National Aeronautics and Space Administration

Cutting edge
Goddard's Emerging Technologies

A Year of Accolades... And Now Another

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in this issue:

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IRAD Innovator of the Year, Tom Flatley (Photo Credit: Pat Izzo/NASA)

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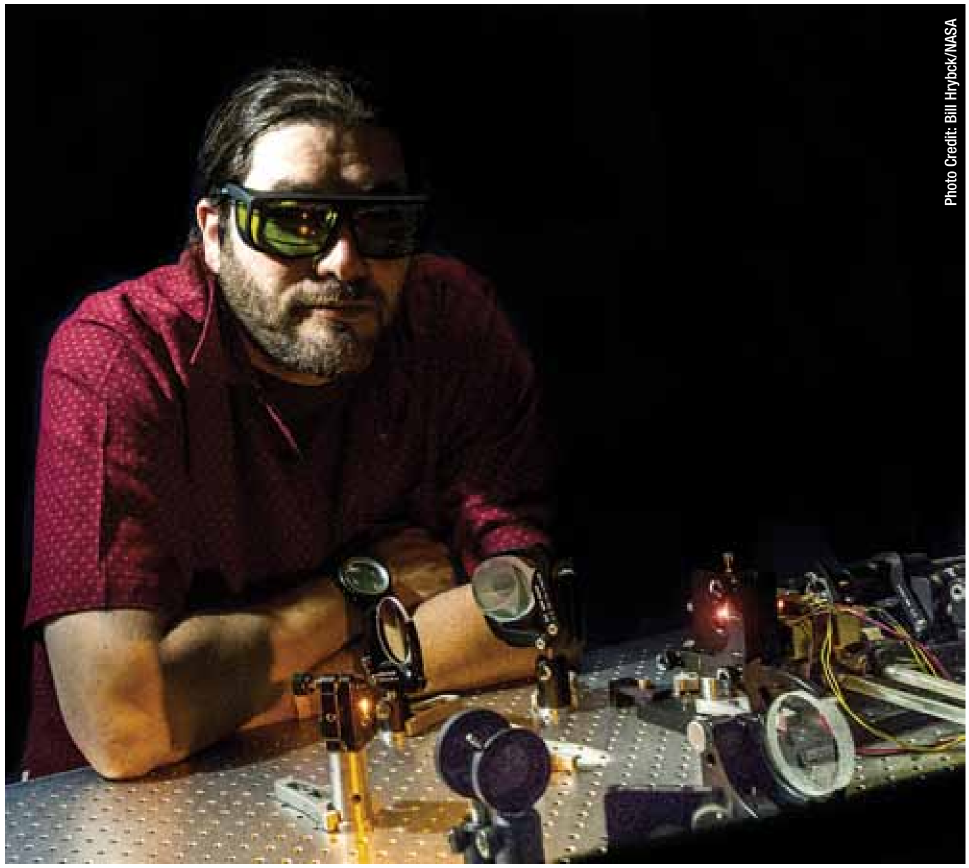
Goddard Advances World's First Spaceborne Sodium Lidar

Small-Scale Measurements of Earth's Mesosphere Sought

It's used as a coolant in nuclear power plants and as a desiccant to remove humidity that otherwise would ruin moisture-sensitive products. Found in every cell in the human body, it transmits nerve impulses and regulates blood pressure.



Principal Investigator Diego Janches (pictured) and his colleague, Tony Yu, are advancing the world's first spaceborne sodium lidar for mesospheric studies.

And as it turns out, sodium — the sixth most abundant element in Earth's crust — also is useful as a tracer for characterizing Earth's mesosphere, a poorly understood region of Earth's atmosphere that's sensitive to both the influences from the Sun above and the atmospheric layers below.

A team of Goddard scientists now wants to develop the world's first spaceborne sodium lidar that would illuminate the complex relationship between the chemistry and dynamics of the mesosphere that lies 40-110 miles above Earth's surface — the region where Earth's atmosphere meets the vacuum of space.

Though this relatively small region 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. This dust is part of the so-called Zodiacal Dust Cloud that originates from the debris produced by asteroids and comets.

"There is literally a layer of atomic sodium in the mesosphere," said Principal Investigator Diego Janches, who is leading the lidar-development team. "When you shoot yellow light into the region, the light bounces off the sodium particles, causing them to resonate, or glow. By detecting the glow-back, you can measure how much sodium is in the mesosphere, its temperature, and the speed at which it's moving."

And because of its relative abundance, sodium provides higher-resolution data that reveals more information about the small-scale dynamics occurring in the upper atmosphere. From this, scientists can learn more about the influence of the Sun's energy, helping to differentiate its effects from that of humans.

Although scientists have used sodium lidars in ground-based measurements for at least four decades, they never before have gathered data from

Continued on page 3

a spaceborne instrument. As a result, the data is limited in time and space and does not offer a global picture of the dynamics. "We want to do this from space," Janches added. "We want to map the entire mesosphere by the fluorescence of sodium."

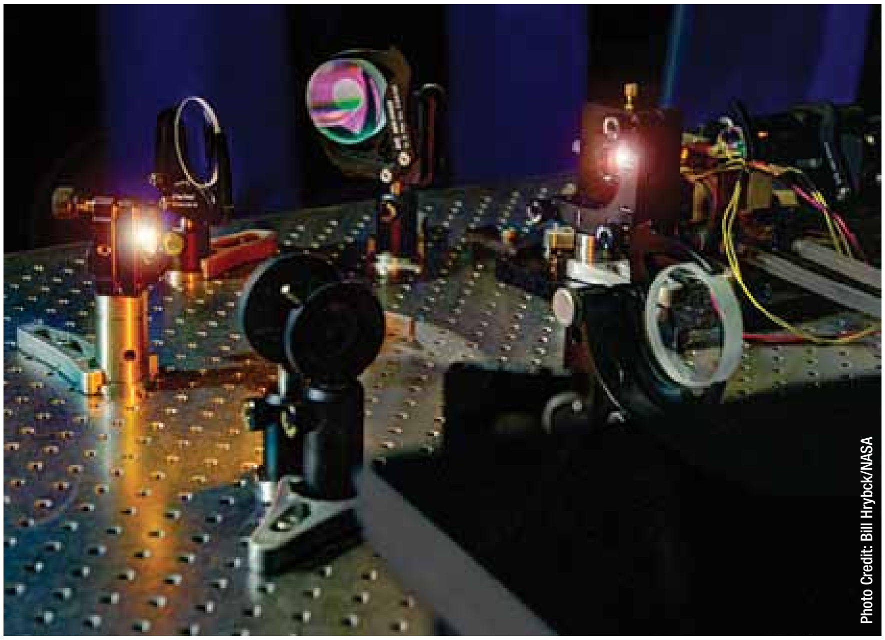


Photo Credit: Bill Hrybck/NASA

Goddard technologists are leveraging laser systems used in a number of NASA science missions to build an instrument capable of detecting sodium from space.

IRAD Seed Funding

To achieve that end, the team is using Goddard Internal Research and Development (IRAD) program funding to advance the lidar technology, with the aim of first demonstrating it on the International Space Station. Ultimately, the team, which also includes Co-Principal Investigator Sarah Jones and Goddard technologists Tony Yu, Mike Krainak, Branimir Blagojevich, and Eduard Luzhansky, would like to fly the instrument on a dedicated mission, possibly as a successor to NASA's Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) spacecraft.

Although TIMED — whose mission NASA has extended several times since its launch in 2001 — has given scientists their first long-term look at this poorly understood region of Earth's atmosphere, the team believes its instrument concept is the logical next step.

"Because of TIMED's high inclination, it takes 60 days for the satellite to cover all longitudes at all local times. As a result, data from the satellite's SABER instrument (Sounding of the Atmosphere using Broadband Emission Radiometry) assume that the dynamics are constant during that time," Janches said. "In addition, SABER is a scanning-type instrument. In other words, it looks at the horizon, gathering signals from all parts of the atmosphere."

In sharp contrast, the sodium lidar will illuminate a specific spot and gather data from that spot only. "Because of this, we get small-scale dynamics, which are the biggest unknowns," Janches explained. "And they are important. They are believed to be the major driver of circulation in the upper atmosphere."

To help advance the instrument, the team is seeking additional NASA technology-development funding, which would put the instrument in good stead should NASA decide to develop a follow-on mission, Janches said. In addition to studying the influences of the Sun on Earth, the instrument is ideal for studying other planetary atmospheres, he added.

Team Leverages Instrument Heritage

Krainak, a recognized expert in laser technologies, believes the concept is a safe bet for NASA, representing minimal risks for the agency.

"We have a lot of leverage from other missions we've done," he said, adding that his colleagues already have developed laser-related technologies for the Geoscience Laser Altimeter System on the NASA ICESat (Ice, Cloud, and land Elevation Satellite) mission and the Atmospheric Laboratory for Applications and Science, a space shuttle payload. The laser itself, developed in large part by Yu, is a modified version of the lasers flown on NASA missions to Mercury and Mars (see related story, page 4).

"All the laser components are the same," Janches said. "This work has put us 20 years ahead and saved us $30 million in development costs. We have a general idea of what's going on," he continued. "We just want to get a bigger picture." ❖

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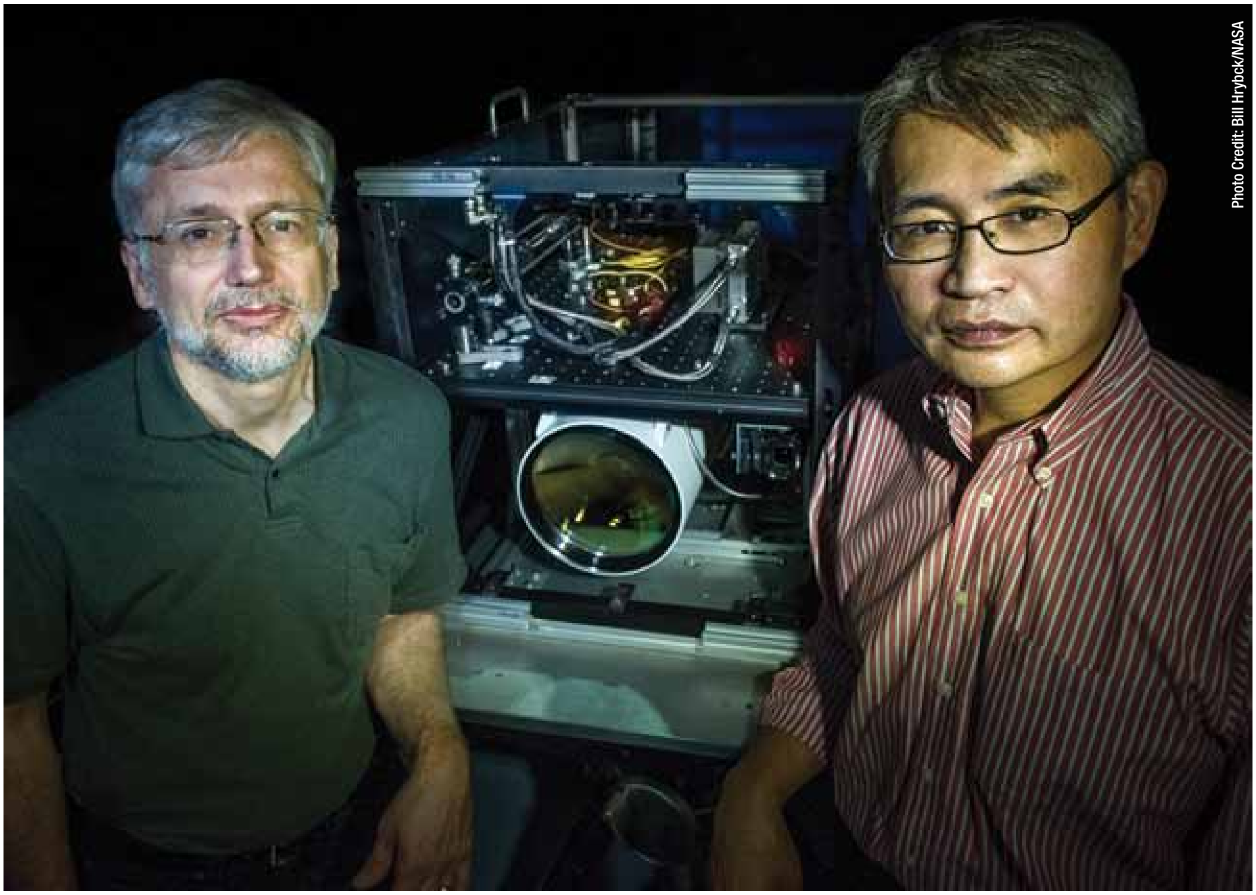
Who Says It Can't Be Done?

Technologists Embrace LIST Mission Challenge



Goddard scientist David Harding (left) and Goddard technologist Tony Yu are developing a lidar system that could meet the ambitious requirements of the proposed LIST mission.

In 2007, the National Research Council (NRC) threw down a challenge: Design a space-based laser altimeter that could measure the height of Earth's surface everywhere to within a mere 10 centimeters — all at 5-meter resolution. To this day, some believe it can't be done.

Goddard scientist Dave Harding begs to differ.

He and his team have embraced the challenge and are now using NASA and Goddard Internal Research and Development (IRAD) program funding to develop a laser altimeter that could provide the data from a berth onboard the NRC-proposed Lidar Surface Topography (LIST) mission. It would generate highly detailed maps of topography and vegetation needed to forecast and respond to natural hazards and study carbon storage in forests.

"There's no launch date for LIST. It's way out there sometime because most people say there's no way anybody can do this," Harding said. "But we want to show, yeah, you can. And we want to move it forward."

Lidar systems use powerful lasers from airplanes to scan swaths of the ground below, timing the return of photons to create a complete and detailed 3-D elevation map of the tree canopy and ground below.

From space, however, things get more complicated. Satellites travel much faster, so scanning a single laser beam would create big gaps between the zigzag pattern. Consequently, more beams are needed and that requires a lot more power — a limited resource on a spacecraft. And from about 250 miles up, it takes very powerful lasers to create a high-resolution elevation map.

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Harding and his colleagues, including Goddard technologist Tony Yu — a recognized expert in lidar technologies — are tackling the LIST lidar challenge from several angles, including power-efficient lasers, more sensitive photon-counting detectors, and a new lidar architecture.

Tackling the Challenge

First is the problem of the laser itself. To get the necessary 5-meter resolution along the planned 5-kilometer swath, Harding says an instrument would need 1,000 beams. In sharp contrast, the first ICESat (Ice, Cloud, and land Elevation Satellite) laser altimeter had one. ICESat-2, scheduled for a 2016 launch, has six.

"You've got to get much more efficient to get from one beam to 1,000 beams because the spacecraft has three limits — power, mass, and volume," Harding said. "We can't have big huge honking lasers, shooting out high-power beams."

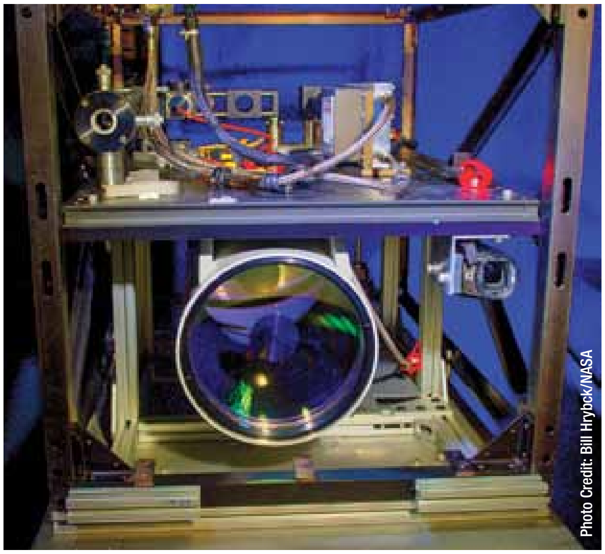
To get a more efficient, space-friendly laser, Yu has been working with the Raytheon Co. to combine several technologies, including a highly polished rare-earth-metals microchip laser and a thin, planar waveguide amplifier to increase power and efficiency. Yu also has scrapped more traditional high-voltage electro-optic switches to generate the laser pulses, opting instead for a passive switching technique that doesn't require any power. The new laser, Yu said, already has proven to be more than twice as efficient as more traditional models.

With these features and more, the team believes it will be able to generate a laser that is close to 50 watts — compared with the 9-watt ICESat-2 laser. The scientists' idea is to have an array of 10 of these 50-watt lasers, each split up into 100 beams, to get LIST to the 1,000 beams necessary for high-resolution coverage.

"I think we're on the path to getting there, to demonstrating one stage of the 10 we'd have to build for LIST," Yu said.

But having the right number of lasers firing the right number of photons isn't enough. The LIST instrument also will have to detect those photons when they bounce back to the satellite. Harding and Yu's vision for LIST is to have an array of detectors that could count the number of individual photons that return to the satellite at the same time, providing a more complete picture that maps the shrubs, low branches, and forest canopies.

The detectors also would be sensitive to the



This airborne LIST simulator, which was developed with NASA funding, is a 16-beam, non-scanning swath mapping altimeter. It forms the basis of the proposed LEaVEs instrument.

polarization of the returning photons. Laser pulses are polarized when they leave the lidar, Harding said, but when they bounce off trees or the ground, some of the photons change polarization. When they bounce off water, however, they all reflect with the same polarization. Having a photon-counting detector that could record polarization would help researchers characterize the land cover, elevation, and identify the location of surface water.

An Eye Toward Space

With funding from NASA's Earth Science Technology Office (ESTO) and Goddard's IRAD program, the team has developed two airborne instruments that demonstrated the polarization measurement and the more efficient measurement approach.

ESTO now is providing funds to fly one of these highly sensitive multi-photon detector arrays in space on a small Cubesat. In addition, the team is applying for funding to build an instrument called the Lidar Earth Venture Ecosystem Explorer, or LEaVEs, which would fully demonstrate the technologies that are key for LIST. The team wants to fly this instrument, which would be equipped with 25 laser beams and other advanced technologies, on the International Space Station.

"Our airborne instruments are smart, but we want to get way smarter with an instrument on the space station for LIST," Harding said. ❖

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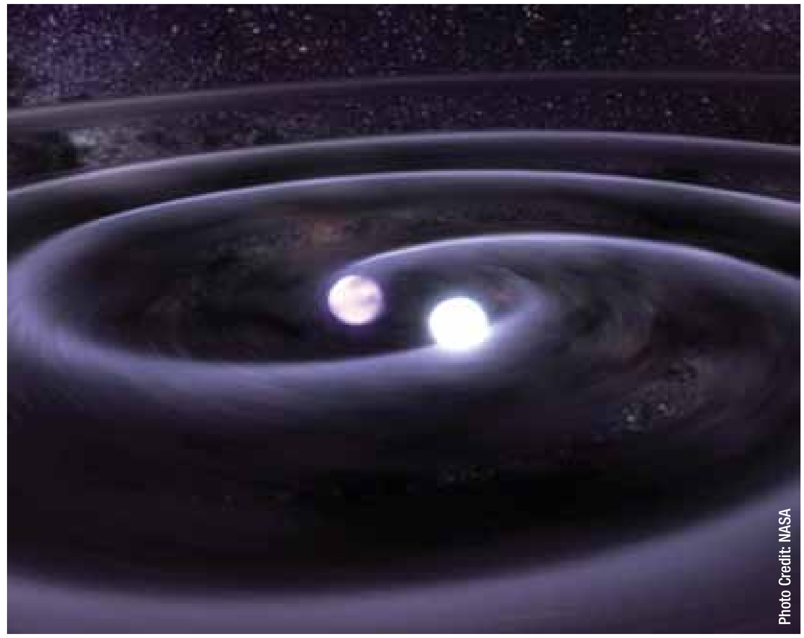
Technologists Pursue New Application for Emerging Atom-Optics Technology

Goddard technologists who recently received NASA funding to advance a pioneering technology that promises to detect tiny perturbations in the curvature of space-time now want to apply the same technique to map variations in Earth's gravity field.

The NASA Innovative Advanced Concepts (NIAC) program, which funds high-risk, potentially revolutionary technologies, recently awarded Goddard technologist Babak Saif and his team Phase-2 funding to continue developing an atom interferometer. With its potential picometer-level sensitivity, the instrument may one day detect what so far has remained imperceptible: gravitational waves or ripples in space-time caused when massive celestial objects move and disrupt the space around them (*CuttingEdge*, Summer 2013, Page 2).



Cataclysmic events, such as this artist's rendition of a binary-star merger, are believed to create gravitational waves that cause ripples in space-time.

However, detecting these infinitesimally small ripples — predicted by famed physicist Albert Einstein, but never directly observed — isn't the only application for the technology, said Bernie Seery, a Goddard executive who was instrumental in establishing Goddard's strategic alliance with Stanford University and the California-based AOSense, Inc. Both organizations have received more than $50 million in Defense Advanced Research Projects Agency (DARPA) funding to build and ruggedize atom optics-based sensors for a number of terrestrial applications.

Seery says the technology also is ideal for geodesy, the science of measuring and monitoring Earth's size, shape, and gravitational field.

More Powerful Interferometer

At its core, atom interferometry works much like optical interferometry, a 200-year-old technique widely used in science and industry to measure small displacements in objects. It obtains measurements by comparing light that has been split into two equal halves. Because the path that one beam travels is fixed in length and the other travels an extra distance or in some other slightly different way, the two light beams overlap and interfere when they meet up, creating an interference pattern that scientists inspect to obtain highly precise measurements.

Atom interferometry, however, hinges on quantum mechanics, the theory that describes how matter behaves at sub-microscopic scales. Just as waves of light can act like particles called photons, atoms can be cajoled into acting like waves if cooled to near absolute zero. At those frigid temperatures, which scientists achieve by firing a laser at the atom, its velocity slows to nearly zero. By firing another series of laser pulses at laser-cooled atoms, scientists put them into what they call a "superposition of states."

In other words, the atoms have different momenta permitting them to separate spatially and be manipulated to fly along different trajectories. Eventually, they cross paths and recombine at the detector, just as with a traditional interferometer. The power of atom interferometry is its precision. If the path an atom takes varies by even a picometer, an atom interferometer would be able to detect the difference.

With this level of precision, the technology not

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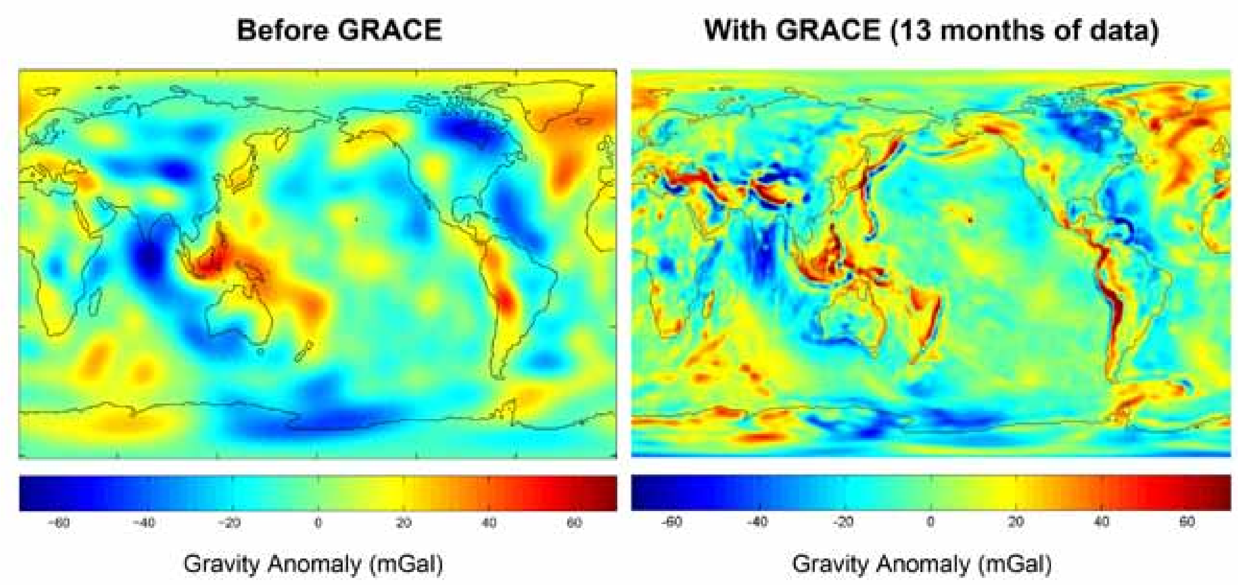

Scientists' knowledge of Earth's gravity field formerly was based on data from geodetic satellites (left image). NASA's GRACE mission has generated measurements that are more than 100 times more accurate, permitting scientists to characterize how Earth's gravity field varies over time and space, as illustrated by the map on the right. They now believe an emerging atom optics-based technology will provide even more accurate data.

only could map Earth's gravitational field, which appears lumpy due to the uneven distribution of mass, but also chart how it changes over time, Seery said.

"The gravitational field changes because of lots of reasons, including the influences of the Sun and Moon, but the most significant is due to the change in water mass, which includes Earth's ice sheets, oceans, ground water, lakes, and rivers," said Scott Luthcke, a Goddard Planetary Geodynamics Laboratory scientist, who is working on the application. "If a glacier or ice sheet melts, this will affect mass distribution, and therefore, Earth's gravitational field."

By gathering both spatial and temporal measurements, scientists have another tool for studying Earth's response to climate change, he added. "In essence, you capture the Earth's mass changing in fine detail and over time."

Using Goddard Internal Research and Development (IRAD) program funding, the team is adapting an atom optics-based gravity gradiometer that AOSense has developed primarily for terrestrial purposes under DARPA funding.

The instrument, which the military currently is demonstrating in field trials under harsh environmental conditions, is up to three orders-of-magnitude more sensitive than comparable technology. Once modified for use in a microgravity environment, it could potentially succeed NASA's Gravity Recovery and Climate Experiment (GRACE), a two-satellite mission that has generated since its launch in 2002 monthly gravity maps showing how mass is distributed and how it changes over time, Seery said.

"This unique sensor is capable of significantly improved spatial resolution and greater accuracy detecting surface-mass changes, eliminating the need for a two-satellite system, as with GRACE. Consequently, we could choose to save money by deploying only one satellite or we could opt for even greater accuracy by deploying a second in a complimentary orbit," Luthcke added. "This technology is a significant step forward and would provide an extraordinary data set for understanding Earth's water cycle and its response to climate change."

So convinced of the instrument's potential for a future GRACE-type mission, the team also is seeking additional NASA funding to enhance the instrument's design and possibly fly the AOSense gradiometer as a payload on the International Space Station, Seery added. "This is a powerful technology," he said. "Given the investments already made by DARPA, NASA's NIAC program, and our own IRAD program, it's only a matter of time until we fly this technology in space." ❖

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Cover Story: A Year of Accolades

Tom Flatley Chosen Goddard 'IRAD Innovator of the Year'

Goddard engineer Tom Flatley, who has spent the past several years enhancing the Goddard-developed SpaceCube flight processor and finding new applications for the more powerful technology, has received his share of accolades this year, and now he has another to add to his curriculum vitae.

The Office of the Chief Technologist has announced that it has chosen Flatley as its 2013 "IRAD Innovator of the Year," a prize it awards annually to those who exemplify the best in innovation and contribute substantially to NASA's mission and goals.

"His accomplishments, as evidenced by his vigorous pursuit of new SpaceCube products and applications, made him a stand-out within Goddard's technology community this year. He richly deserves not only our recognition but also that of the American Astronautical Society, which bestowed its 2012 William Randolph Lovelace II Award on him earlier this year," said Goddard Chief Technologist Peter Hughes.

This year's winner of Goddard's "IRAD Innovator of the Year" award, Tom Flatley (inset), has played a pivotal role advancing the SpaceCube family of products. Shown here is the SpaceCube-Mini, along with two other devices that show the relative sizes of tiny satellites or Cubesats on which SpaceCube is slated to fly in the future.

SpaceCube Offers Alternative

Ten to 100 times faster than the current radiation-hardened flight processor — the RAD750 — SpaceCube offers science missions a much-needed alternative, particularly those requiring more robust computing power to handle significantly higher data rates from a smaller, more energy-efficient platform, Hughes said.

SpaceCube achieves its data-crunching prowess because Flatley and his team have married commercial radiation-tolerant Xilinx Virtex field programmable gate array technology to Goddard-developed algorithms that detect and correct radiation-induced upsets. As a result, SpaceCube is nearly as reliable on orbit as the fully radiation-hardened RAD750, while providing "order-of-magnitude" improvements in onboard computing power.

First demonstrated in 2009 on Hubble Servicing Mission-4, the first-generation processor — SpaceCube 1.0 — has since evolved into a family of products that can meet nearly any spaceflight need (*Goddard Tech Trends*, Spring 2010, Page 7). All members of the product line-up — SpaceCube 1.0, 1.5, 2.0, and the SpaceCube-Mini — were developed with support from IRAD, the Satellite Servicing Capabilities Office, and Defense Department funding. And all have flown or have been selected to fly on a variety of spaceflight missions, including the most recent Defense Department's Space Test Program-H4 mission deployed on the International Space Station.

"Not only has Tom innovated new products under the SpaceCube brand, he continuously looks for new applications, benefitting NASA, the U.S. military, and private research institutions. If anyone can find an application for this technology, it's Tom. We congratulate him for his success," Hughes said. ❖

SPECIAL REPORT

Smaller is definitely getting better. In this issue of CuttingEdge, we've published a number of stories that directly or indirectly address Goddard's efforts to reduce the size, volume, and cost of spaceflight technologies through miniaturization. Long a priority of Goddard's technology community, miniaturization now is increasingly becoming more important to NASA. Just recently, the agency awarded funding to 13 teams — four of them from Goddard — to advance smallsat technologies. The aim: Providing scientists with less costly access to space.

Pint-Size Spacecraft No Longer the Domain of University Researchers

NASA Funds NASA-University Teams to Advance Smallsat Technologies

Building and flying tiny spacecraft — some weighing no more than a few kilograms — has long been the domain of the university research community. No longer.

Thirteen NASA-university teams — four of them hailing from Goddard — have received funding under the agency's Smallsat Technology Partnerships program to develop and demonstrate new technologies for small spacecraft. Managed by the Space Technology Mission Directorate, NASA specifically created the program to spur innovation and transform small spacecraft into powerful, but affordable tools for science, exploration, and space operations.

Under this two-year program, university teams partner with engineers and scientists from NASA centers to spur innovation in communication, navigation, propulsion, science instruments, and advanced manufacturing.

"In some respects, NASA is behind the game in smallsat technology," said Carl Adams, a Goddard assistant chief for technology who played a pivotal role helping match university technologists with their Goddard counterparts. "We have the largest percentage of scientists, and they want to fly their instruments. But they need the technology to fly their experiments on these small satellites. By building relationships with our university partners, which has been a priority of Goddard's technology community, we improve our in-house smallsat capabilities and university researchers and students get hands-

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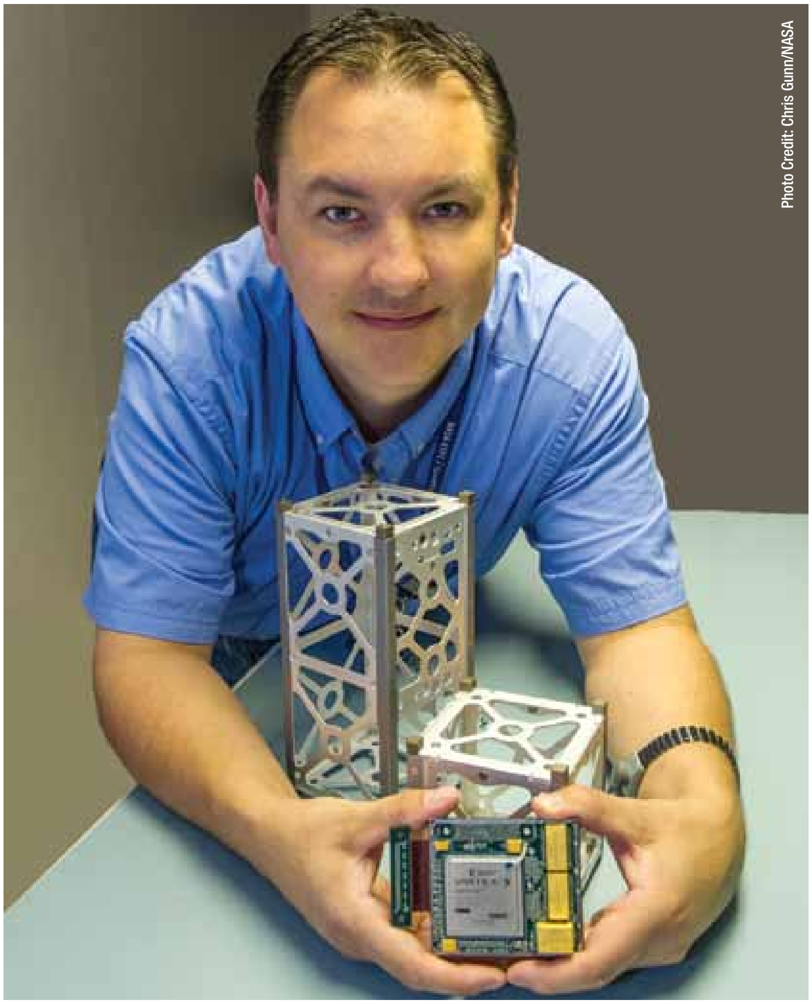

Photo Credit: Chris Gunn/NASA

Engineer Gary Crum holds the SpaceCube-Mini, the smallest in a family of Goddard-developed onboard processors. The other devices show the relative sizes of a two-unit and one-unit Cubesat structure. Crum and Tom Flatley are working with a university team to further advance the SpaceCube technology for use on Cubesats.

on experience. It really is a win-win situation for all of us."

Of the program's five specific technology areas of interest, the Goddard teams will address three.

Communications

For years, university-developed smallsats have used the UHF-frequency band for ground-to-spacecraft communications. However, the channel is slower and cannot accommodate the high-data rates that NASA scientists typically enjoy with S-band communications.

Not for long, however.

Teaming with Scott Palo of the University of Colorado, Goddard engineers Gary Crum and Tom Flatley will apply field programmable gate array (FPGA) circuitry used in SpaceCube — a reconfigurable, hybrid-computing platform that is 10 to 100 times faster than current radiation-hardened flight processors — to create a "software-defined radio."


Photo Credit: Bill Hrybyk/NASA

Shahid "Ish" Aslam holds his "spectrometer-on-a-chip," which, if fully developed, could carry out the same science as the Goddard-built Composite Infrared Spectrometer shown in the background. He and his partners are advancing the technology under a new NASA R&D program.

FPGAs are integrated circuits that can be programmed to carry out a specific job, making them ideal for a range of spaceflight uses. In this application, the technology will allow users to change how the radio performs just by programming the circuitry, allowing them to communicate in either S- or X-band at an even higher data rate.

"The software-defined radio capability will offer up to 100 times the data rates of UHF," said Flatley, the winner of this year's "IRAD Innovator of the Year" award (see related story, page 8) because of his pioneering work advancing SpaceCube. "Scientists will be able to do real science onboard."

Flatley and Crum also are working with another university team, led by Montana State University researcher Brock LaMeres, to apply a next-generation commercial radiation-tolerant FPGA — the Xilinx Virtex-7 — on SpaceCube. By marrying the circuitry to Goddard-developed algorithms that detect and correct radiation-induced upsets, SpaceCube is nearly as reliable on orbit as the fully radiation-hardened RAD750, while providing an order-of-magnitude improvement in onboard computing power.

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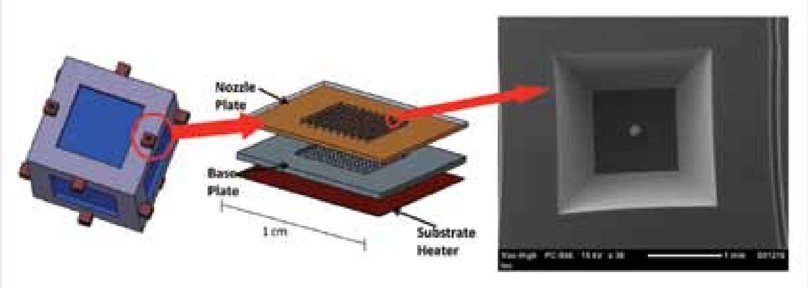
"FPGAs are key," Crum explained. "They are so versatile and can do so many things, which enable us to help shrink the size and power needs of the spacecraft."

Instruments

Retired Goddard scientist John Allen, now a research professor at Appalachian State University in North Carolina and Goddard emeritus, has teamed with scientist Shahid "Ish" Aslam to advance the potentially revolutionary "Miniaturized Waveguide Fourier Transform Spectrometer." Funded initially by Goddard's Internal Research and Development program, the technology would be sensitive to the mid-infrared bands and could be used to study the spectra of planets and stars and identify their chemical makeup and other physical properties (*CuttingEdge*, Summer 2012, Page 4).

Film Evaporation Mems Tunable Array for PicoSat Propulsion and Thermal Control



These images show the layout of the dual-use thermal-control unit that technologist Eric Cardiff is developing for smallsats. Not only would the technology cool instruments, it also would propel the tiny satellites that carry the device.

> *"We have the largest percentage of scientists, and they want to fly their instruments. But they need the technology to fly their experiments on these small satellites. By building relationships with our university partners, which has been a priority of Goddard's technology community, we improve our in-house smallsat capabilities and university researchers and students get hands-on experience."*
>
> *— Carl Adams, Goddard Assistant Chief for Technology*

But unlike the microwave oven-size components found in more traditional spectrometers, the components inside this particular instrument literally would fit onto a silicon wafer. The goal is to reduce the number of moving parts and dramatically slash the instrument's mass and power consumption, Allen said. Appalachian State students will use the institution's state-of-the-art laboratory equipment to characterize the samples Goddard already has produced, he added.

Propulsion

Goddard technologist Eric Cardiff has joined forces with Purdue University researcher Alina Alexeenko to advance and demonstrate a dual-use technology that not only would cool instruments, but also propel the tiny satellites that carry the device.

"Thermal control is critical, but there's not enough room or surface area for radiative cooling because these small satellites are packaged so tightly," said Cardiff, who also is developing other propulsion-related technologies under separate smallsat technology-development programs sponsored by NASA's Space Technology Mission Directorate.

His idea is to have a reservoir of ionic liquid sitting next to hot devices. The rejected heat, which would exit in the form of vapor through small orifices, then could be used to propel smallsats. The warm gas also could be accelerated electrostatically in a throttleable fashion to provide even greater thrust. Cardiff said such a capability could enable orbital maneuvering, formation flying, proximity operations, and rendezvous, docking, and precision operations.

Adams said Goddard has made a priority of reaching out to the university-research community — an investment that he believes paid off under this call for proposals. "Goddard had 40 percent of these wins, which really was a good showing," Adams said. "Our guys really capitalized on these calls." ❖

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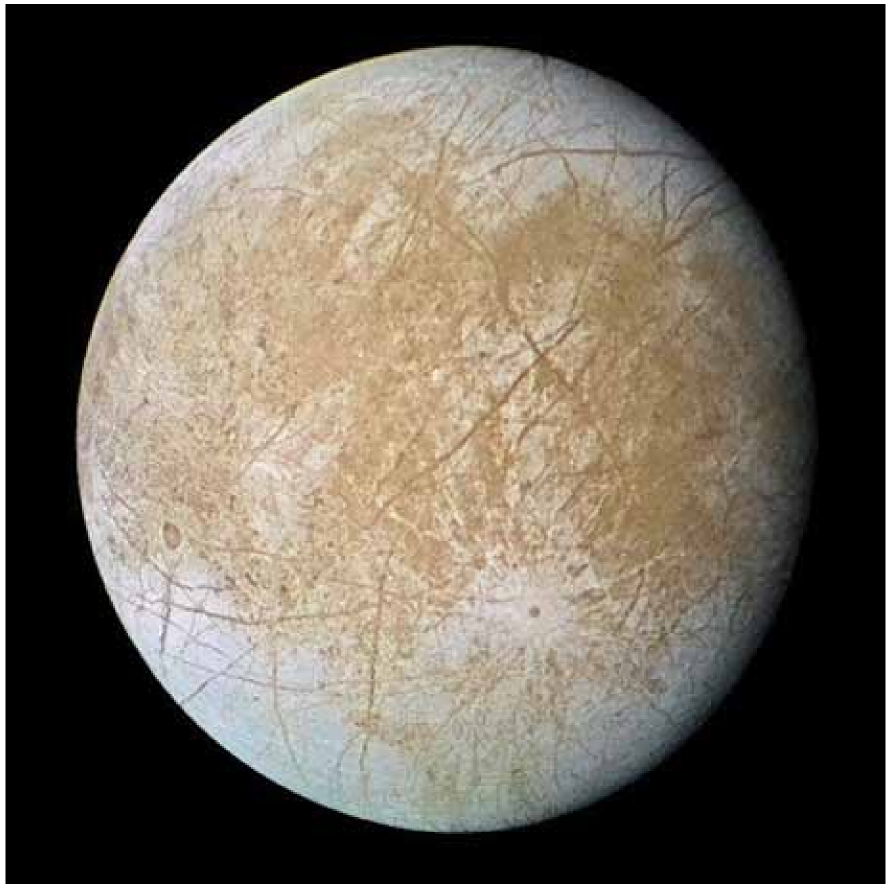
Never Say Never to Potential Mission to Europa



This Galileo image, taken when the spacecraft was about 450,000 miles from Europa, shows the reddish-brown material that covers Jupiter's icy moon.

NASA hasn't given up on a potential mission to Jupiter's ice-covered moon Europa and neither have two Goddard instrument-development teams.

The two groups recently received one-year funding under NASA's Instrument Concepts for Europa Exploration (ICEE) program to further advance both a laser altimeter used for topographical measurements and a thermal sensor or radiometer for calculating surface temperature, salinity, ice, and precipitation, among other meteorological and oceanographic applications.

These instruments potentially could fly on the Europa Clipper, a conceptual fly-by mission to determine whether the icy moon could harbor conditions suitable for life. Although scientists strongly suspect the presence of a water ocean, due to the eccentricity of the moon's orbit, NASA has yet to launch a mission dedicated to solving this mystery. Over the years, NASA has proposed several missions, but subsequently cancelled them due to budget constraints, coupled with their estimated $4-billion-plus cost estimates.

Keeping Mission on Track

The Clipper is aimed at realizing NASA's long-sought goal. Though the $2-billion Clipper remains unfunded, Congress approved resources to help reduce the risks of a handful of instrument technologies to keep the mission on track should the nation commit to full-scale development sometime in the future.

"This is the most recent attempt to fly a mission to Europa," said Dave Smith, a principal investigator from the Massachusetts Institute of Technology (MIT). Formerly a Goddard scientist, Smith teamed with Maria Zuber and Erwan Mazarico, also from MIT, and Goddard's instrument team, led by technologist Xiaoli Sun. Together the team won $600,000 in ICEE funding to mature the altimeter over the next 12 months. The team specifically is designing its instrument to measure Europa's shape and surface topography and calculate the thickness of the ice shell and the depth of the ocean. "There are no guarantees that this mission will fly, but this is the closest we've come," Smith added.

Because of the intense radiation around Europa, previously proposed missions baselined heavy shielding to protect instruments and components. The latest mission incarnation, however, attempts to significantly slash costs by dispatching a spacecraft that flies by Europa, thereby reducing exposure to the radiation.

The Clipper spacecraft then would carry out its studies by flying by the moon up to 40 times over the course of two years. On its closest passes, the Clipper would come within 15 miles of Europa's

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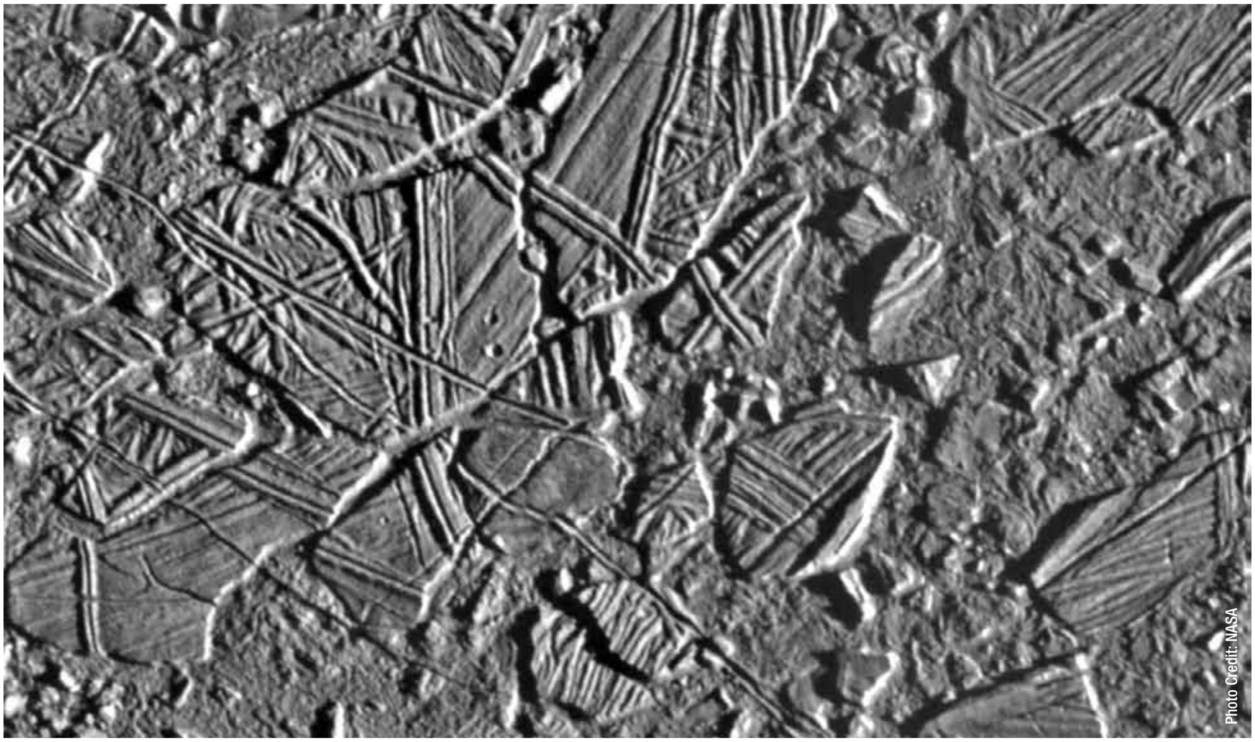

This high-resolution Galileo image shows Europa's ice-rich crustal plates, which are about 8 miles in diameter. They have broken apart, much like the ice pack that breaks apart in Earth's polar seas during spring thaws.

frozen surface, which could help scientists solve some of the moon's most intriguing enigmas, such as the thickness of its ice shell and the saltiness and approximate depth of its water ocean. This information, along with the spacecraft's imagery of the moon's surface, could help scientists decide where to deploy a lander sometime in the future.

IRAD Heritage

Both Goddard teams also have long wanted to build and fly Europa-bound instruments, the teams' principal investigators said. To help retire technological risks early, both applied for and received funding from the center's Internal Research and Development (IRAD) program. "This support was critical," said Shahid "Ish" Aslam, principal investigator of the Thermal Imager for Europa Reconnaissance (TIMER).

TIMER is a radiometer that will detect fissures in Europa's ice crust and possibly see "slushy" water and other oceanic material emanating from these cracks. "We wanted to make sure that when a Europa mission opportunity arises, we are ready to go," he added, attributing his team's selection to the initial IRAD seed funding.

Although a flyby will endure smaller doses of radiation, radiation still poses a threat. Consequently, Aslam's team will use the $1.2 million in ICEE support to further improve TIMER's detector focal-plane assembly, especially the integrated circuitry readout. The goal is assuring TIMER's ability to withstand the radiation, which is estimated to be 20 to 30 times harsher than that on other solar-system bodies.

The altimeter team shares the same goal. Although Goddard has a long and storied reputation in the field of laser altimetry, and, in fact, is basing its Europa altimeter on the Goddard-developed Mercury Laser Altimeter that last year provided evidence of water at Mercury's poles, the team needs to enhance its radiation-mitigation techniques. It also wants to further reduce the size of its receiver to make it easier to shield, Sun said.

"We believe our instrument will make a significant contribution to the mission," Sun added. "The IRAD program has played a critical role in our instrument's development and in mitigating the risks. Although these IRADs were targeted for a different Europa mission that has been canceled, the technologies we developed were critical for us to win this ICEE proposal. We're grateful for the support." ❖

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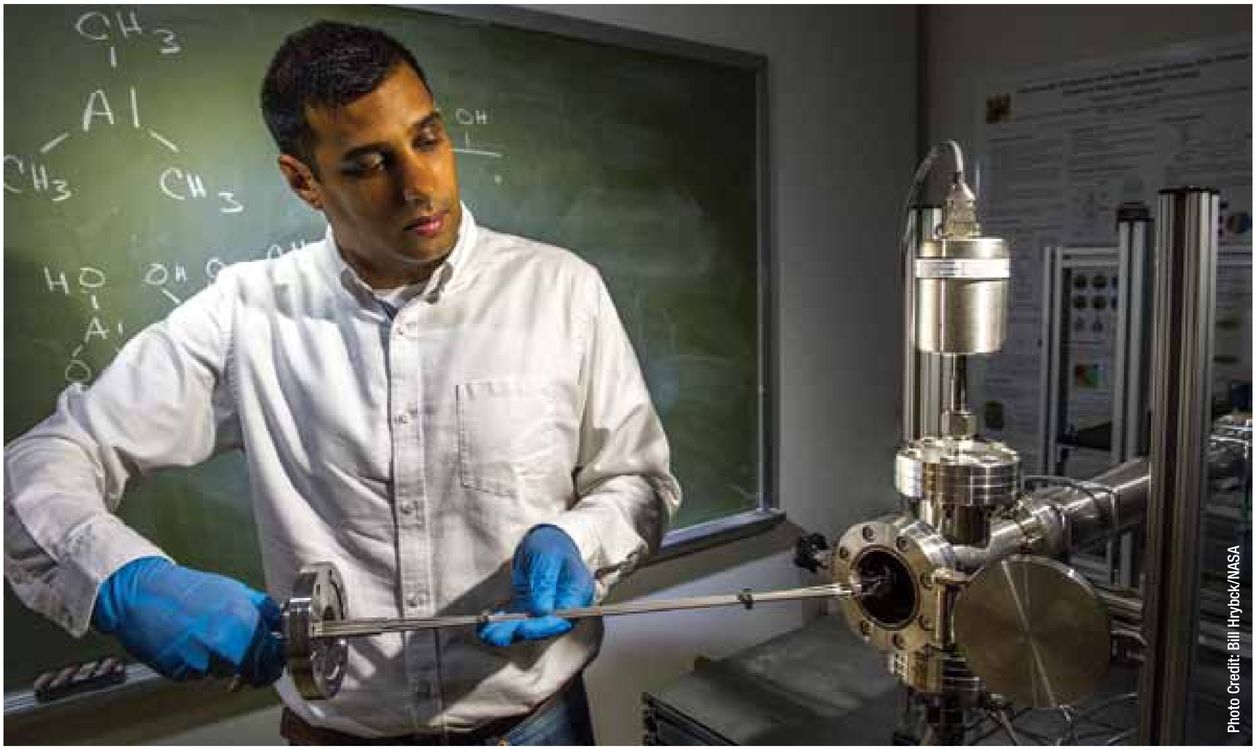
Virtual Toothpick Helps Technologist 'Bake' the Perfect Thin-Film Confection



Technologist Vivek Dwivedi, who has distinguished himself as the go-to engineer for atomic layer deposition, has assembled a new reactor that he plans to use for thin-film experimentation. He is inserting the Quartz Crystal Microbalance, one of the technologies included in his "virtual toothpick."

Creating thin films using a rapidly evolving technology that promises to solve some of NASA's thorniest engineering challenges is a lot like baking a cake. That's why Goddard technologist Vivek Dwivedi has assembled a special "oven" and a "virtual toothpick" to monitor the progress of his confections.

The technology, called atomic layer deposition (ALD), is one of many techniques for applying thin films, which among other applications can improve computer memory, protect materials against corrosion, oxidation, and wear, and perform as batteries when deposited directly onto chips. It involves placing a substrate material inside a reactor chamber, which can be likened to an oven, and sequentially pulsing different types of precursor gases to create an ultra-thin film whose layers are literally no thicker than a single atom.

Although other thin-film deposition techniques exist, ALD offers an advantage over competing approaches. It can deposit films inside pores and cavities, giving ALD the unique ability to coat in and around three-dimensional objects.

In a recent application, for example, Goddard technologists employed the services of a multi-million-dollar reactor operated by an Australian nanofabrication center to lay a highly uniform catalyst layer of iron oxide on a number of intricately shaped instrument components. The objective was seeing whether they then could grow carbon nanotubes — a super-black material that promises to make spacecraft instruments more sensitive without enlarging their size — on the ALD-coated samples. The team succeeded, proving ALD's effectiveness in this application (*CuttingEdge*, Summer 2013, Page 4).

Given ALD's vast potential for helping to downsize instrument size, increase efficiency, and deposit thin films on complicated, three-dimensional objects, Goddard technologists now are developing in-house tools to more cost effectively experiment

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The 'Mission of Firsts' Uses Low-Cost TDRSS Transceiver

The Minotaur V, which carried NASA's latest mission to the Moon, is seen streaking across the sky from Annapolis, Md.

As the Minotaur V lifted off from its gantry at the Wallops Flight Facility, ferrying NASA's latest mission to study the Moon's thin atmosphere and demonstrate for the first time a laser-communications (lasercom) system, an unheralded technology worked behind the scenes.

Built with industrial-grade components, the Wallops-developed Low-Cost TDRSS Transceiver — also known as LCT2 — relayed mission-critical S-band telemetry data to the ground through the agency's Tracking and Data Relay Satellite System (TDRSS), eliminating the need for more traditional ground stations downrange.

The technology, one of several that Wallops has developed since launching an effort to decrease costs associated with tracking and command infrastructure, performed flawlessly as the Minotaur and its cargo, the Lunar Atmosphere and Dust Environment Explorer (LADEE), streaked across the sky in a "rollercoaster-type" trajectory over the Atlantic Ocean — a flight path witnessed by millions living along the Eastern seaboard from North Carolina to Connecticut.

"We had a good clean link during critical events," said Steve Bundick, a Wallops engineer who has led the technology's development.

Wallops has used this transceiver — configured for transmit-only applications on previous sounding-rocket and Minotaur missions — but never with so many people watching. "This isn't the first time for LCT2, but certainly it was the most high profile," Bundick said.

Indeed, LADEE has captured the attention of many. Considered a "mission of firsts," LADEE is the first moonshot from Wallops. It also is NASA's first to demonstrate laser communications from lunar distances. So far, it hasn't disappointed.

Shortly after the launch, the lasercom experiment, NASA's Lunar Laser Communication Demonstration, made history using a pulsed laser beam to transmit data over the 239,000 miles between the Moon and Earth at a record-breaking download rate of 622 megabits per second. The demonstration paves the way for a full-scale operational system, the Laser Communications Relay Demonstration, now under development at Goddard (*CuttingEdge*, Summer 2012, Page 12).

In addition to demonstrating optical communications, LADEE is gathering data about the Moon's exosphere — an atmosphere that is so thin and tenuous that molecules don't collide, a condition found on Mercury and some of Jupiter's larger moons. The mission also is tracking how moon dust moves across the lunar surface, which is of key interest because the abrasive material clings to everything with which it comes into contact.

Taking Stock of LCT2

Now that the LADEE spacecraft is performing as planned, Wallops technologists take stock of what they've accomplished so far with the new transceiver.

Bundick and his team originally designed LCT2 to support space network S-band communications, targeting suborbital platforms. "The goal was to

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Toothpick, *continued from page 14*

with the technique and investigate its usefulness in a variety of space applications.

'Like Baking a Cake'

With NASA and Goddard R&D funding from, Dwivedi has built an inexpensive, relatively simple reactor chamber that measures three inches in diameter and two feet in length as well as a suite of monitoring tools that he collectively calls his virtual toothpick. "In my mind, it's a simple process," said Dwivedi, Goddard's resident expert in ALD. "But we have to make sure everything is being done under the right conditions. It's like baking a cake."

As with baking, creating thin films using ALD requires the perfect recipe, executed under exacting conditions. In addition to choosing the gas, selected because of its properties and the job the resulting film is supposed to perform, technologists must determine how long to flow the gas inside the chamber and at what temperature and pressure level.

"What we do is place the substrate or sample inside the reactor and follow the recipe. We also cross our fingers and hope the recipe is successful. It can be a time-consuming process," Dwivedi said. When depositing iridium to coat an X-ray mirror, for example, Dwivedi said he had to wait 24 hours to see if he had succeeded.

That's why he decided to augment his reactor with the virtual toothpick, a suite of tools he uses to monitor the process in real time and test to see if his confection is done.

The Tool Set

The tool set includes a modeling program to determine how much gas to deposit on the substrate or component, a quartz crystal microbalance to actually measure the thickness of the film being deposited, and a residual gas analyzer that detects the gases that flow through the reactor, both reacted and unreacted. "These tools save time," Dwivedi said, adding he can determine in real time how well the deposition is progressing.

They also save money, he added. One gram of an iron precursor gas used to create a film can cost as much as $1,000. "We have a responsibility to use money in a cost-effective manner. So we certainly don't want to waste material in trial and error," Dwivedi said.

"What we've done is develop a less-expensive platform and tools with which to experiment," he added. "This reactor gives us an advanced processing tool, which will allow us to investigate new material systems at a fraction of the cost." ❖

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come up with a unit that you could use with the space network, but didn't require space-rated parts due to the mission's short duration, such as sounding rockets, expendable launch vehicles, and even scientific balloons," he said. "Most commercial hardware available was geared to long-term space applications and was too expensive for lower-cost suborbital missions."

With funding from Goddard's Internal Research and Development program, the team took the same base unit and incorporated an S- to Ku-band frequency converter module to accommodate higher data rates. The team also modified and demonstrated in 2010 a similar unit to communicate from a sounding rocket in the X-band, another band allowing for higher data rates (*Goddard Tech Trends, Fall 2010*, Page 4).

"We're continuing to look at areas where we can expand on it. It has turned into a nice flight platform to demonstrate new modulation and coding techniques," Bundick said. ❖

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Cutting edge Goddard's Emerging Technologies

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