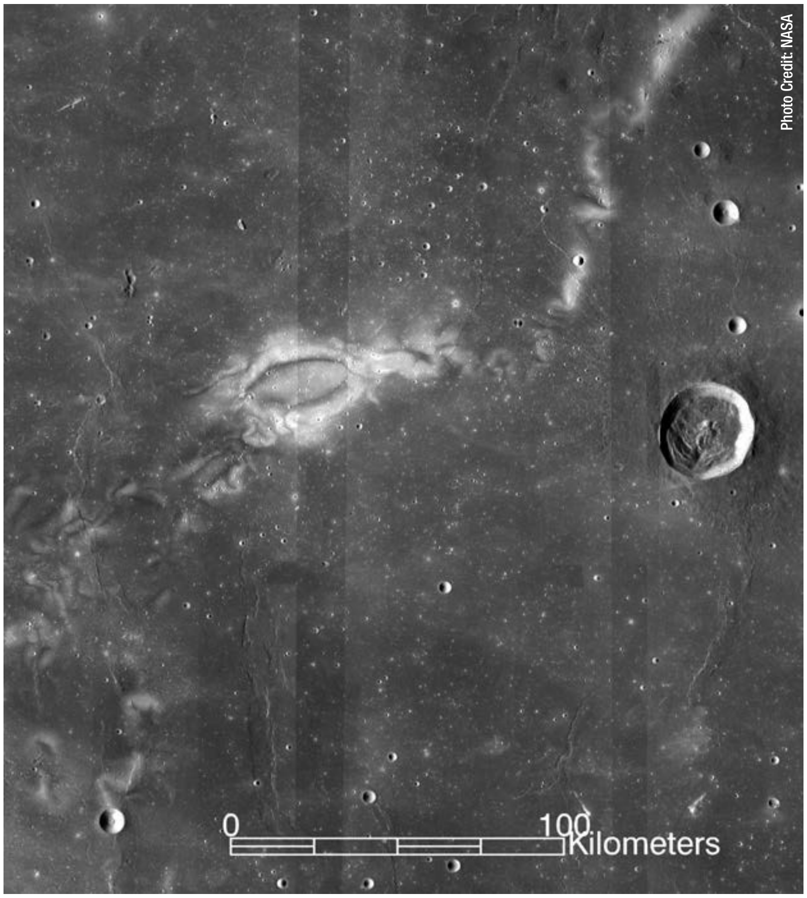
For scientists attempting to better understand the moon's odd, airless environment, the lower they can deploy the CubeSat, the better.

Equipped with a nearly identical suite of miniaturized instruments, including spectrometers and imagers already advanced by BOLAS co-investigators and collaborators, the twin satellites would characterize the lunar hydrogen cycle from both a low and high altitude.

Continued on page 11

"There is a lot of science you can do with this instrument suite," Stubbs said, adding that the team plans to leverage subsystems developed by Kentucky's Morehead State University, which is leading NASA's Lunar IceCube mission. Lunar IceCube will prospect for lunar volatiles and water during its six months in lunar orbit after its launch aboard NASA's Space Launch System in 2019 (CuttingEdge, Summer 2015, Page 2).

During its proposed one year in orbit, the BOLAS instruments would characterize the mechanisms for hydrogen implantation on the moon's surface as well as their dependence on the moon's composition, regolith, local topography, plasma conditions, time of day, and magnetic fields within the crust.



Lunar swirls, such as the Reiner-Gamma swirl imaged by NASA's Lunar Reconnaissance Orbiter, are strange markings on the moon.

Target: Swirls

One of the mission's primary goals is understanding the formation of lunar swirls — the odd markings of light and dark that look almost as if they were painted on the surface of the moon — and the role that magnetic anomalies and space weathering could play in their creation. They are unique to the moon and their origin remains a mystery even though a combination of observations and computer simulations is beginning to shed some light.

Observations indicate that the swirls appear where ancient bits of magnetic field are embedded in the lunar crust. They also show that the bright areas appear to be less weathered than their surroundings. Several phenomena can cause material exposed to space to change both physically and chemically, resulting in darkening over time, including solar wind and micrometeoroid impacts.

Those clues have led to three prominent theories about their formation.

One theory suggests that the swirls and the magnetic fields both formed from plumes of material ejected by comet impacts. Another hypothesis states that when micrometeoroid bombardment lofts the moon's fine dust particles, an existing magnetic field over the swirls sorts them according to their susceptibility to magnetism, forming light and dark patterns with different compositions. And another theory postulates that since particles in the million-mile-per-hour solar wind are electrically charged, they respond to magnetic forces. Perhaps the magnetic field shields the surface from weathering by the solar wind.

Observations from NASA's LRO lend credence to the magnetic-shield hypothesis, scientists say. However, no one is ruling out anything yet.

"A Paradigm Shift"

Until scientists launch a mission capable of carrying out close-to-the-ground global measurements, a definitive answer isn't likely, Collier said. However, he believes the two-satellite BOLAS mission could provide the data the scientific community needs.

"This could be a paradigm shift," Collier said. "All indications show that this mission can be done with existing technology." ❖

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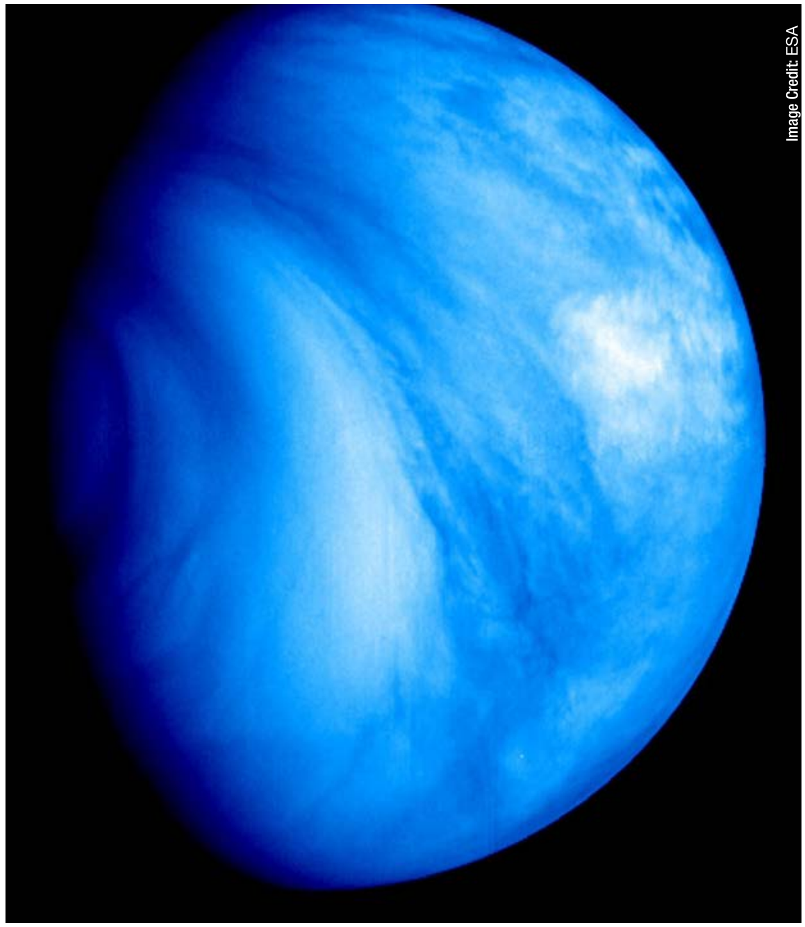
Volume 13 • Issue 4 • Summer 2017

Conceptual CubeSat Mission Focused on Solving Venusian Mystery

Team Leverages Past R&D Investments in Instruments and Subsystems

Venus looks bland and featureless in visible light, but change the filter to ultraviolet, and Earth's twin suddenly looks like a different planet. Dark and light areas stripe the sphere, indicating that something is absorbing ultraviolet wavelengths in the planet's cloud tops.



As seen in the ultraviolet, Venus is striped by light and dark areas indicating that an unknown absorber is operating in the planet's top cloud layer.

A team of scientists and engineers working at Goddard has received funding from NASA's Planetary Science Deep Space SmallSat Studies, or PSDS3, program to advance a CubeSat mission concept revealing the nature of this mysterious absorber situated within the planet's uppermost cloud layer. Called the CubeSat UV Experiment, or CUVE, the concept mission would investigate Venus' atmosphere using ultraviolet-sensitive instruments and a novel, carbon-nanotube light-gathering mirror advanced through Goddard's Internal Research and Development, or IRAD, program if it were ultimately built and launched (CuttingEdge, Summer 2016, Page 14).

Similar in structure and size to Earth, Venus spins slowly in the opposite direction of most planets. Its thick atmosphere, consisting mainly of carbon dioxide, with clouds of sulfuric-acid droplets, traps heat in a runaway greenhouse effect, making it the hottest planet in our solar system with surface temperatures hot enough to melt lead.

Although NASA and other international space programs have dispatched multiple missions to Venus, "the exact nature of the cloud top absorber has not been established," said CUVE Principal Investigator Valeria Cottini, a University of Maryland researcher who is leading a team of experts in the composition, chemistry, dynamics, and radiative transfer of the planet's atmosphere. "This is one of the unanswered questions and it's an important one," she added.

Past observations of Venus show that half of the solar energy is absorbed in the ultraviolet by an upper layer of the sulfuric-acid clouds, giving the planet its striped dark and light features. Other wavelengths are scattered or reflected into space, which explains why the planet looks like a featureless, yellowish-white sphere in the optical — wavelengths visible to the human eye.

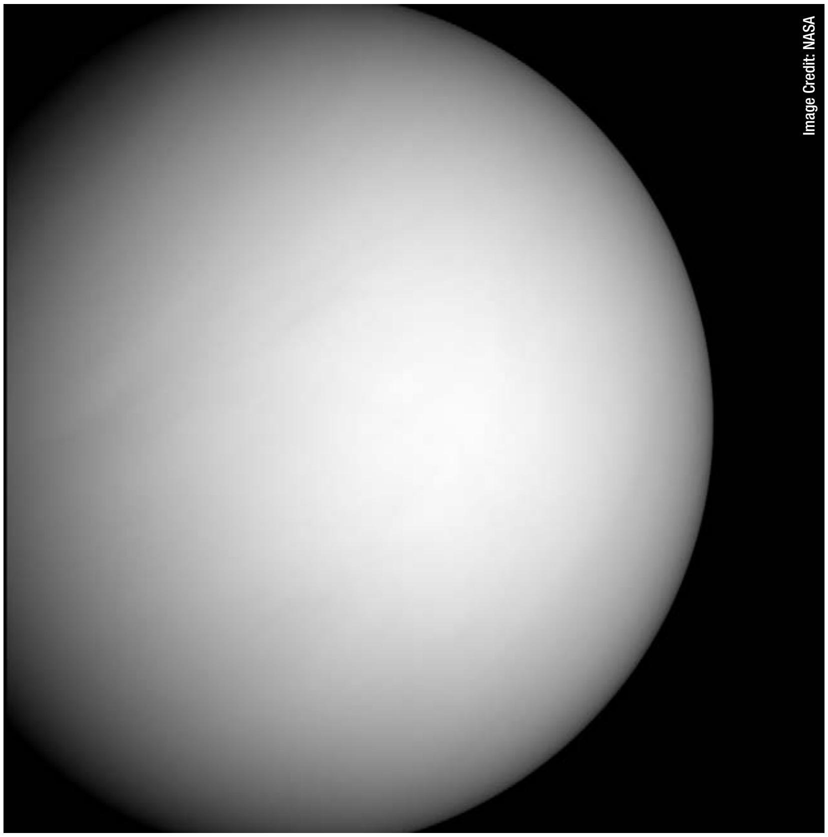
Theories Abound

Theories abound as to what causes these streaked, contrasting features, Cottini said. One explanation is that convective processes dredge the absorber from deep within Venus' thick cloud cover, transporting the substance to the cloud tops. Local winds disperse the material in the direction of the wind, creating the long streaks. Scientists theorize the bright areas, as observed in the ultraviolet, are prob-

Continued on page 13

ably stable against convection and do not contain the absorber, while the dark areas do.

"Since the maximum absorption of solar energy by Venus occurs in the ultraviolet, determining the nature, concentration, and distribution of the unknown absorber is fundamental," Cottini said. "This is a highly-focused mission — perfect for a CubeSat application."



The cloud-enshrouded Venus appears featureless in visible light, as shown in this image taken by NASA's MESSENGER mission. In ultraviolet, however, the planet takes on a completely different appearance.

Revealing the Absorber

To learn more about the absorber, the CUVE team, which includes Goddard scientists as well as researchers affiliated with the University of Maryland and Catholic University, is leveraging investments Goddard has made in miniaturized instruments and other technologies. In addition to flying a miniaturized ultraviolet camera to add contextual information and capture the contrast features, CUVE would carry an IRAD-investigated spectrometer to analyze light over a broad spectral band — 190-570 nanometers — covering the ultraviolet and visible. The team also plans to leverage investments in CubeSat navigation, electronics, and flight software.

"A lot of these concepts are driven by important IRAD investments," said Tilak Hewagama, a CUVE team member who has worked with Shahid Aslam, Nicolas Gorius, and others to demonstrate a CubeSat-compatible spectrometer. "That's what got us started."

Carbon-Nanotube Mirror Eyed

One of the other novel CUVE adaptations is the potential use of a lightweight telescope equipped with a mirror made of carbon nanotubes in an epoxy resin. To date, no one has been able to make a mirror using this resin.

Such optics offer several advantages. In addition to being lightweight and highly stable, they are relatively easy to reproduce. They do not require polishing — a time-consuming and often-times expensive process that assures a smooth, perfectly shaped surface.

Developed by Goddard contractor Peter Chen, the mirror is made by pouring a mixture of epoxy and carbon nanotubes into a mandrel, or mold, fashioned to meet a specific optical prescription. Technicians then heat the mold to cure and harden the epoxy. Once set, the mirror is coated with a reflective material of aluminum and silicon dioxide.

Study Objectives

The team plans to further enhance the mission's technologies and evaluate technical requirements to reach a polar orbit around Venus as a secondary payload. The team believes it would take CUVE one-and-a-half years to reach its destination. Once in orbit, the team would gather data for about six months.

"CUVE is a targeted mission, with a dedicated science payload and a compact bus to maximize flight opportunities such as a ride-share with another mission to Venus or to a different target," Cottini said. "CUVE would complement past, current, and future Venus missions and provide great science return at lower cost." ❖

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Volume 13 • Issue 4 • Summer 2017

Technologist Develops Self-Calibrating Magnetometer

They've flown on high-profile interplanetary and more modest low-Earth-orbiting missions, but in all cases the ubiquitous fluxgate magnetometers that scientists use to measure the intensity of a magnetic field will degrade over time.

A Goddard technologist now is developing a self-calibrating magnetometer that would be ideal for measuring the intensity and orientation of magnetic lines from both CubeSat and more traditional spacecraft.

With funding from Goddard's Internal Research and Development, or IRAD, program, Todd Bonalsky is developing a functioning prototype, which he hopes will be ready for the planned launch of a sounding-rocket mission called Visualizing Ion Outflow via Neutral Atom Sensing-2, or VISIONS-2, in 2018. VISIONS-2 is designed to study the outflow of oxygen ions from Earth's upper atmosphere and into the magnetosphere (CuttingEdge, Spring 2016, Page 13).

The prototype combines two types of magnetometers — the highly precise fluxgate and the optically pumped atomic magnetometer — into one relatively small package that could be used on constellation-type missions where multiple CubeSats are deployed to gather simultaneous, multi-point observations. This technique particularly is effective for studying Earth's ever-changing, enveloping magnetic fields.

"We've already shown we can take relatively large, power-hungry fluxgate magnetometers and shrink them down to fly on CubeSats," said Bonalsky, who successfully miniaturized a fluxgate magne-

Continued on page 15

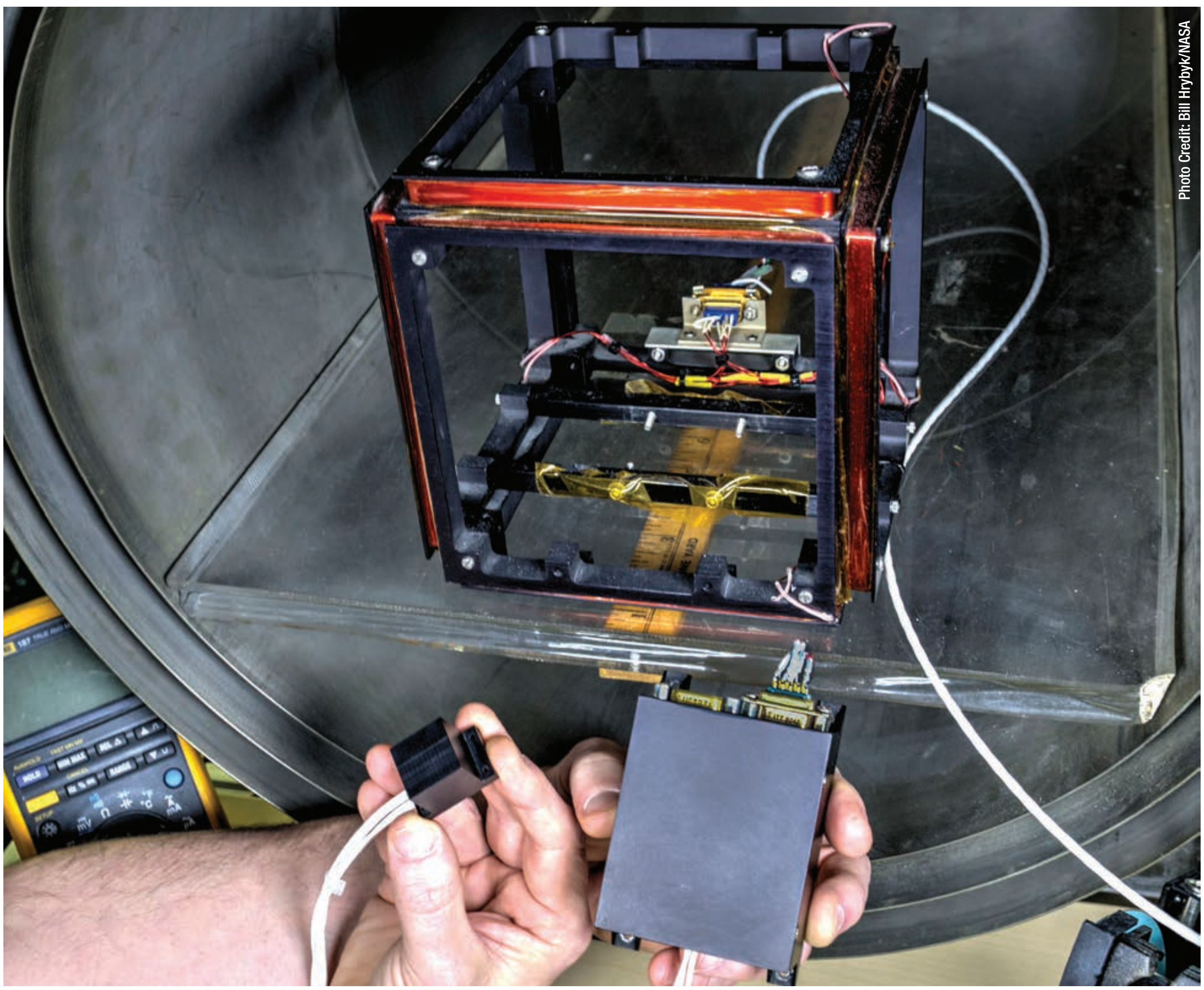

Photo Credit: Bill Hrybyk/NASA

The prototype hybrid magnetometer may fly on a sounding-rocket mission, called VISIONS-2, next year.

tometer for the Dellingr mission (see related story, page 2). "Now, I want to incorporate our miniaturized fluxgate with an absolute atomic magnetometer to create a fully self-calibrating, miniaturized vector magnetometer for CubeSats and small satellites, alike. This hasn't been done before."

Need for a Hybrid System

The need for an all-in-one instrument lies in the inherent advantages and disadvantages of both magnetometers, made more challenging as technologists attempt to further shrink the size of these instruments to fit inside a CubeSat.

Made of a core, which is highly susceptible to magnetization, and two coils of wire to resemble a transformer, fluxgate magnetometers have long been scientific workhorses due to their overall rugged construction and accuracy. They work when an alternating current, or AC, is passed through one coil, called the primary, to produce an alternating magnetic field that induces AC in the other coil, called the secondary.

The intensity and phase of the AC in the secondary are constantly measured. When a change occurs in the external magnetic field, the output of the secondary coil changes. The extent and phase of this change can be analyzed to determine the intensity and orientation of the magnetic fields in question. Consequently, the device measures not only the magnetic field of an object, but also its direction, whether it's north, south, east, or west.

However, ever-changing temperatures such as those encountered in space will reduce its performance over time. Consequently, mission planners occasionally fly an atomic magnetometer, which operates under a different set of principles, to maintain the fluxgate's calibration.

First developed more than 50 years ago, atomic magnetometers are made of alkali gases, such as rubidium or cesium, which send out a frequency proportional to the magnetic field. In other words, they literally resonate — like a crystal wineglass when its rim is rubbed — indicating the extent of a magnetic field.

Atomic magnetometers, unfortunately, aren't a panacea, either. While not prone to drifting, they only can measure the field's magnitude, not its direction.

IRAD Goal

Under his IRAD, Bonalsky is developing a self-calibrating hybrid system combining both measurement techniques.

To achieve this, he has built an ultra-small, "chip-scale" atomic magnetometer filament, which he plans to install within the sensor coils of the fluxgate magnetometer he developed for the Dellingr mission. He then plans to test the device at Goddard's upgraded Magnetic Test Facility in preparation for its possible inclusion on the VISIONS-2 sounding rocket mission.

"If we succeed, Goddard will be at the forefront of science-grade CubeSat magnetometry," he said. ❖

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Exoplanets, *continued from page 9*

re-imaged onto a detector. In practice, each micro-lens, or lenslet, isolates a small portion of the coronagraphic image, creating micro-spectra for the light that passes through each tiny lenslet. The multiple spectra then are combined into a data cube that scientists analyze.

The IFS provides all the wavelength information simultaneously across the entire field of view. With more traditional imaging observations, scientists must cycle through the different wavelengths, which takes time and requires a mechanism to change the filters — requirements not desirable with an orbiting observatory that only has limited time to spend on a target. The optical system itself changes over time due to thermal and dynamic variations, further underscoring the need for simultaneous spectral observations.

"That's why WFIRST planners baselined the IFS-type spectrograph in the first place," Rizzo said. "In this case, PISCES offered information over a full 18 percent of the bandpass, instead of the traditional 10 percent that had been demonstrated at JPL without an IFS. PISCES showed that it could enable more science."

Even though the team demonstrated the deep contrast over a greater portion of the visible to near-infrared bandpass, and in doing so, raised the technology's readiness level, work remains, said Avi Mandell, the WFIRST IFS project scientist. "The success has opened up all new starlight-suppression ideas that we want to test." ❖

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SPECIAL REPORT
The Goddard Fellows Innovation Challenge

Goddard's Senior Fellows — a distinguished group of researchers who advise the center director — have rolled out a new R&D funding program, the Goddard Fellows Innovation Challenge. Focused on advancing potentially radical or high-risk, high-reward efforts that could have dramatic, longer-term consequences for science and engineering, the program recently selected 10 proposals for further development. Here, CuttingEdge focuses on two: an online database that puts one terabyte of space-related information literally at the fingertips of users and a miniaturized ionospheric sounder for heliophysics studies.

Team Enhances Online Scientific Tool Used by Hundreds Worldwide

Hundreds of scientists worldwide currently use an online application that accesses at least one terabyte of data to calculate everything from the spectrum of an exoplanet and the weather on Mars to the chemical makeup and orbit of a celestial object. It's now expected to get even better.

With funding from the Goddard Fellows Innovation Challenge, an R&D funding program designed to advance high-reward technologies, a team of center scientists plan to further enhance the Planetary Spectrum Generator, or PSG.

Top on the team's list is incorporating additional databases that catalogue detector characteristics of current and future ground- and space-based instruments, said Principal Investigator Geronimo Villanueva, a Goddard planetary scientist who is advancing the tool with help from his colleagues, Michael Smith, Avi Mandell, Tilak Hewagama, Sara Faggi, and Silvia Protopapa.

With this new development, scientists will be able to use the tool to predict what an instrument might detect when observing a rocky planet, gas giant, comet, or even one of the thousands of exoplanets already identified by NASA's Kepler Space Telescope — insights scientists value when reserving observation time on any observatory. It likewise will help them conceive and plan future missions, including the type of instruments necessary for gathering a certain type of measurement.

Worldwide Users

Since going online just a year ago, the PSG has attracted hundreds of expert and non-expert users worldwide, mainly through word-of-mouth advertising.

"No tool out there does what it can do," said Villanueva, who conceived the application mainly out of frustration. "I remember trying to find out how many photons (light particles) I could collect from Mars. I thought everyone should know that, but I ended up spending a lot of time trying to get the right numbers."


Photo Credit: Bill Hrybyk/NASA

Planetary scientist Geronimo Villanueva has created an online application that accesses at least one terabyte of data to calculate everything from the spectrum of an exoplanet and the weather on Mars to the chemical makeup and orbit of a celestial object. The simple-to-use Planetary Spectrum Analyzer employs high-performing computer clusters at Goddard.

He thought, why not create an online tool that stores validated data on a server and then allows users to access and manipulate the measurements using embedded, behind-the-scenes computer algorithms and a user-friendly Web-based interface that's accessible on any computing device, including tablets and smart phones? "Basically, I collected knowledge and put it here," Villanueva said.

Initially, PSG allowed users to synthesize spectra — the analysis of light — of planets, comets, asteroids, moons, and thousands of exoplanets over

Continued on page 20

SPECIAL REPORT

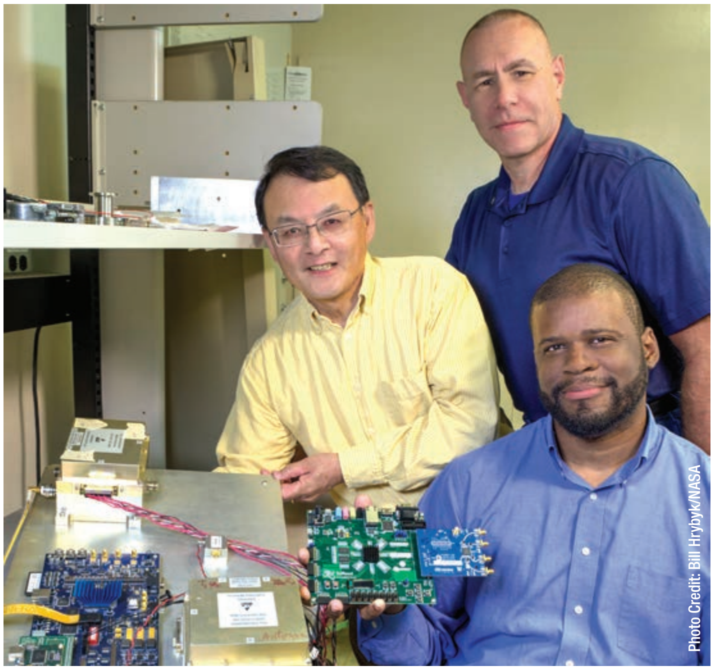
The Dedicated Radio Station

Team Miniaturizes Century-Old Technology for Potential Use on CubeSats

A century-old technology that scientists use to probe the ionosphere — the important atmospheric layer that can interfere with the transmission of radio waves — is getting smaller.

A team of Goddard scientists and engineers has received funding from the Goddard Fellows Innovation Challenge, an R&D funding program designed to advance high-reward technologies, to upgrade and miniaturize the electronics on the prototype Electron Concentration vs. Height for an Orbiting Electromagnetic Sounder, or ECHOES. The team plans to demonstrate the improved ECHOES later this year in a ground-based test.

Scientists will use the instrument to "sound" the ionosphere from the ground, contributing to a network of instruments that support space-weather prediction and real-time mapping of the ionosphere.



Goddard's Shing Fung (left), Mark Adrian (standing), and Damon Bradley (right) are miniaturizing a century-old technology for studying the ionosphere potentially from a constellation of CubeSats. Bradley is holding an electronics board that the team will migrate to the Goddard Geophysical and Astronomical Observatory later this year for testing.

CubeSat Compatible

However, the goal is to fly ECHOES on a constellation of CubeSats that would make simultaneous, multi-point soundings of the top-side of Earth's enveloping ionosphere, which lies 46 to about 621 miles above Earth's surface.

This layer, which is electrically charged or ionized primarily by extreme-ultraviolet radiation emanating from the sun during the day or by the bombardment of cosmic rays during the night, is of interest to scientists because of the role it plays in the transmission of radio waves. Depending on the concentration of electrons in the ionosphere and the frequency of the radio waves, the layer reflects radio waves to Earth, rather than allowing them to escape into space.

However, solar flares, the spontaneous eruption of high-energy radiation from the surface of the sun, can cause a sharp increase in the number of ionized particles. "Gravity pulls the denser plasma (ionized gas) down toward Earth to lower altitudes that are less dense. This is an unstable configuration," said ECHOES Principal Investigator Mark Adrian, a Goddard heliophysicist. "This motion leads to a turbulent mixing of the ionosphere, not unlike pouring cream into your morning coffee. This produces density irregularities or structures that reflect and refract radio waves — what we simply refer to as interference."

To determine the electron density vertically in the ionosphere, scientists have long used radio sounders — in essence, dedicated radio stations. A range of different radio frequencies are directed vertically to the ionosphere and a receiver then collects and measures the values of the returning signals or echoes.

Scientists use this data to determine the density of electrons over the full depth or altitude of the ionosphere, which can shrink or expand down depending on geomagnetic conditions. "The conducting layer in the atmosphere is a mix of ions and electrons. Depending on the density, signals will bounce back to Earth," Adrian said.

Miniaturizing a Century-Old Technique

The sounding technique is at least a century old. However, it wasn't until the dawn of the space

Continued on page 20

Volume 13 • Issue 4 • Summer 2017

Altered Realities

Team Develops Six Pilots to Highlight Potential of Virtual and Augmented Reality for Space Engineering and Science

Virtual and augmented reality are transforming the multi-billion-dollar gaming industry. A team of Goddard technologists now is investigating how this immersive technology could profit NASA engineers and scientists, particularly in the design and construction of spacecraft and the interpretation of scientific data.

Principal Investigator Thomas Grubb and his team of center technical experts and university students are developing six, multidisciplinary pilot projects highlighting the potential of virtual and augmented reality, also known as VR and AR. These pilots showcase current capabilities in engineering operations and science, but also provide a glimpse into how technologists could use the technology in the future.

"Anyone who followed the popularity of Pokémon Go has seen how the public has embraced this technology," said Grubb, referring to the augmented-reality game that quickly became a global sensation in 2016. "Just as it's changing the gaming industry, it will change the way we do our jobs," Grubb added. "Five years from now, it's going to be amazing."

To understand the potential, Grubb said people need to understand the technology's differences and how it has evolved.

Virtual reality typically involves wearing a headset that allows the user to experience and interact with an artificial, computer-generated reality. By combining computer-generated 3-D graphics and coded behaviors — that is, how the app will respond when the user chooses an action — these simulations can be used for design and analysis, entertainment, and training. They allow the user to feel like he or she is experiencing the situation firsthand.

Augmented reality, on the other hand, doesn't move the user to a different place, but adds something to it. As with Pokémon Go, augmented reality is made possible through low-end devices like smartphones and high-end AR headsets that blend digital components into the real world.

Although the computer-generated technology can trace its heritage to the 1980s with the advent of electronic-gaming devices, it has advanced rapidly over the past 15 years, driven mainly by more sophisticated computer technologies that render more realistic 3-D experiences and the decline in prices for headsets, handheld devices, and other gear.

"For several years, commercial VR and AR technology has been showing promise, but without real

Continued on page 19

A new virtual-reality application allows users to visualize the magnetic connections in Earth's magnetosphere.

tangible results," said Ted Swanson, senior technologist for strategic integration for Goddard's Office of the Chief Technologist. "However, recently there have been substantial developments in VR/AR hardware and software that may allow us to use this technology for scientific and engineering applications."

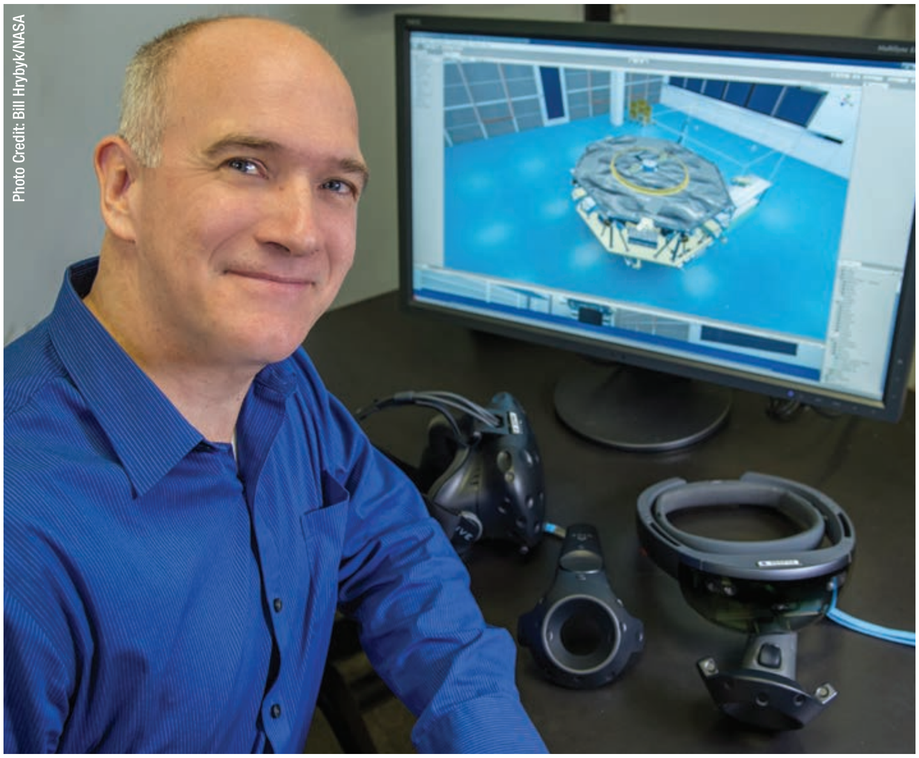


Photo Credit: Bill Hrybyk/NASA

Goddard technologist Tom Grubb believes that low-cost, high-capability augmented- and virtual-reality hardware, combined with NASA-oriented apps, will transform how NASA scientists and engineers work.

The aim isn't to reinvent the hardware and software developed by technology companies, but to be a consumer of the products and create NASA-oriented applications, Swanson said.

The Pilots

The pilots, which involve students from the University of Maryland and Bowie State University, are as diverse as the specialties in which Goddard excels, Swanson said.

Under one, Grubb and his university collaborators are creating a collaborative virtual-reality environment where users don headgear and use hand controls to design, assemble, and interact with spacecraft using pre-defined, off-the-shelf parts and virtual tools, such as wrenches and screwdrivers. "The collaborative capability is a major feature in VR," Grubb said. "Even though they may work at locations hundreds of miles apart, engineers could work together to build and evaluate designs in real-time due to the shared virtual environment. Problems could be found earlier, which would save NASA time and money."

In another engineering-related app, the team has created a 3-D simulation of Goddard's thermal-vacuum chamber to help engineers determine whether all spacecraft components would fit inside the facility before testing begins. In another involving on-orbit robotic servicing, the augmented app combines camera views and telemetry data in one location — an important capability for technicians who operate robotic arms. All information is within the operator's field of view, alerting them to potential problems before they happen.

Just as important is applying the technology to scientific analysis, Grubb said.

The team has applied digital elevation maps and lidar data to create a 3-D simulation of terrestrial lava flows and tubes. The goal is to develop a proof-of-concept app that would allow scientists to compare remotely collected data with what they observe in the field. In another, the team is creating a 3-D visualization of solar space for mission planning. This simulation involves a constellation of CubeSats surrounding the sun to investigate the structure of the solar atmosphere, including the formation of coronal mass ejections.

And last, the team is creating a virtual-reality environment where users can explore and visualize topographical features of Earth's protective magnetosphere. This app allows users to study magnetic reconnection sites, which are difficult to interpret without stereoscopic imagery, Grubb said.

"I'm a gamer, but I see the potential for engineering and science applications," Grubb said. "We're in the early stages, but I believe this technology will transform how we work here. It will enhance engineering and give scientists a unique perspective of data." ❖

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Scientific Tool, *continued from page 16*

a broad range of wavelengths using validated data collected by observatories, orbiters, and landers.

The original tool also included a 3-D orbital calculator, programs that simulated instrument "noise" and coronagraphs — devices that block starlight to reveal orbiting objects — and profiles of temperature and chemical abundances for Venus, Earth, Mars, Titan, Neptune, and other smaller bodies, just to name a few features. PSG proved to be a "great asset" and relatively easy to use, as evidenced by the number of non-technical users who access the online tool, Villanueva said.

Since its debut, scientists have used the tool to develop Mars mission concepts, plan James Webb Space Telescope observations, and define scientific and technical requirements for a proposed follow-on to the Webb Observatory.

Tool to Benefit from Upgrades

Despite its success, Villanueva and his team believed it could be improved.

"The foundational elements are there, but the tool didn't include performance data for detectors," he said, adding that he and his team plan to incorporate detector characteristics for eight assets, including the Webb Observatory, Hubble Space Telescope, New Horizons, Cassini, ExoMars, the NASA Infrared Telescope Facility, and the Stratospheric Observatory for Infrared Astronomy.

With these performance specifications, coupled with the tool's already-existing databases, scientists will be able to define which missions to fly and develop accurate and precise models of how instruments would be expected to perform.

"Once you know how to model the performance of different technologies, you can accurately design a wide range of future instruments," Villanueva said. "It could tell you, for example, if you needed a bigger mirror or a better detector. In the end, these developments will reduce costs, time and resources when designing future instruments and missions." ❖

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Radio Station, *continued from page 17*

age that the technique was applied to sounding-rocket and full-fledged satellite missions, such as the Canadian-built and NASA-launched Alouette 1 in 1962. More recently, NASA launched the Radio Plasma Imager on a mission called the Imager for Magnetopause-to-Aurora Global Exploration, or IMAGE. Also, the Jet Propulsion Laboratory, in collaboration with its European partners, provided another sounder, the Mars Advanced Radar for Subsurface and Ionospheric Sounding, for the European Space Agency's Mars Express mission.

"Basically, what we're doing is miniaturizing a 100-year-old radio receiver signal-processing technology," said ECHOES Co-Principal Investigator Damon Bradley, who led the development of the digital signal-processing system for the radiometer on NASA's Soil Moisture Active Passive, or SMAP mission, which tracks global soil-moisture levels. "ECHOES is essentially a low-frequency radar that uses space-based digital-signal processing, as on SMAP, but for probing the ionosphere as opposed to mapping global soil-moisture levels."

Before the miniaturized instrument can fly in space, however, the team needs to prove that it's capable of obtaining density measurements in a relevant environment. As part of its technology-development effort, the team plans to integrate ECHOES electronics and antenna systems with other instrument hardware and execute a test at the Goddard Geophysical and Astronomical Observatory.

"A successful proof-of-concept demonstration of the ECHOES instrument would place Goddard in a unique position to compete for other future Heliophysics or planetary opportunities, particularly those involving CubeSat or small-satellite platforms," Adrian said. ❖

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Cutting edge Goddard's Emerging Technologies

CuttingEdge is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Maryland. The publication describes the emerging, potentially transformative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, *Peter.M.Hughes@nasa.gov*. If you wish to be placed on the publication's distribution list, contact Editor Lori Keesey, *Lori.J.Keesey@nasa.gov.* NP-2017-6-031-GSFC

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CuttingEdge

Summer 2017 issue of CuttingEdge is now availabe. The Office of the Chief Technologist publishes CuttingEdge (formerly Goddard Tech Trends) quarterly. The magazine describes technology developments at the Center and explains how they are helping NASA to achieve its mission. If you wish to be placed on the magazine distribution list or if you want more information about Goddard technology, contact Barbara Medina at barbara.b.medina@nasa.gov.

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