National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

Volume 13 | Issue 3 | Spring 2017

SWEET SIXTEEN:

R&D Technologies Reach New Heights

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Volume 13 • Issue 3 • Spring 2017

Sweet 16

R&D Teams Fly Extraordinary Number of Payloads in 2017

As launches go, 2017 is shaping up to be an extraordinary year for Goddard technologists.

Sixteen different missions whose instruments and components were developed at least in part with Internal Research and Development, or IRAD, program funding have either launched or are scheduled to launch this year aboard commercial launch vehicles, sounding rockets, balloons, and high-altitude research aircraft.

"Every year, a handful of technologists will demonstrate their technologies or launch a full-fledged science mission, but by any measure 2017 is extraordinary," said Goddard Chief Technologist Peter Hughes, who manages the center's IRAD program.

"It sometimes can take years to conceive and mature a technology to the point where it is ready for spaceflight, as evidenced by this year's boom in launches. Some of these payloads were begun many years ago. Getting to this point testifies to the staying power of the technology our people have developed and its usefulness to NASA."

Of the 16 missions, three are on sounding rockets, four on CubeSats, two on high-altitude balloons, five on research aircraft, and two on the International Space Station (see chart, page 3). In this issue of *CuttingEdge,* we profile a few of those missions and payloads.

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Spring 2017

About the Cover

To scientists, the interaction of solar winds and Earth's atmosphere is more than a light display. It produces many questions about the role the interaction plays in Earth's meteorological processes and the impact on the planet's atmosphere. To help answer some of these questions, NASA launches instrument-equipped sounding rockets. This composite shot shows the launch of four different sounding rockets from the Poker Flat Research Range in Alaska.

Photo Credit: Jamie Adkins/NASA

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Sweet Sixteen • Opportunities At-A-Glance

ONE

Launch Date: February 19

International Space Station's (ISS) Space Test Program-H5 (STP-H5)

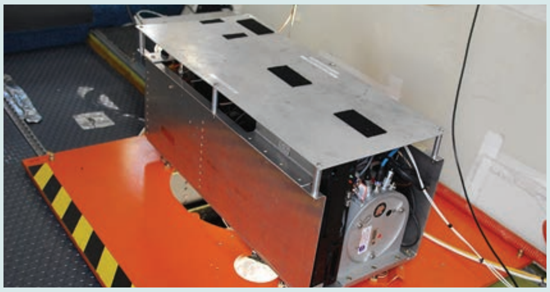
STP-H5, an ISS experiment pallet, is flying multiple SpaceCube processors: 2.0 operates Raven; ISS SpaceCube Experiment Mini (ISEM) runs the electrohydrodynamic pump (EHD) experiment; and 1.0 interfaces with ISS's data services and multiple STP-H5 experiments. STP-H5 also flies the Innovative Coatings Experiment (ICE). (SpaceCube Team; EHD Pumps PI: Jeff Didion; ICE PI: Mark Hasegawa)

TWO

Launch Date: March 1

Fluorescence Airborne Research Experiment (FLARE)

FLARE flew Goddard's Lidar, Hyperspectral, and Thermal Airborne Imager, or G-LiHT, aboard a research aircraft over Puerto Rico to study rates of regrowth in tropical forests. Since its commissioning in 2011, G-LiHT has become a workhorse for scientists interested in mapping the composition, structure, and health of terrestrial ecosystems. (PI: Bruce Cook)



THREE

Launch Date: March 1

AuroralJets Sounding Rocket for Auroral Dynamics Study

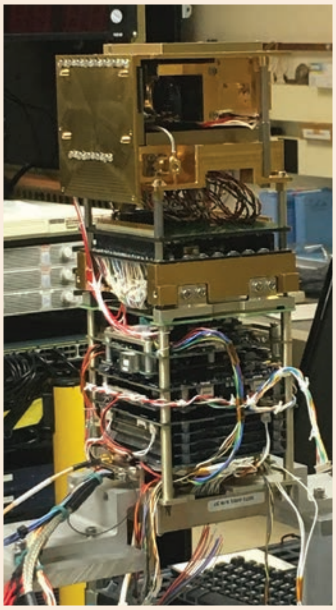
This mission studied auroral dynamics with an integrated suite of sounding-rocket instruments, including Wire Electric Field Booms (PI: Robert Pfaff); two magnetometers (PI: Larry Kepko/Eftyhia Zesta); and the Adaptive Langmuir Probe (PI: Jeff Klennzing).

FOUR

Launch Date: April 18

IceCube

IceCube is demonstrating a more capable submillimeter instrument needed to assess the global distribution of atmospheric ice, which plays a key role in Earth's climate system. IceCube is the first CubeSat mission managed by the Wallops Flight Facility. (PI: Dong Wu)



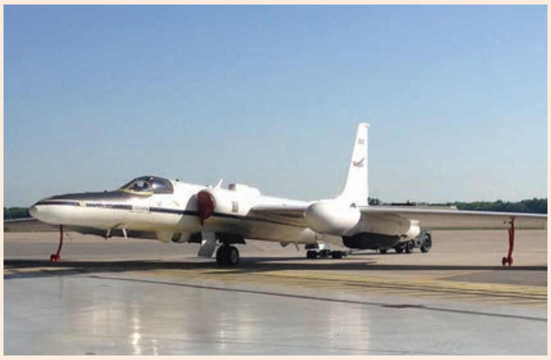
Sweet Sixteen • Opportunities At-A-Glance

FIVE

Launch Date: Spring

GOES-R Validation/Calibration

The NOAA-sponsored ER-2 aircraft mission is flying the R&D-supported Cloud Radar System, ER-2 X-Band Radar, GEO-CAPE Airborne Simulator, and the Cloud Physics Lidar. The suite of instruments is validating GOES-R, the next generation of geostationary weather satellites. (PIs: Gerry Heymsfield, Scott Janz, and Matt McGill)



SIX

Launch Date: Spring

Neutron Star Interior Composition Explorer/ Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT)

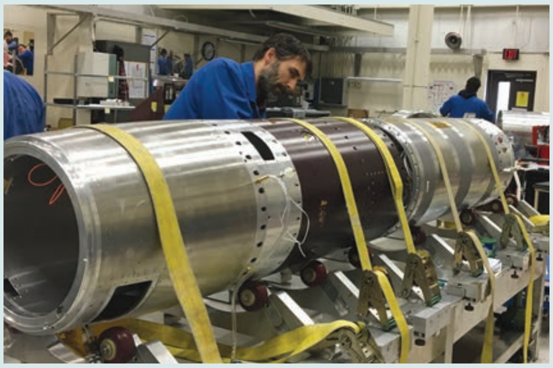
NICER is a two-in-one X-ray telescope that will study neutron stars and demonstrate for the first-time pulsar-based navigation from the International Space Station. It also may demonstrate X-ray communications, which also would be a NASA first. (PIs: Keith Gendreau/Zaven Arzoumanian)

SEVEN

Launch Date: Spring

Suborbital Technology Carrier (SubTEC7)

SubTEC7, a specially equipped sounding rocket, will demonstrate 23 technologies, including a Goddard-developed low-cost star tracker and three capabilities funded by NASA's Game Changing Development Program. Payloads also include those developed by private industry. (Wallops Flight Facility)



EIGHT

Launch Date: Spring

Carbon Airborne Flux Experiment (CARAFE)

CARAFE, installed aboard NASA's C23 Sherpa aircraft, will study carbon flux on a regional basis. The measurements will help scientists better understand flux and improve computer models that predict Earth's carbon sinks. (PI: Randy Kawa)

Sweet Sixteen • Opportunities At-A-Glance

NINE

Launch Date: Late Spring

Primordial Inflation Polarization Explorer (PIPER)

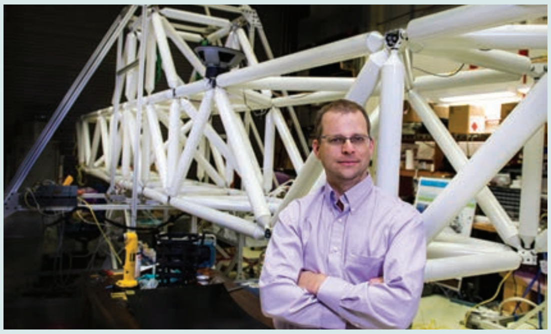
PIPER is searching for the predicted signature of primordial gravitational waves that could prove the theory of inflation. Should PIPER find the signature from its high-altitude balloon, the discovery would have profound consequences for cosmology and high-energy physics. (PI: Al Kogut)

TEN

Launch Date: Summer

Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

BETTII will demonstrate spatial interferometry, an observing technique where light gathered by two smaller telescopes is combined to provide the viewing power of a much larger telescope. During the balloon mission, BETTII will observe in the far-infrared band, gathering data every 1 millisecond of clustered stars. (PI: Stephen Rinehart)



ELEVEN

Launch Date: Summer

Arctic-Boreal Vulnerability Experiment (ABoVE): Land, Vegetation and Ice Sensor (LVIS)

This airborne mission, which studies large-scale environmental change in Alaska and Western Canada, is flying the Goddard-developed LVIS. LVIS has flown many times gathering topographical and vegetation data. (PI: Bryan Blair)

TWELVE

Launch Date: Summer

Hands-on Project Experience—East Pacific Origins and Characteristics of Hurricanes (HOPE-EPOCH)

HOPE-EPOCH, which includes six flights on the Global Hawk aircraft, will fly three instruments, including the Goddard-developed ER-2 X-Band Radar. HOPE is aimed at giving early-career scientists hands-on flight experience. (PI: Amber Emory)

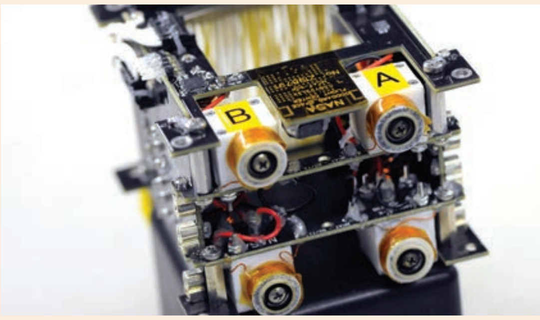
Sweet Sixteen • Opportunities At-A-Glance

THIRTEEN

Launch Date: Summer

CubeSat Astronomy by NASA and Yonsei Using Virtual Telescope Alignment Experiment (CANYVAL-X)

CANYVAL-X will demonstrate technologies that create a virtual telescope — two spacecraft aligned along an inertial line of sight to a celestial source. Goddard partnered with South Korea's Yonsei University and the Korea Aerospace Research Institute to develop the mission. (PI: Neerav Shah)

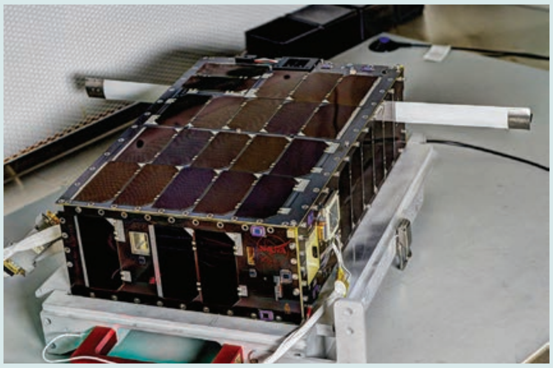


FOURTEEN

Launch Date: Summer

Dellingr

The 6U CubeSat, developed to demonstrate that CubeSats can be reliable and cost-effective also while delivering compelling science, carries the mini Ion and Neutral Mass Spectrometer, a boom-mounted and two internal magnetometers, and other technologies. (Initiative Leads: Michael Johnson and Larry Kepko; Project Manager: Chuck)

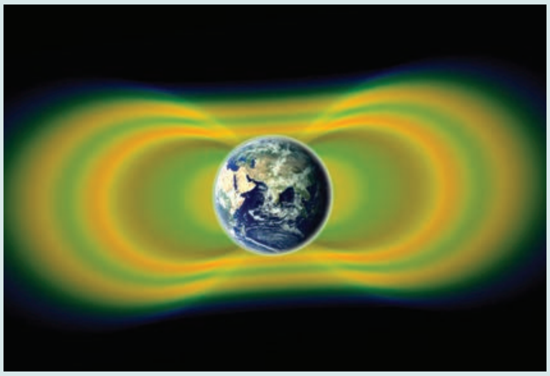


FIFTEEN

Launch Date: Fall

Compact Radiation Belt Explorer (CeREs)

CeREs will study charged-particle dynamics in Earth's Van Allen radiation belts. The mission consists of a small telescope and a stack of solid-state detectors that will measure energetic electrons and protons — data that will provide details about the electron-burst phenomenon. (PI: Shri Kanekal and the Southwest Research Institute)

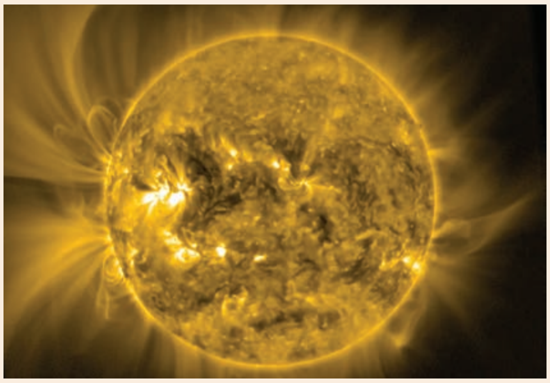


SIXTEEN

Launch Date: Fall

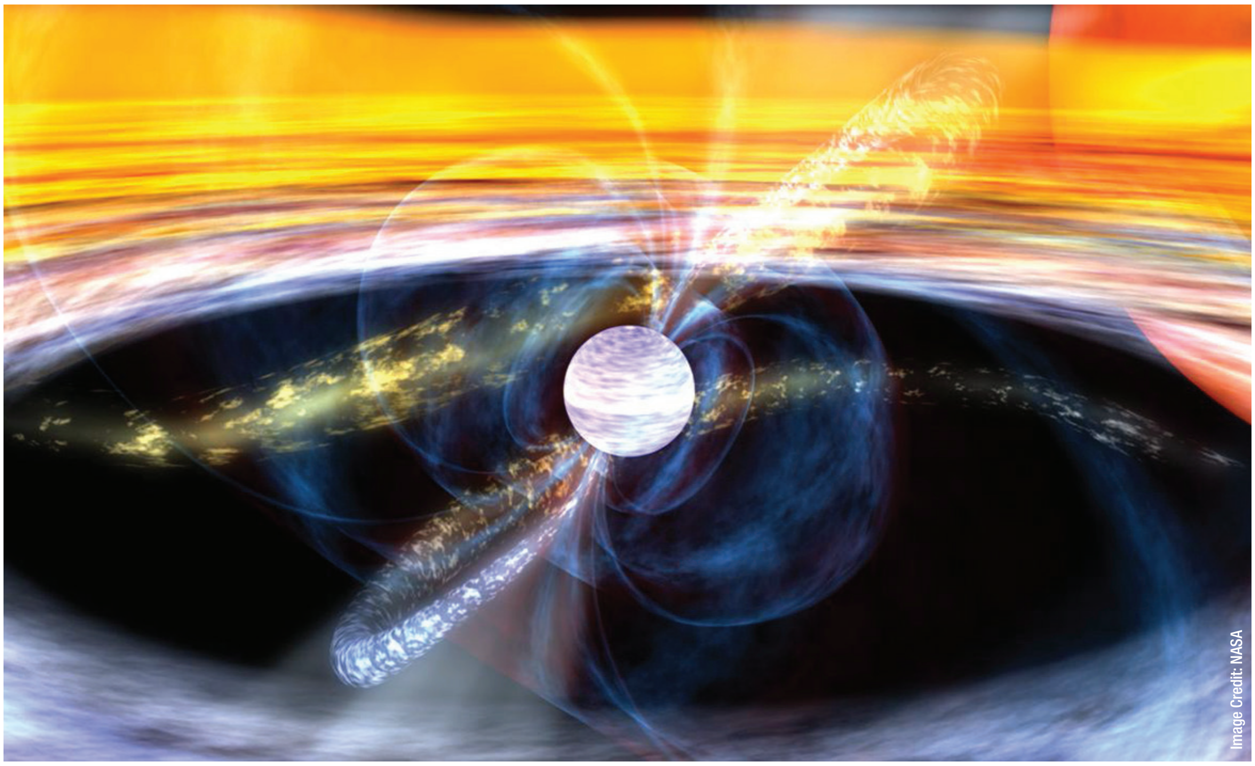
Extreme Ultraviolet Normal-Incidence Imaging Spectrograph (EUNIS)

EUNIS, a sounding rocket mission, will observe the sun in the extreme ultraviolet/soft X-ray wavelengths critically important for understanding the energization of the solar corona, which has never been observed with an imaging spectrograph. (PI: Adrian Daw)



Multi-Purpose NICER Set to Launch

Mission's Space Station Deployment Coincides with 50th Anniversary of Pulsar Discovery



This is an illustration of a pulsar (blue-white disk in center) pulling in matter from a nearby star (red disk at upper right). The stellar material forms a disk around the pulsar (multicolored ring) before falling onto the surface at the magnetic poles. The pulsar's intense magnetic field is represented by faint blue outlines surrounding the pulsar.

Nearly 50 years after British astrophysicist Jocelyn Bell discovered the existence of rapidly spinning neutron stars, NASA is scheduled to launch the world's first mission devoted to not only studying these unusual objects, but also using their pulsations to carry out the word's first demonstration of X-ray navigation in space.

The agency plans to launch the two-in-one Neutron Star Interior Composition Explorer, or NICER, aboard SpaceX CRS-11, a cargo resupply mission to be launched aboard a Falcon 9 rocket in May.

About a week after its installation as an external attached payload on the International Space Station, this one-of-a-kind investigation will begin observing neutron stars, the densest objects in the universe. The mission will focus especially on pulsars — those neutron stars that appear to wink on and off because their spin sweeps beams of light past us, like a cosmic lighthouse.

"The timing of this launch is perfect," said Keith Gendreau, who led the mission that traces its beginnings to support from Goddard's Internal Research and Development program. Although the team had completed and delivered the washing machine-sized payload ahead of schedule last summer, a launch opportunity did not become available until 2017 (*CuttingEdge*, Spring 2015, Page 9).

Soon after the 50th anniversary of Bell's discovery on July 25, the NICER team should have collected enough data "to make a little bit of a splash," added NICER Deputy Principal Investigator Zaven Arzoumanian, referring to this summer's scientific conferences, including one celebrating Bell's detection of regularly pulsing signals that later were identified as rotating neutron stars. "We hope to have something interesting to share."

Studying the Stellar Extreme

Funded by both NASA's Science Mission and Space Technology Mission Directorates, NICER is primarily a science payload designed specifically for studying neutron stars and pulsars — objects that

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make up the stellar extreme.

These objects literally are the remnants of massive stars that, after exhausting their nuclear fuel, exploded and collapsed into super-dense spheres about the size of New York City. Their intense gravity crushes an astonishing amount of matter — often more than 1.4 times the content of the sun or at least 460,000 Earths — into these city-sized orbs, creating stable, yet incredibly dense matter not seen anywhere else in the universe. Just one teaspoonful of neutron star matter would weigh a billion tons on Earth.

During its 18-month mission, NICER will collect X-rays generated from the stars' tremendously strong magnetic fields and from hotspots located at their two magnetic poles using its 56 X-ray telescopes. At these locations, the objects' intense magnetic fields emerge from their surfaces and particles trapped within these fields rain down and generate X-rays when they strike the stars' surfaces.

In pulsars, these flowing particles emit powerful beams of light from the vicinity of the magnetic poles. As Bell discovered, these beams of light are observed on Earth as flashes of light at intervals ranging from seconds to milliseconds depending on how fast the pulsar rotates.

SEXTANT: A World First

Because these pulsations are predictable, they can be used as celestial clocks, providing high-precision timing just like the atomic-clock signals supplied through the Global Positioning System, also known as GPS. Although ubiquitous on Earth, GPS signals weaken the farther one travels out beyond Earth orbit. Pulsars, however, are accessible virtually everywhere in space, making them a valuable navigational solution for deep-space exploration.

In an experiment called the Station Explorer for X-ray Timing and Navigation Technology, or SEXTANT, the team will use NICER's telescopes to

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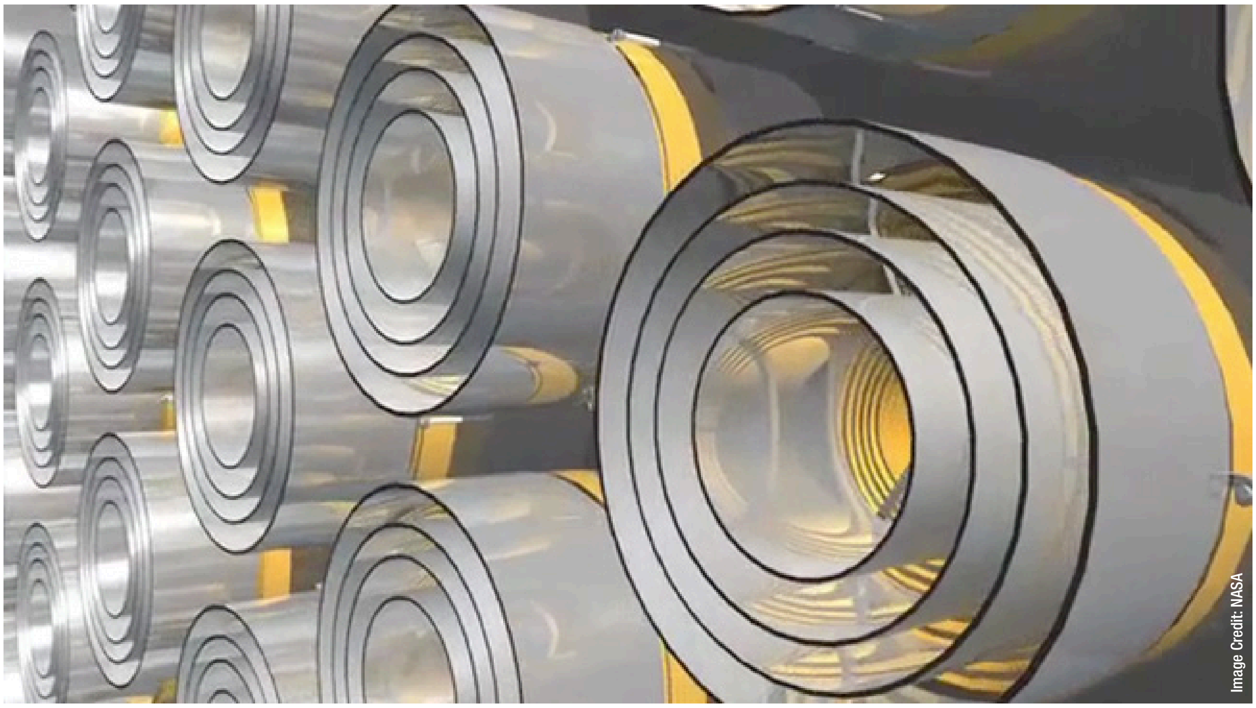
Technicians work on the NICER payload, which is expected to launch in May aboard a cargo resupply vehicle to the International Space Station.



This image shows the configuration of NICER's 56 X-ray mirrors that will gather scientific observations and play an instrumental role demonstrating X-ray navigation.

detect X-ray light emitted within the pulsars' sweeping beams of light to estimate the arrival times of those pulses. With these measurements, the team will use specially developed algorithms to stitch together an onboard navigational solution.

"Our primary goal is science," Gendreau said. "But we can use the same pulsar measurements to demonstrate X-ray navigation. It's rare that we scientists get to develop a multi-purpose experiment such as this one. It's all coming together."

Fingers Crossed for X-ray Communications Demo

However, X-ray navigation using NICER's pulsar timing data is not the only technology the team would like to demonstrate. In another potential first, the team wants to demonstrate X-ray communications — a capability that could eventually allow spacecraft to transmit gigabits of data per second over interplanetary distances.

Central to this potential demonstration is Goddard's Modulated X-ray Source, or MXS, which the NICER team developed to calibrate the payload's detectors and help test the algorithms needed to demonstrate X-ray navigation. This device generates X-rays with rapidly varying intensity, turning on and off many times per second to simulate, for example, a target neutron star's pulsations.

Should enough funding become available to complete hardware for a space-based demonstration, the team would fly the MXS to the International Space Station and deploy it on an external experiment pallet about 166 feet away from NICER. During the experiment, the team would encode digital data in pulsed X-rays using the MXS and transmit the data to NICER's receivers (CuttingEdge, Fall 2016, Page 4).

If the team succeeds in flying MXS perhaps next year, "the resulting demonstration could be game-changing," said MXS Project Manager Jason Mitchell. In addition to promising gigabit-per-second data transmission speeds across vast distances, X-ray communications would enable communication with hypersonic vehicles and spacecraft.

"This is a very interesting experiment that we're doing on the space station," Gendreau said. "We've had a lot of great support from the science and space technology folks at NASA Headquarters. They have helped us advance the technologies that make NICER possible as well as those that NICER will demonstrate. The mission is blazing trails on several different levels." ❖

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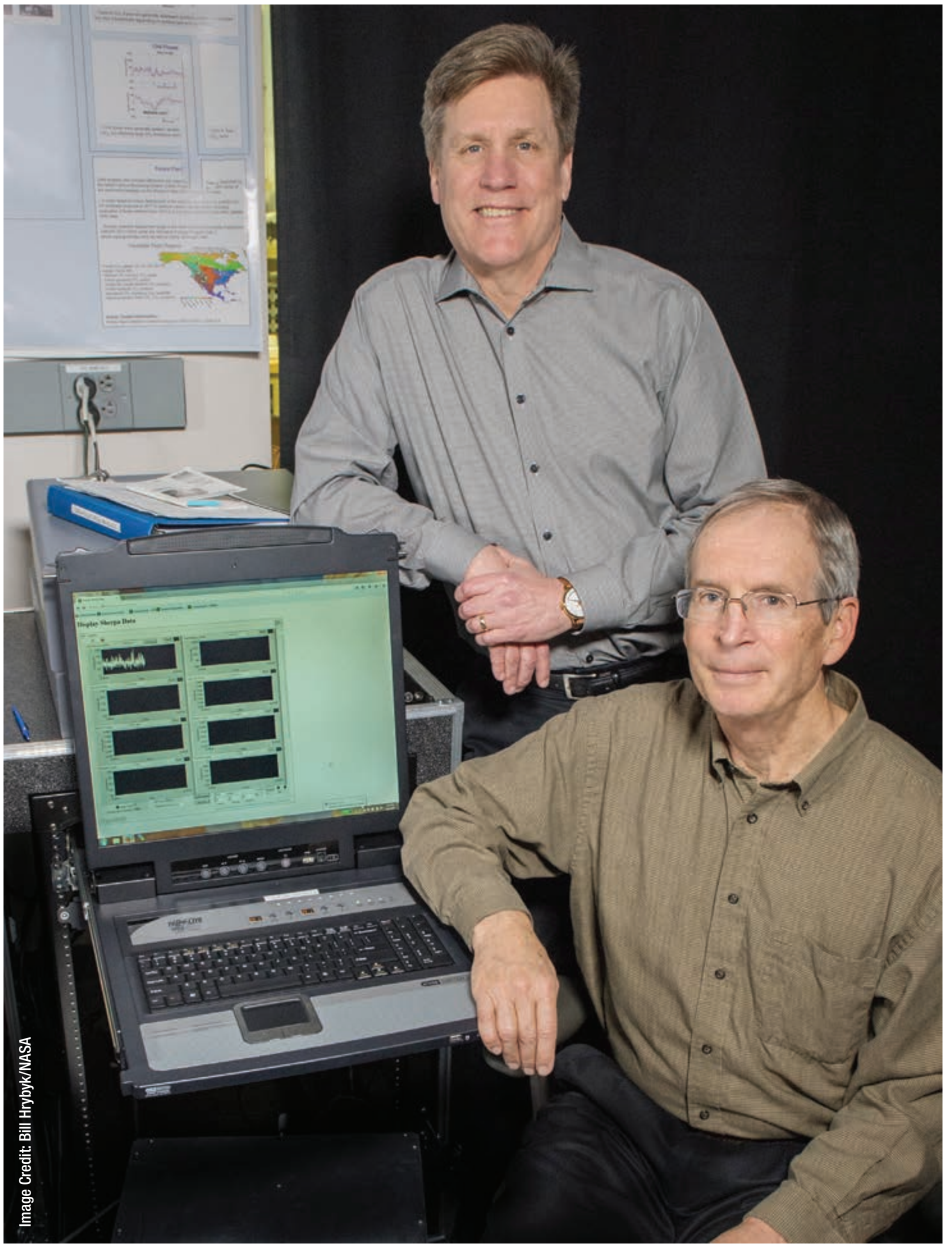
The Carbon Question

CARAFE to Measure Greenhouse Gases Over the Mid-Atlantic Region

In May, a team of Goddard scientists will begin measuring greenhouse gases over the Mid-Atlantic region — an area chosen because it encompasses a range of vegetation, climate, and soil types that would influence the exchange of carbon dioxide and methane between the Earth and the atmosphere.

The airborne campaign, called the Carbon Airborne Flux Experiment, or CARAFE, could help scientists better understand the exchange process, also known as flux, and improve computer models that predict Earth's carbon sinks, natural or artificial reservoirs that suck up and store carbon dioxide from or emit methane into the atmosphere.



Goddard scientists Randy Kawa (seated) and Paul Newman will be flying modified, commercial-off-the-shelf methane/carbon-dioxide analyzers, wind sensors, camera, and GPS on a C-23 Sherpa aircraft to obtain regional carbon-flux measurements. They are pictured here with the computer (in front) and one of the instruments (behind the screen).

What Scientists Know

Scientists know how much carbon dioxide is produced annually through the burning of fossil fuels and deforestation. They also know that about 44 percent of these emissions stay in the atmosphere and that the oceans and land sinks take up the rest.

What they don't know with certainty is what biological mechanisms currently control the uptake and storage in grasses, plants, crops, and trees. They also don't know whether these sinks will remain healthy considering ever-increasing emissions and changing climate.

"The biggest issue is knowing what causes the land sink and how it will evolve with continued emissions and changing climate," said CARAFE Principal Investigator Randy Kawa, an expert in carbon modeling.

CARAFE's Job

Currently, most flux data are gathered at towers or inferred from atmospheric carbon measurements,

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The Wallops Flight Facility Aircraft Office operates the NASA C-23 Sherpa research aircraft available to support airborne science research. The C-23 is a two-engine turboprop aircraft designed to operate under the most arduous conditions, in a wide range of mission configurations.

including those from satellites. Unfortunately, towers measure only the conditions occurring within their immediate vicinities and not on a regional scale.

CARAFE will rectify that. The team will use CARAFE data to determine how well computer models represent regional flux variations and compare actual surface flux rates against those inferred from satellite data — both of which will help improve existing atmospheric and ecosystem computer modeling.

"Hopefully we will be able to demonstrate the value of these measurements," Kawa said. "We want to build a confident and consistent picture of both carbon-dioxide and methane fluxes and their dependence on underlying biological, geological, weather, and chemical processes. This will allow decision-makers to make better informed decisions about greenhouse gas policy and impacts."

Month-Long Campaign

During the month-long campaign, a NASA C-23 Sherpa aircraft from the Wallops Flight Facility will fly at various altitudes over the Pocomoke Forest area on the Eastern Shore of Maryland; agricultural areas and tidal marshlands from the Eastern Shore of Virginia to southern Delaware; the Chesapeake Bay and the Atlantic Ocean; southern Maryland; the New Jersey Pine Barrens in the southern portion of the state; and the Alligator River and the Great Dismal Swamp in eastern North Carolina and southeastern Virginia.

While flying "low and slow" at about 500 feet above the tops of vegetation, the campaign's modified, commercial-off-the-shelf methane/carbon-dioxide analyzers, wind sensors, camera, and GPS will gather 10 carefully synchronized measurements per second. Specifically, the instruments will measure both greenhouse gas levels along tree lines and vertical wind speeds, which, when combined, reveal how fast these gases transfer to or from the atmosphere.

"If the GPS data is off by even a half second, the flux measurements are off," said CARAFE Co-Principal Investigator Paul Newman, adding that the team used Goddard Internal Research and Development program funding to modify the instruments and develop the data system.

"What we're trying to determine is how fast are trees taking up carbon dioxide," he said. "This rate differs for different trees, shrubs, grasses, and other conditions. All have different uptake levels. It changes if the vegetation doesn't have enough water, for example, or if it is healthy. We must represent that in or models. We have to understand the rates." ❖

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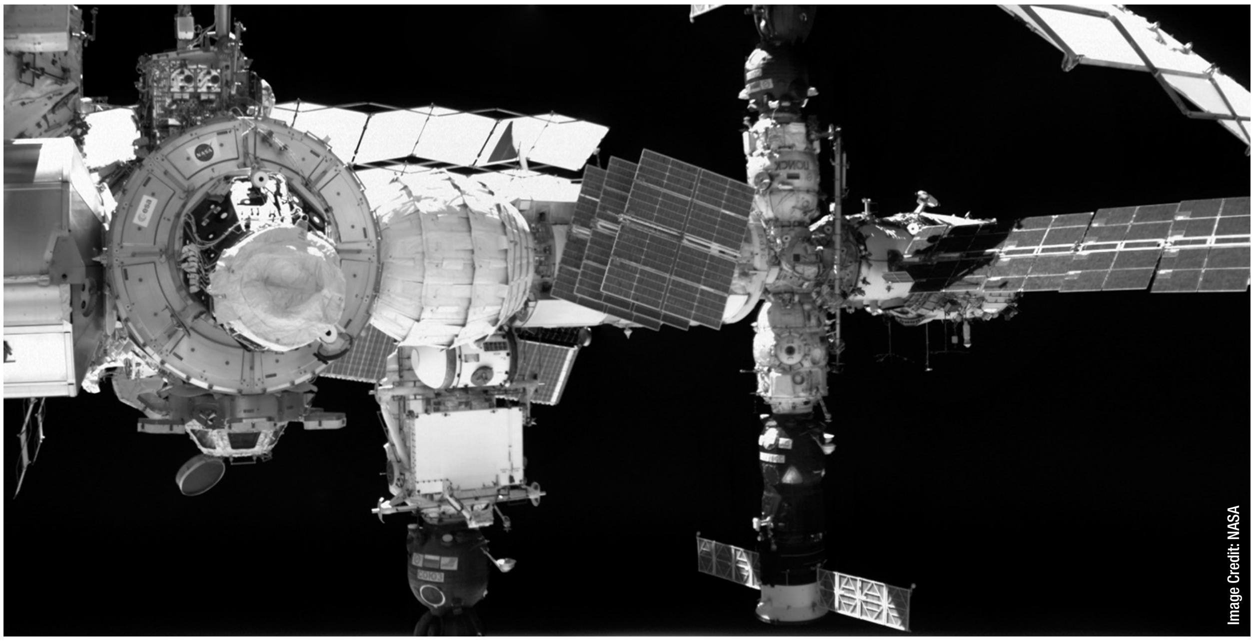
NASA's Hybrid Computer Enables Raven's Autonomous Rendezvous Capability



This panorama of the International Space Station was composed by piecing together images taken by Raven's visible camera. These images were processed by a hybrid computing platform, SpaceCube 2.0

The homegrown SpaceCube 2.0 hybrid computing system is the enabling technology behind Raven, the ambitious experiment that currently is testing relative navigation and autonomous docking capabilities from its perch on the International Space Station.

Developed by the Satellite Servicing Projects Division, or SSPD, the carry-on luggage-sized module was launched February 19 aboard SpaceX's Dragon spacecraft, along with other experiments deployed on the Defense Department's Space Technology Program-H5, or STP-H5, an experiment pallet.

Raven is testing and maturing visible, infrared, and lidar sensors and machine-vision algorithms — technologies that will bring NASA one step closer to realizing the groundbreaking autopilot capability that can be applied to many NASA missions for decades to come, including Restore-L (see related story, page 23).

"Everything is working beautifully," said SSPD Avionics Technology Lead and SpaceCube Lead Engineer David Petrick, who, along with his team, were recognized in 2016 as IRAD innovators of the year (CuttingEdge, Fall 2016, Page 2). "All three of the sensors are returning images and SpaceCube is fully operational."

Raven: The Precursor to Restore-L

As with the Goddard Reconfigurable Laser Ranger (see related story, page 23) and a growing list of other technologies, Raven depends on SpaceCube 2.0. This reconfigurable computing platform has evolved into a family of flight computers all distinguished by their computing speed, which is 10 to 100 times faster than the commonly used spaceflight processor — the RAD750.

During its two-year stay on the space station, Raven will sense incoming and outgoing visiting space station spacecraft, feeding the data it "sees" to SpaceCube 2.0, which then runs a set of pose algorithms, or a set of instructions, to gauge the relative distance between Raven and the spacecraft it is tracking.

Then, based on these calculations, SpaceCube 2.0 autonomously sends commands that swivel the Raven module on its gimbal or pointing system to keep the sensors trained on the vehicle, while continuing

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This image shows the STP-H5, held by Canada's robotic arm, during its installation on the outside of the International Space Station.

to track it. "The SpaceCube processor is the behind-the-scenes technology that is making this important demonstration possible," Goddard Director Chris Scolese said.

"Tracking spacecraft with this system is only possible because we have SpaceCube," Petrick added. "This type of operation requires fast computing."

Other SpaceCube Siblings Onboard

SpaceCube 2.0, however, isn't the only processor now at work on STP-H5.

SpaceCube 1.0 is being used as the communication interface between the space station's data services and multiple experiments on the pallet. In addition, a miniaturized version of SpaceCube 2.0 — the ISS SpaceCube Experiment Mini, or ISEM — is operating NASA and U.S. Defense Department experiments.

Included is an electrohydrodynamic, or EHD, pumps experiment developed by Principal Investigator Jeffrey Didion. EHD demonstrates the feasibility, long-term operation, and heat removal capabilities of electrically based thermal-management systems — concepts Didion conceived under previous IRADs.

NASA also is testing two other miniature computers, developed with the University of Florida. These smaller computers are mostly equipped with commercial parts.

SpaceCube's utility hasn't gone unnoticed. While the processors continue their work on the space station, Goddard's Strategic Partnerships Office announced that a Maryland company had signed a patent license to manufacture and sell a flight processor based on SpaceCube 2.0's technology (see related story, page 15).

Other Experiments Aboard STP-H5

Unrelated to SpaceCube operations, STP-H5 is flying multiple coating samples, including two versions of the Molecular Adsorber Coating, or MAC, that Goddard engineers developed to entrap outgassed contaminants (*CuttingEdge*, Summer 2015, Page 16). The samples, which look like paint chips, adhere to the sides of the pallet. After a stay on orbit, they will be returned to Principal Investigator Mark Hasegawa who will analyze them to determine how they performed while exposed to the harsh space environment. ❖

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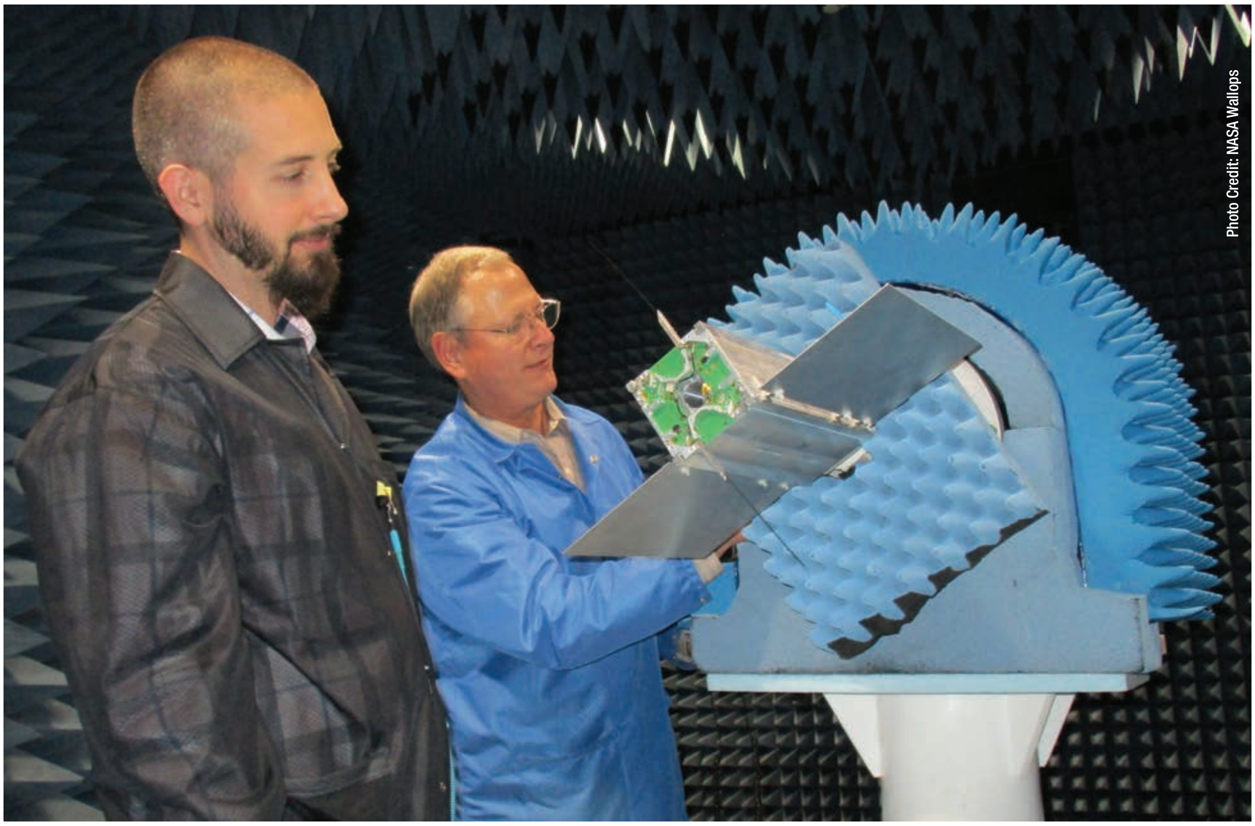
IceCube to Space-Qualify Submillimeter Radiometer



The Wallops Flight Facility's Brian S. Abresch (left) and Con Duer are shown here working on IceCube's UHF antenna. IceCube is designed to study ice clouds and test a commercial receiver for NASA's proposed Aerosol-Cloud-Ecosystems mission.

IceCube, the first small satellite project managed by the Wallops Flight Facility, successfully launched on an Atlas V rocket from the Cape Canaveral Air Force Station on April 18.

Once the breadloaf-sized satellite is deployed from the International Space Station, it will demonstrate a more capable submillimeter instrument needed to assess the global distribution of atmospheric ice, which plays a key role in Earth's climate system. The mission employs a commercially available submillimeter-wave, 883-gigahertz radiometer developed by Virginia Diodes Inc., of Charlottesville, Virginia, under a NASA Small Business Innovation Research contract.

Although NASA has flown submillimeter radiometers on airborne missions — namely, with the Goddard-developed Compact Scanning Submillimeter-wave Imaging Radiometer — it has not flown them in space.

Ultimately, the team wants to fly a submillimeter-wave radiometer on NASA's proposed Aerosol-Cloud-Ecosystems mission, which would study ice clouds that can dramatically affect the Earth's emission of infrared energy into space and its reflection and absorption of the sun's energy over broad areas. To this day, the amount of atmospheric ice on a global scale remains highly uncertain.

First Map of Cloud-Induced Radiances at 883-Gigahertz

Funded and managed through the Earth Science Technology Office's In-Space Validation of Earth Science Technologies program, IceCube's job from its low-Earth orbit is to qualify the instrument that could fly on such a mission and collect the first global map of cloud-induced radiances at 883-gigahertz. Goddard scientist Dong Wu is serving as the principal investigator on the mission.

Although sensing atmospheric ice is effective over a broad frequency band — from the infrared to the submillimeter — it's particularly critical in the latter. The submillimeter wavelength fills an important data

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gap in the middle and upper troposphere where ice clouds are often too opaque for infrared and visible sensors to penetrate.

In building, integrating, and testing the 3-unit, or 3U, CubeSat, the Goddard team faced several challenges. Notably, to keep down project costs, the team used commercial off-the-shelf components to build the spacecraft. The components, coming from multiple commercial providers, didn't always "plug and play" together, creating significant engineering challenges, said Small Satellite Manager Tom Johnson.

The team persevered, integrating the radiometer to the spacecraft, building the spacecraft support systems, and conducting thermal-vacuum, vibration, and antenna testing all at Goddard's Greenbelt, Maryland, campus and Wallops' facilities in Virginia. "The team had to overcome so many challenges and they worked hard to meet the delivery date," said Johnson. "I am very proud of the engineering team that worked so hard to achieve this milestone."

Typically found at heights greater than 20,000 feet, cirrus clouds are composed of ice crystals, which IceCube will measure.

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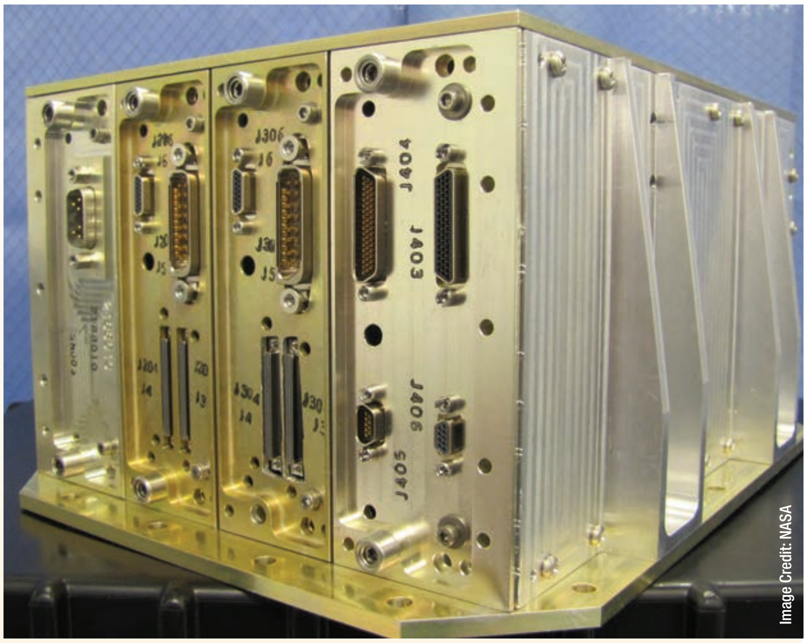
Company to Build and Sell SpaceCube 2.0-Based Flight Processors

A Maryland firm has signed a patent license with Goddard to manufacture and sell space-based processors founded on the highly successful SpaceCube 2.0 computer now operating NASA's Raven experiment (see related story, page 12).



The SpaceCube 2.0 team enjoyed another success: a Maryland-based company has signed a patent license with Goddard to manufacture and sell space-based processors founded on the SpaceCube 2.0 design.

The center's Strategic Partnerships Office recently announced the signing of a patent license between Goddard and Genesis Engineering Solutions, Inc., of Lanham, Maryland. The company is licensed to build and sell SpaceCube 2.0-based processors, which NASA will be able to buy in the future.

SpaceCube 2.0 is a reconfigurable, very fast processing platform. It achieves its data-crunching prowess because Goddard technologists married radiation-tolerant integrated circuits programmed to execute specific computing jobs simultaneously, with algorithms that detect and fix radiation-induced upsets in collected data. Consequently, these hybrid systems are nearly as reliable as traditional fully radiation-hardened flight systems, yet orders-of-magnitude faster, capable of executing complex computations once limited to ground-based systems.

SpaceCube 2.0 now is operating the Goddard-developed Raven experiment, which is testing and maturing visible, infrared, and lidar sensors and machine-vision algorithms needed to bring NASA one step closer to realizing an autopilot capability in space. ❖

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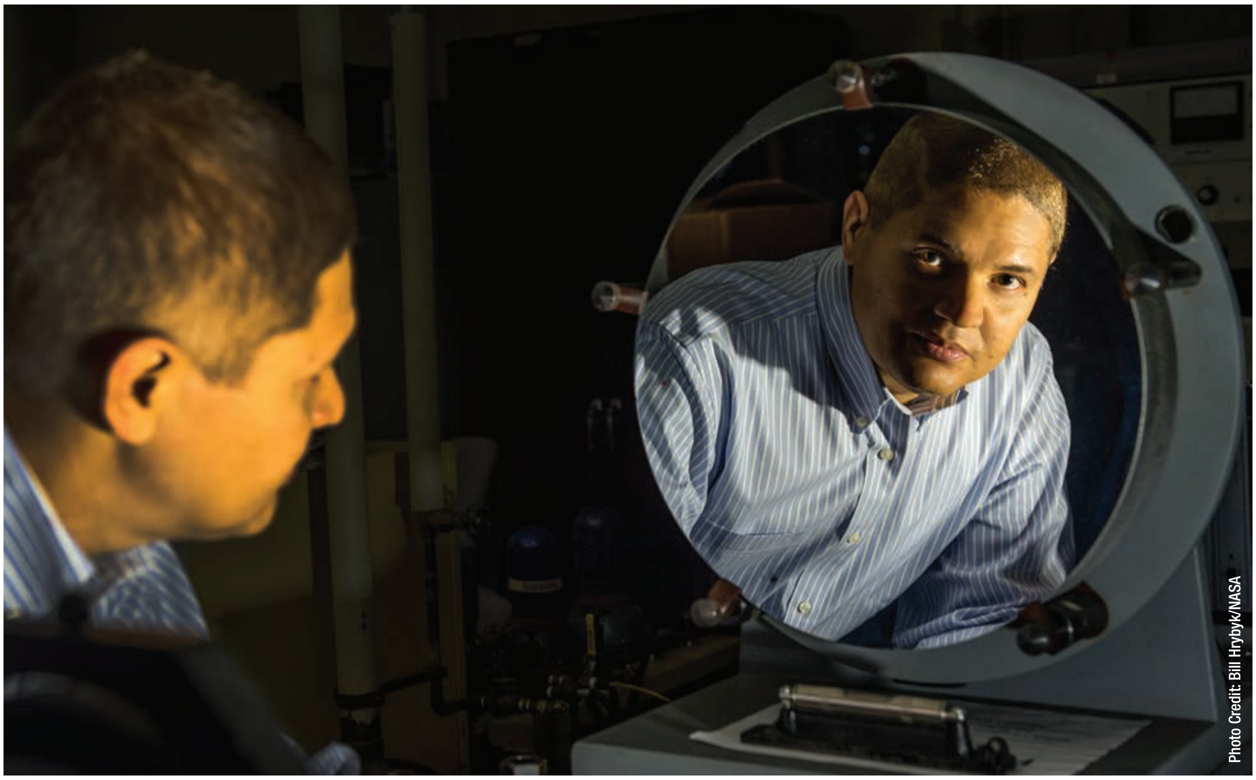
NASA Team Takes on a New Optical Challenge — the Lyman Alpha Range



Principal Investigator Manuel Quijada is shown here with the type of optic he and his team would coat with a fluoride film to provide maximum reflectance over a wide spectral range.

Goddard technologists produced telescope mirrors with the highest reflectance ever reported in the far-ultraviolet spectral range. Now, they're attempting to set another record.

Manuel Quijada and his team are investigating techniques for creating highly reflective aluminum mirrors sensitive to the infrared, optical, and far-ultraviolet wavelength bands — a broad spectral range envisioned for proposed space telescopes after the James Webb Space Telescope and Wide Field Infrared Survey Telescope. These proposed missions would tackle a broad range of astrophysics studies, from the epoch of reionization, through galaxy formation and evolution, to star and planet formation.

Quijada's team specifically is studying different techniques and materials for creating and applying protective coatings on aluminum mirrors to prevent them from oxidizing when exposed to oxygen and losing their reflectivity.

"Aluminum is a metal that nature has given us the broadest spectral coverage," Quijada said. "However, aluminum needs to be protected from naturally occurring oxides with a thin film or substrate of transparent material."

Unfortunately, no one has developed a coating that effectively protects and maintains a mirror's high reflectivity in the 90- to 130-nanometer range, also known as the Lyman Alpha range. At this spectral regime, scientists can observe a rich assortment of spectral lines and astronomical targets, including potentially habitable planets beyond our solar system. "The low reflectivity of coatings in this range is one of the biggest constraints in far-ultraviolet telescope and spectrograph design," Quijada said.

Ultraviolet light, which is shorter than that of visible light but longer than X-rays, is invisible to the human eye. Only with instruments tuned to this wavelength can objects be observed.

One of the recent NASA missions fully dedicated to far-ultraviolet observations was the Far Ultravio-

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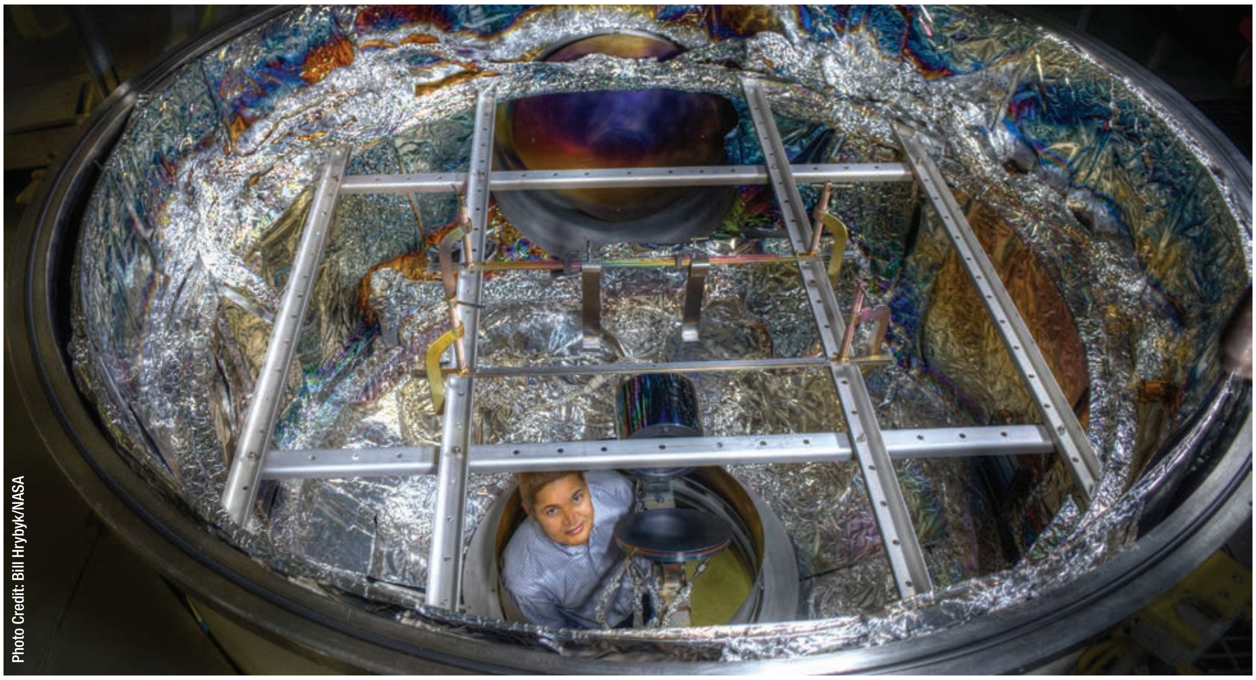

Photo Credit: Bill Hrybyk/NASA

Principal Investigator Manuel Quijada is dwarfed by the two-meter coating chamber where he applies thin films onto telescope mirrors that can be as large as one meter in diameter. The ability to coat large mirrors is key to enabling astronomical instruments of the future.

let Spectroscopic Explorer, or FUSE, which was decommissioned in 2007 after a successful prime mission. Although it acquired 6,000 observations of nearly 3,000 separate astronomical objects over its eight years in orbit, FUSE's lithium fluoride substrate coating was not stable enough and began to degrade with time, Quijada said.

"More Bang for the Buck"

Quijada's goal is to develop a coating and process that not only improves reflectance in the far ultraviolet, but also allows observations in the other wavelength bands.

"Traditional coating processes have not allowed the use of aluminum mirrors to their full potential," Quijada said. "The new coatings we're investigating would enable a telescope covering a very broad spectral range, from the far ultraviolet to the near-infrared in one single observatory. NASA would get more bang for the buck."

Under one coating approach, the team would use physical vapor deposition to apply a thin layer of xenon difluoride gas to an aluminum sample. According to Quijada, studies have shown that the treatment of xenon difluoride creates fluorine ions that tightly bind to the aluminum surface, preventing further oxidation.

He also is investigating the use of two other thin-film deposition techniques — ion-assisted physical vapor deposition and atomic layer deposition — to apply thin films of aluminum trifluoride, which is environmentally stable compared with other coatings.

Quijada and his team already have succeeded in developing a coating for another region of the ultraviolet spectral band.

In 2016, a validation test proved that a protective coating the team devised provided 90 percent reflectance in the 133.6-154.5-nanometer range — the highest reflectance ever reported for this ultraviolet band. To achieve this unprecedented level of performance, the team developed a three-step physical vapor deposition process to coat aluminum mirrors with protective magnesium fluoride or lithium fluoride films.

These high-reflectance coatings are now enabling new types of instruments, Quijada said. Two new heliophysics missions that will study the interactions between Earth's ionosphere and solar winds — the Ionospheric Connection Explorer and the Global-scale Observations of the Limb and Disk — will employ this coating technology.

"We need to push further down in the ultraviolet spectrum," Quijada said, referring to the targeted far-ultraviolet spectral range. "We need to get access to the whole ultraviolet to infrared range. We are blazing a trail in mirror coatings." ❖

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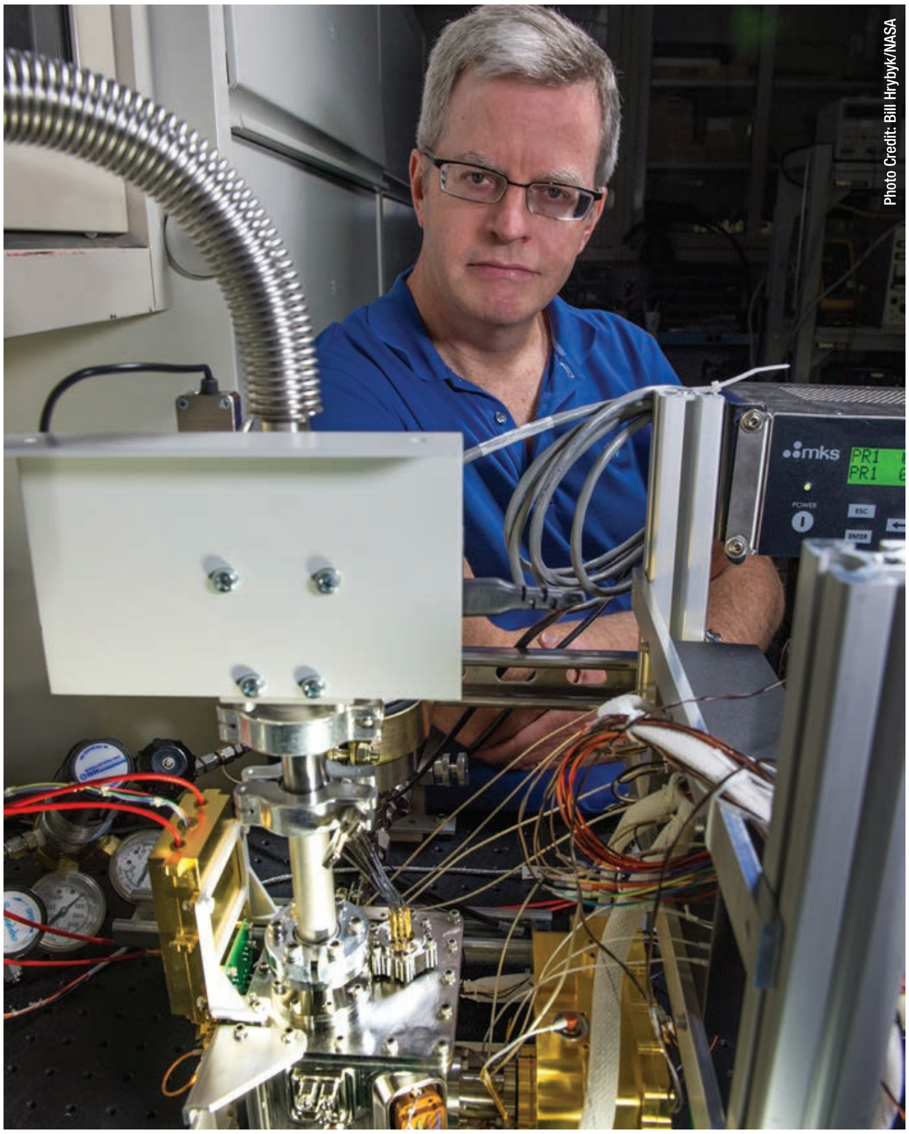
The Art of Leverage

Goddard Scientist Parlays Experience to Build Ocean Worlds Instrument

An instrument originally developed to search for organic molecules on Mars is being repurposed to potentially hunt for life on a handful of moons in the outer solar system that appear to host oceans, geysers, and cryovolcanic vents.

Goddard scientist Will Brinckerhoff, who helped build a mass spectrometer for the European Space Agency's 2020 ExoMars Rover mission and then leveraged the same model to create an even more capable instrument for a future NASA Mars mission, is parlaying these experiences to build yet another instrument under a new multi-million-dollar technology-development award.



Goddard scientist Will Brinckerhoff is leveraging an instrument developed for the exploration of Mars to create another that would look for life forms possibly inhabiting the oceans believed to exist on a handful of moons in the outer solar system.

The latest incarnation, the Europan Molecular Indicators of Life Investigation, or EMILI, would search the surfaces and subsurfaces of Europa or other icy moons for molecular biosignatures: structures or patterns of organic compounds indicating the presence of current or past life on these intriguing worlds.

Although at least six moons are believed to harbor liquid, Jupiter's Europa has special appeal among astrobiologists — so much so, in fact, that NASA now is conducting an early feasibility study for a dedicated lander mission that would follow the planned Europa Clipper multiple flyby mission in the 2020s. Such a lander would study surface samples of the ice overlaying Europa's vast subsurface ocean. Scientists believe the ocean may have existed for billions of years, time enough for potential life forms to evolve.

"If life exists in Europa's subsurface ocean, its molecular signs may be barely detectable in surface samples," Brinckerhoff said. "We're talking about microbial organic concentrations at levels well below a part per billion by weight."

NASA's Concepts for Ocean Worlds Life Detection Technology program, or COLDTech, awarded Brinckerhoff and his team $2.3 million in two-year funding to advance EMILI as a potential instrument on a lander. The goal is to mature the instrument to a technology readiness level of six, or TRL-6, which means EMILI is ready for flight development and capable of detecting and analyzing microbial life forms.

Continued on page 19

EMILI has a headstart.

The prototype would carry a similar suite of capabilities already developed for the Mars Organic Molecule Analyzer-Mass Spectrometer, or MOMA-MS, and the Linear Ion Trap Mass Spectrometer, or LITMS.

MOMA-MS, which Brinckerhoff's team will deliver in less than a year for integration onto ESA's 2020 ExoMars mission, will identify organic material by measuring the mass of the individual molecules locked inside crushed Martian rock samples. LITMS, under development for a potential future Mars mission with support from NASA's Maturation of Instruments for Solar System Exploration program, is nearly at TRL-6, pending a final round of Mars environmental tests.

Both instruments detect and identify organic material on Mars with two techniques. In one, called laser desorption mass spectrometry, an onboard high-intensity laser converts a sample's molecules into ions, which once formed, are directed into a mass analyzer where they are separated according to their mass-to-charge ratios. The result is a spectrum that reveals elements and structural details that make up the molecules.

The other technique, called gas-chromatography mass spectrometry, involves heating powdered samples with a miniature oven and analyzing the released gases. All these capabilities are linked through a single, highly miniaturized linear ion trap analyzer.

LITMS, however, takes these capabilities to the next level. In addition to these capabilities, LITMS carries a precision core sample-handling system and can analyze both positive and negative ions, which broadens the range of molecules the instrument can identify.

"EMILI represents a redevelopment of LITMS for Europa. In some respects, EMILI is a more straightforward implementation than MOMA or LITMS at Mars," Brinckerhoff said, adding that Europa doesn't have a significant atmosphere, eliminating the need for certain types of hardware that add size and complexity to the instrument.

"What we have with the EMILI breadboard is far enough along in development that we are confident we can build a flight version," he said. ❖

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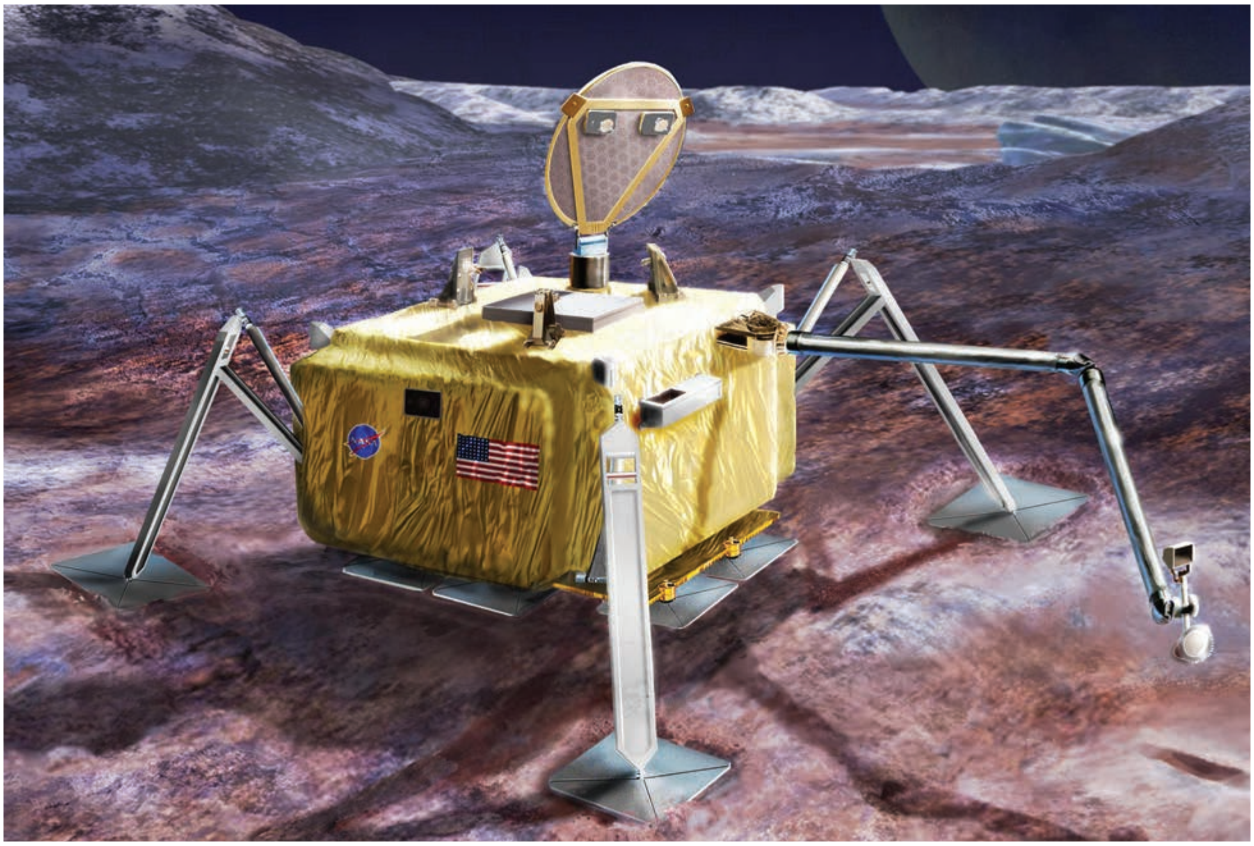

This illustration shows a conceptual design for a potential future mission to land a robotic probe on Jupiter's moon Europa.

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SPECIAL REPORT

Focus on New NASA Technology-Development Awards

Technologies that received seed funding from Goddard's Internal Research and Development program continue to demonstrate their value to NASA and the scientific community. So far this fiscal year, 14 research teams have won millions of dollars in follow-on technology-development funding to further advance their concepts. Here we highlight two of five recent awards from the NASA Heliophysics Technology and Instrument Development for Science program, also known as H-TIDeS.

Goddard Aims to Create First-Ever Space-Based Sodium Lidar

Instrument Leverages Sounding Technologies

A team of Goddard scientists and engineers now believes it can leverage recent advances in a greenhouse-detecting instrument to build the world's first space-based sodium lidar to study Earth's poorly understood mesosphere.

Scientist Diego Janches and laser experts Mike Krainak and Tony Yu recently received funding to further advance the sodium lidar, which the group plans to deploy on the International Space Station if it succeeds in proving its flightworthiness. The instrument's development is in part due to NASA's past investments in promising new lidar instruments that have proven in aircraft demonstrations to accurately detect carbon dioxide and methane in Earth's atmosphere.

From its berth on the orbiting outpost, the instrument would illuminate the complex relationship between the chemistry and dynamics of the mesosphere that lies 40-100 miles above Earth's surface — the region where Earth's atmosphere meets the vacuum of space.

Given the progress the researchers have made with the Earth-observing instruments, coupled with Goddard's legacy in laser technology, they are optimistic about the instrument's ultimate success.

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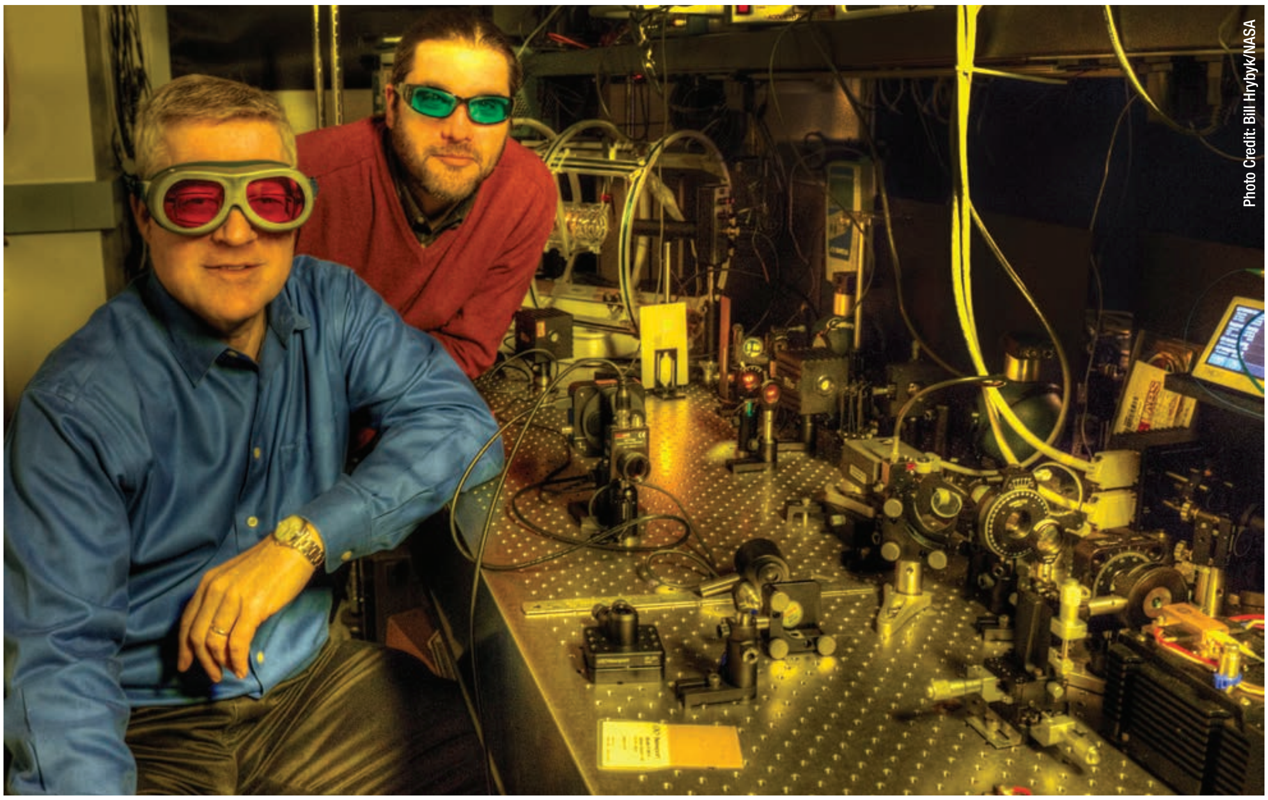

Mike Krainak (left) and Diego Janches recently won NASA follow-on funding to advance a spaceborne sodium lidar needed to probe Earth's poorly understood mesosphere.

The Big Leverage

"What we're doing is leveraging what we learned with the CO_2 and Methane Sounders," Krainak said. Both instruments have demonstrated in multiple aircraft campaigns that they accurately measure greenhouse gases by pulsing a laser light off Earth's surface (*CuttingEdge*, Summer 2016, Page 12). Like all atmospheric gases, carbon dioxide and methane absorb the light in narrow wavelength bands. By tuning the laser across those absorption lines, scientists can detect and then analyze the level of gases in that vertical path. The more gas along the light's path, the deeper the absorption lines.

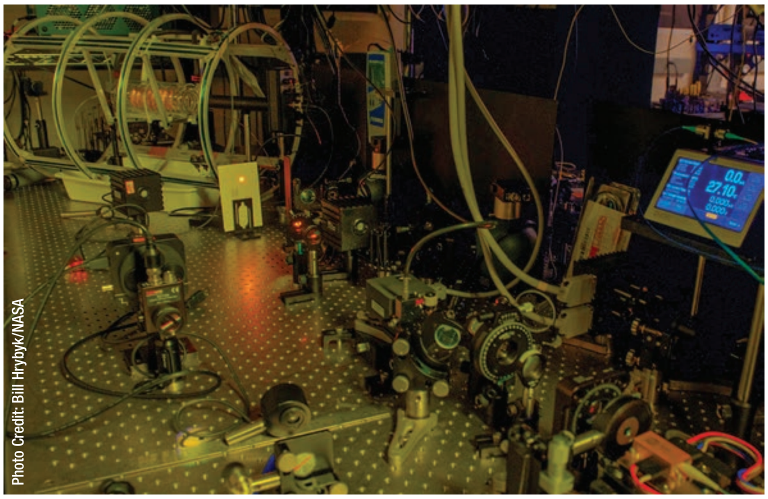
Photo Credit: Bill Hrybyk/NASA

With NASA technology-development funding, a Goddard team of scientists and engineers will advance a sodium lidar instrument for use in space. This image shows the laboratory breadboard.

"The same principle applies here," Janches said. "Instead of carbon dioxide and methane, we're detecting sodium because of what it can tell us about the small-scale dynamics occurring in the mesosphere."

Sodium — the sixth most abundant element in Earth's crust — is a useful tracer for characterizing the mesosphere. Though this atmospheric layer contains other granules of metals, including iron, magnesium, calcium, and potassium — all produced by the evaporation of extraterrestrial dust when it encounters Earth's atmosphere — sodium is easiest to detect. Literally, a layer of sodium exists in the mesosphere.

Because of its relative abundance, sodium provides higher-resolution data that can reveal more information about the small-scale dynamics occurring in the upper atmosphere. From this, scientists can learn more about how weather in the lower atmosphere influences the border between the atmosphere and space.

Work Begins

The group has begun developing its instrument, which is electronically tuned to the 589-nanometer range, considered yellow light. While on orbit, the lidar would rapidly pulse the light at the mesospheric layer, down nearly one-half to two miles over a swath measuring more than two to five miles in width.

The light's interaction with sodium particles would cause them to glow or resonate. By detecting the glow-back, the lidar's onboard spectrometer would analyze the light to determine how much sodium resided in the mesosphere, its temperature, and the speed at which the particles were moving. Although scientists have used sodium lidars in ground-based measurements for at least four decades, they have never gathered measurements from space. As a result, the data is limited in time and space and does not offer a global picture of the dynamics. With a specially designed spaceborne sodium lidar, however, scientists would be able to illuminate specific areas, revealing the small-scale dynamics that currently are the biggest unknown, Janches said.

Goddard R&D Heritage

The team originally received seed funding from Goddard's Internal Research and Development program to lay the foundation for a space-based instrument. It will use NASA's follow-on support to fine-tune the technology that locks the lidar onto the sodium lines. "It's like a guitar string," Krainak explained. "If you want a certain tone, you need to lock down the string at a particular length. It's the same thing with the laser cavity length."

The team also plans to demonstrate an environmentally tested engineering test unit of the laser, thereby improving its technology-readiness level to six.

"We've made significant progress on the laser," Krainak said, adding that the new funding will help reduce any risk associated with the concept, making it a strong contender for a future mission preferably aboard the space station. "If we win, we could be the first space-based sodium laser spectrometer for remote sensing." ❖

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SPECIAL REPORT

Focus on New NASA Technology-Development Awards

In the Pursuit of Blobs and Bubbles

Goddard Team Selected to Advance petitSat

Figuring out how plasma bubbles and blobs affect one another and ultimately the transmission of GPS, radar, and other communication signals in Earth's ionosphere will be the job of a recently selected CubeSat mission.

A team of Goddard scientists and engineers, led by Jeffrey Klenzing and Sarah Jones, recently won NASA funding to build the Plasma Enhancements in The Ionosphere-Thermosphere Satellite. The mission, also known as petitSat, is a precursor to a possible Explorer-class mission and leverages several R&D-supported technologies, including the satellite bus itself.

When it launches from the International Space Station in 2021, the mission will study density irregularities in the mid- and low-latitude ionosphere, which occupies a tiny fraction of the atmosphere and is basically an ionized layer coexisting with the thermosphere roughly 50 to 250 miles above Earth's surface.

The ionosphere is a plasma, an ionized gas consisting of positive ions and free electrons. It is important to long-distance radio communication because it reflects radio waves back to Earth. Consequently, any perturbations in the density of the plasma interfere with GPS and radar signals.

These perturbations or irregularities come in the form of ionospheric depletions or bubbles, structures that contain fewer electrons, and enhancements or blobs that contain a greater number of electrons. "All these irregularities can distort the transmission of radio waves," Klenzing said.

Blobs and Bubbles: A Different Story

Previous studies of the blobs indicate that they can be the direct result of bubbles forming near the geomagnetic equator, Klenzing said. Other observations, however, tell a different story.

They suggest that multiple mechanisms are at play, including fast-traveling waves coming from the thermosphere, a warm neutral atmospheric layer where most of the ionosphere resides. In fact, these wave-like thermospheric structures create waves in the ionosphere through ion-

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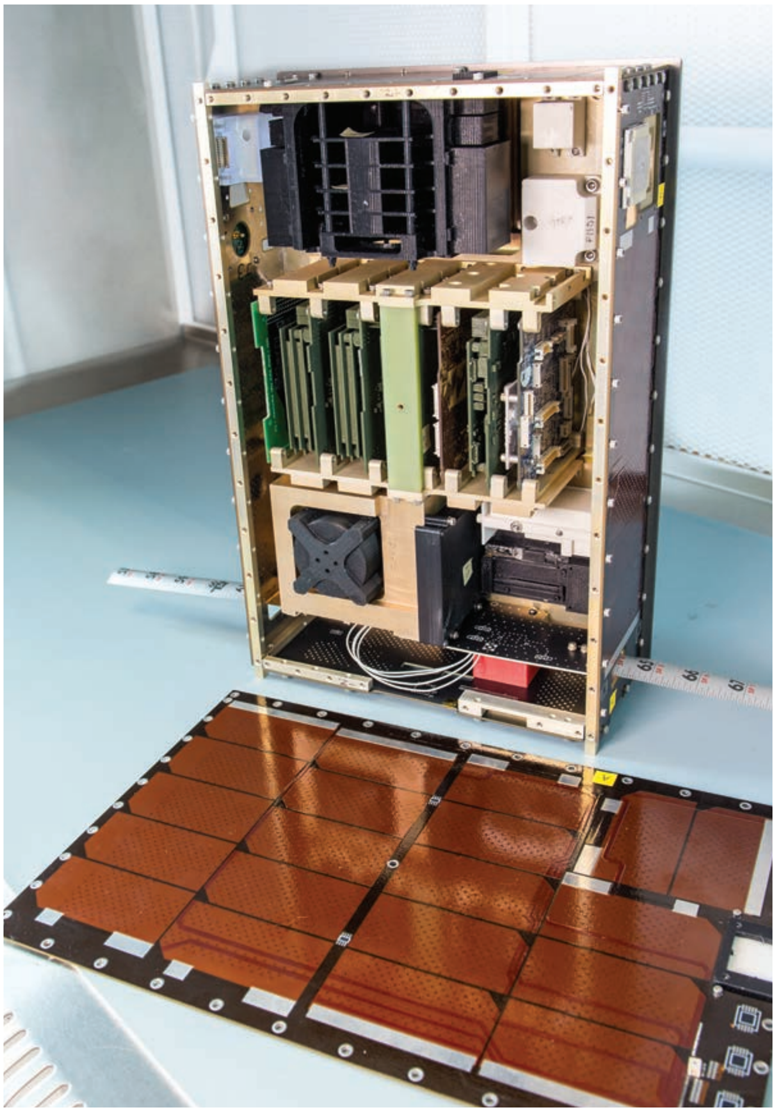

The Goddard-led petitSat team is basing its mission on a 6U CubeSat — Dellingr. Goddard engineers developed this small satellite to show that CubeSats could be both reliable and cost effective also while gathering compelling scientific data. The black-colored device at the top of the Dellingr 3-D model depicts the Ion-Neutral Mass Spectrometer that also is flying on petitSat.

neutral drag — a phenomenon called Medium-Scale Traveling Ionospheric Disturbances, or MSTIDs. The resulting MSTIDs create electric fields that can transport energy from the summer hemisphere to the winter hemisphere. It is thought that the observed plasma blobs are the consequence of these electric fields.

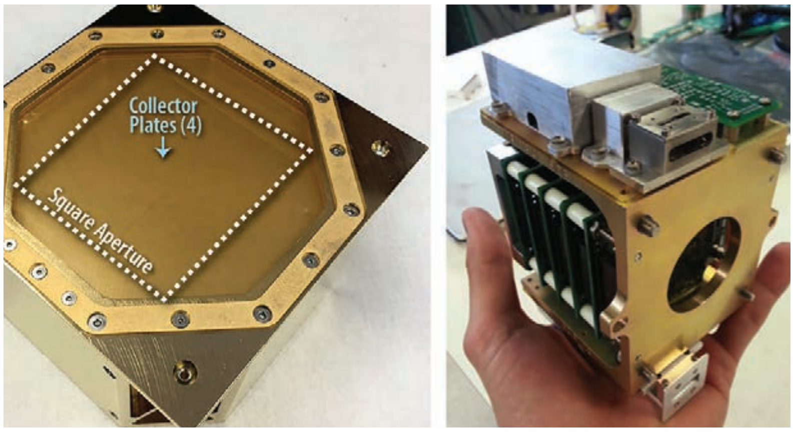

Photo Credit: NASA

petitSat is flying a version of the Goddard-developed Ion-Neutral Mass Spectrometer (right) and the university-provided Gridded Retarding Ion Drift Sensor.

"Our mission will investigate the link between these two phenomena — enhanced plasma density measurements, or blobs, and the wave action in the thermosphere," Klenzing said.

To find out, the team will fly two instruments: a version of the Goddard-developed Ion-Neutral Mass Spectrometer, or INMS — the world's smallest mass spectrometer that already has flown on a previous CubeSat mission (CuttingEdge, Fall 2015, Page 18) — and the Gridded Retarding Ion Drift Sensor, or GRIDS, provided by Utah State University and Virginia Tech.

The mass spectrometer will measure the densities of a variety of particles in the upper reaches of Earth's atmosphere, observing how these densities change in response to daily and seasonal cycles. The university-provided instrument, meanwhile, will measure the distribution, motion, and velocity of ions.

Dellingr-Based Mission

The team will integrate its instruments on a Dellingr-based spacecraft. A team of Goddard engineers specifically created this 6U CubeSat to demonstrate that that these tiny craft could be reliable and cost-effective also while delivering compelling science (CuttingEdge, Fall 2014, Page 4). Dellingr, which also carries the INMS, magnetometers, and other technologies, is expected to launch in August.

Unlike Dellingr whose solar panels are mounted on the side of the spacecraft, petitSat will fly deployable solar arrays — an enhancement that will allow mission operators to more easily point the arrays to the sun to recharge batteries. It also will carry a more advanced star tracker, said Jones, the INMS principal investigator.

When petitSat is deployed 249 miles above Earth — consistent with the International Space Station's orbit — the resulting data will be compared with that gathered by other ground- and space-based assets, Klenzing said. "Through comparative analysis, we will bring closure to our key science question: what is the link between plasma enhancements and MSTIDs. We've studied bits and pieces, but we've never had a full complement of instruments." ❖

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Grizzly Becomes a Growler and Selected for Restore-L Mission

A technology formerly referred to as grizzly has evolved into growler and, in the transition, it secured an important job helping NASA demonstrate a next-generation autonomous satellite-servicing capability.

Officials with NASA's Satellite Service Projects Division, or SSPD, has selected the Goddard Reconfigurable Laser Ranger, or GRLR (pronounced growler), to provide distance-ranging data during the Restore-L mission. Slated to fly in 2020, Restore-L will demonstrate how a specially equipped robotic servicer spacecraft can extend a satellite's lifespan — even one not originally designed for on-orbit servicing.

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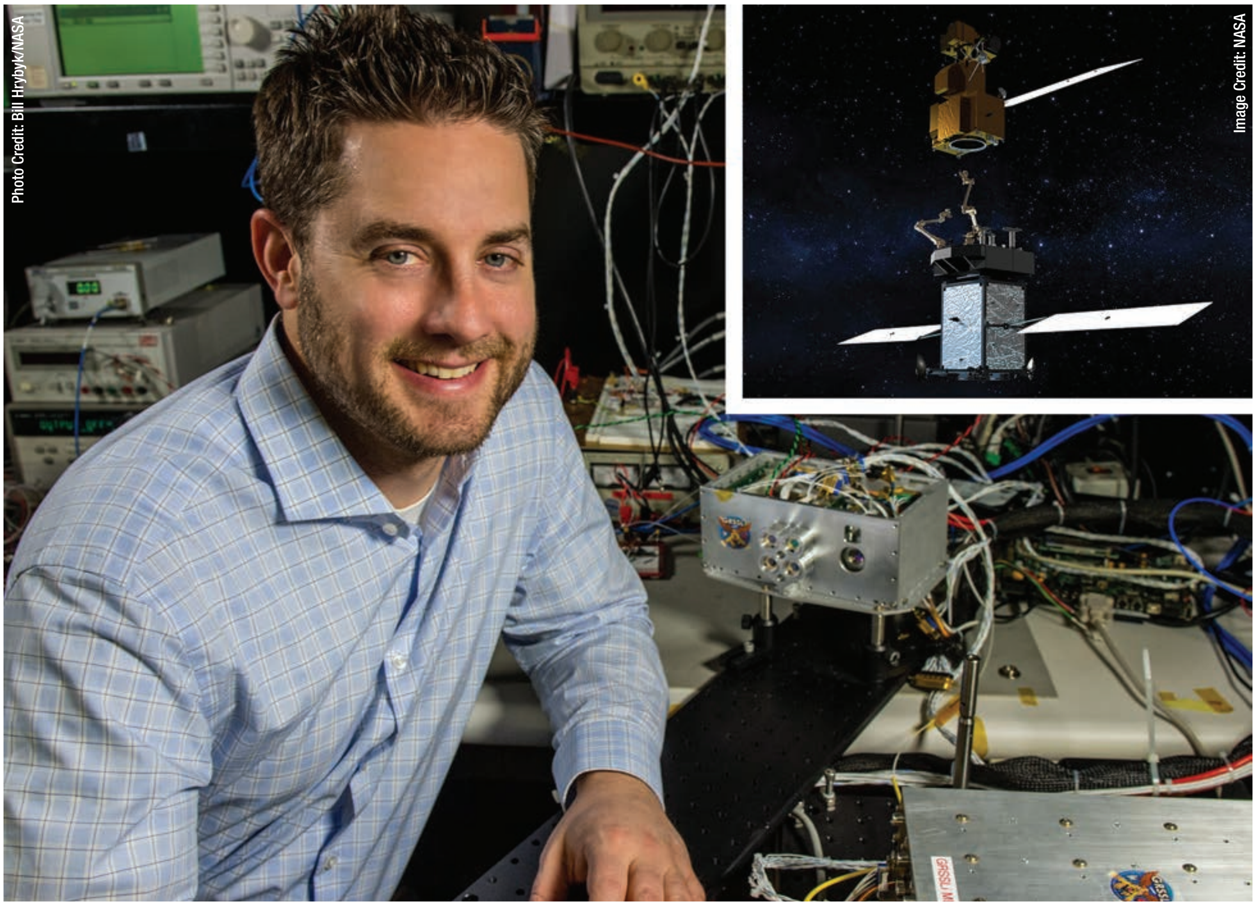

NASA's Satellite Service Projects Division has selected the Goddard Reconfigurable Laser Ranger, or GRLR (pronounced growler), to provide distance-ranging data during the Restore-L mission. GRLR uses about 90 percent of the components for a similar capability pictured here with GRLR's creator, Nat Gill.
INSET: This artist's rendition shows a Restore-L servicer spacecraft robotically repairing a satellite.

During the mission, the Restore-L robotic servicer will use its relative navigation technologies — of which GRLR is a part — its dexterous robotic arms, and software to autonomously locate, grasp, refuel, and relocate Landsat 7, an Earth-observing satellite that had not been designed for servicing.

"Big Win"

While the servicer and target satellite are traveling through space at thousands of miles per hour, GRLR will provide ranging measurements, guiding the servicer as it approaches the satellite from 1.5 miles down to five feet. "This was a big win for us," said Nat Gill, a SSPD engineer who developed the technology.

To carry out its job, GRLR will flash laser light at Landsat 7 every 25 microseconds. Its onboard telescopes and detectors will collect the returning light as it bounces off the satellite while another Goddard-developed technology — a hybrid computing platform called SpaceCube 2.0 — calculates the light's time of flight to determine distance.

GRLR uses about 90 percent of the components developed for a similar capability called the Goddard Reconfigurable Solid-State Scanning Lidar, or GRSSLi (pronounced grizzly), which still is in development (CuttingEdge, Fall 2014 Page 16). ❖

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