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Cutting edge
Goddard's Emerging Technologies

Innovator of the Year: William Zhang
Goddard's Own Mirror-Making Whiz

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Office of the Chief Technologist Announces FY19 IRAD Innovator of the Year: Astrophysicist William Zhang

Goddard's Office of the Chief Technologist has named astrophysicist William Zhang as IRAD (Internal Research and Development) Innovator of the Year, an honor the office bestows annually on individuals who demonstrate the best in innovation.

Chosen because of his foresight, perseverance, and leadership, Zhang spent nearly two decades advancing the state-of-the-art in X-ray optics. He and his team ultimately succeeded in their years-long endeavor, creating a new type of optic, made of mono-crystalline silicon, an abundantly available material commonly used to manufacture computer chips.

The mirror offers a large collection area, high angular resolution, and is lightweight. Just as important, the new mirror is inexpensive and efficient to manufacture. To date, no other X-ray mirror incorporates all of these performance goals and implementation advantages.

As a result, NASA has baselined the mirror type for the Design Reference Mission of the conceptual Lynx X-ray Observatory — one of four potential large missions now being considered by the 2020 Decadal Survey for Astronomy and Astrophysics.

"Will saw a need and pursued his mirror-making concepts with tenacity," said Goddard Chief Technologist Peter Hughes. "Silicon has never been used to make super-thin, lightweight, easily reproducible X-ray mirrors. His innovation could represent a paradigm shift in X-ray astronomy for decades to come. Certainly, he and his team have reinvented the way NASA builds these highly specialized mirrors. He is the poster child for how to advance innovative new technologies."

On page 3, *CuttingEdge* profiles the man who at times doubted whether his idea would work, but persevered, nonetheless. ❖

in this issue:

Fall 2019

About the Cover

Astrophysicist William Zhang was named the FY19 IRAD Innovator of the Year for his foresight, perseverance, and leadership advancing the state-of-the-art in X-ray optics. He spent nearly 20 years developing a new type of X-ray mirror, now baselined for the conceptual Lynx X-ray Observatory.

Photo Credit: Chris Gunn/NASA

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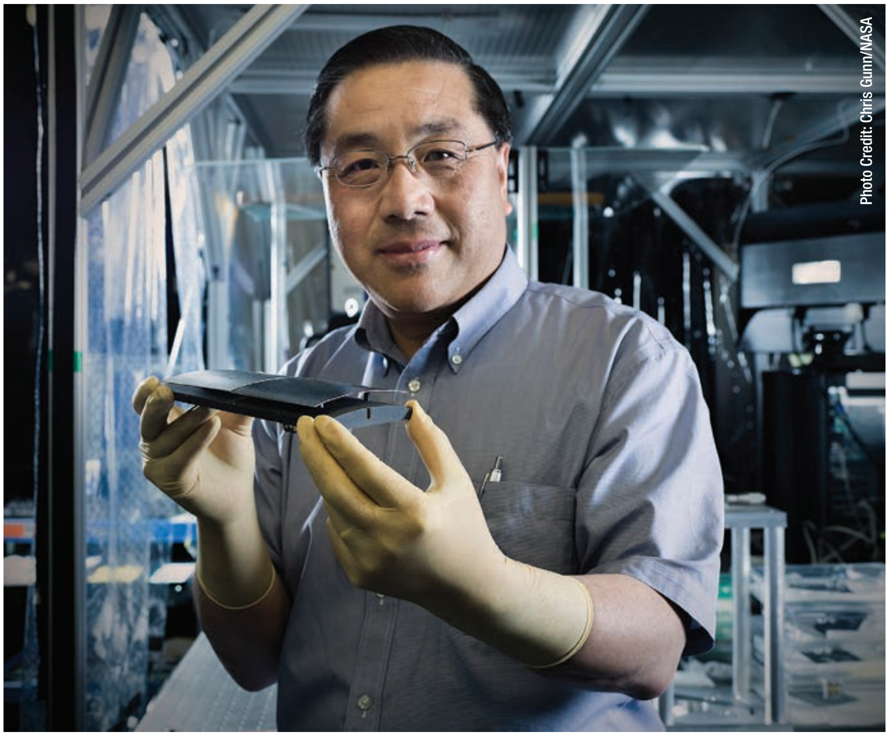
Meet the Innovator

Former Subterranean Researcher Turned Mirror-Making Whiz

Goddard scientist and this year's IRAD Innovator of the Year William Zhang wasn't always a mirror-making whiz. In fact, he started his career working underground — literally.



FY19 IRAD Innovator of the Year William Zhang holds one of the X-ray mirror segments that he and his team manufactured from mono-crystalline silicon — a material never before configured for capturing high-energy X-ray photons.

Zhang, who won the Office of the Chief Technologist's top prize this year for his pioneering work advancing state-of-the-art X-ray optics, actually trained as a particle physicist and detector scientist. As a graduate student at the University of Pennsylvania, he spent his daylight hours searching for neutrinos at the Kamioka Observatory located in the Mozumi mine two miles beneath a mountain peak in western Japan — a site chosen so that cosmic rays wouldn't interfere with the measurements.

Although the experiment did not succeed in detecting proton decay, which was its original purpose, it successfully detected neutrinos from supernova 1987A and the Sun using state-of-the-art electronics and data-acquisition systems that Zhang helped build.

The experience served another useful purpose.

"I'd go down there before sunrise and wouldn't come back up until nightfall," Zhang recalled. After three years as a subterranean worker, "I discovered I would prefer having an office with windows. I had enough of mining."

NASA Wins

It's a good thing for NASA.

After a stint with Los Alamos National Laboratory in New Mexico, Zhang came to the center specifically to build and calibrate the Proportional Counter Array aboard the Rossi X-ray Timing Explorer that launched in late 1995. With scientific papers published in technical journals, Zhang began casting about for a new challenge and got one when his former boss suggested he apply his talents to Constellation-X, a conceptual X-ray mission at the time.

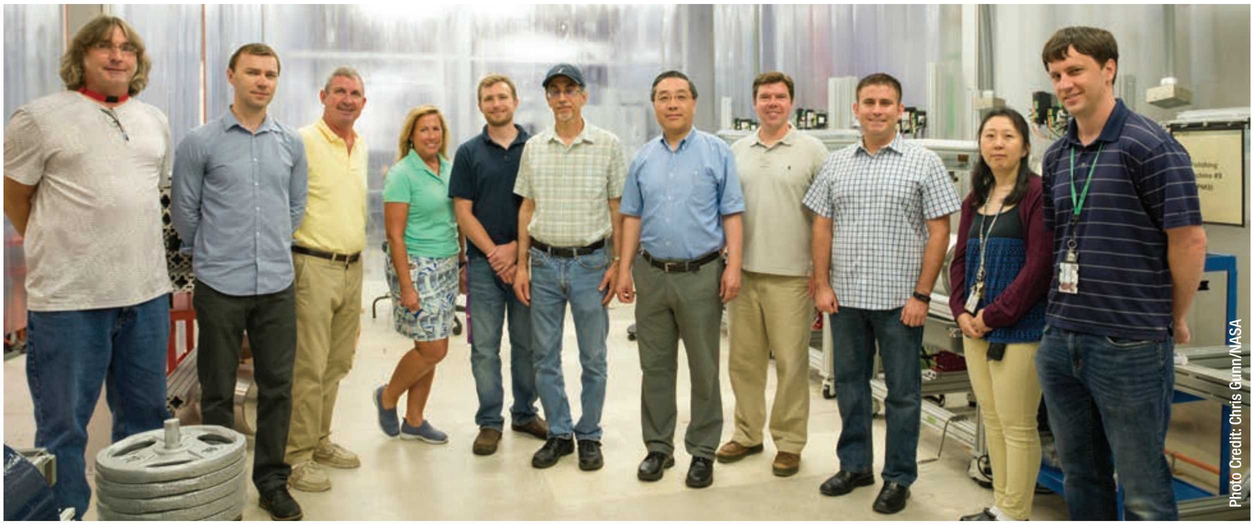
"Optics turned out to be the most important technology for X-ray astronomy," Zhang said, adding that these highly specialized mirror segments are curved and aligned inside a canister-type assembly to collect highly energetic X-ray photons emanating from hot objects, such as pulsars, supernova remnants, and the accretion disk of black holes.

Because the mirrors are curved, X-ray photons graze their surfaces — much like skipping stones — and deflect into an observatory's instruments rather than passing through them. "They had a default technique for making these optics and I thought it wasn't working very well."

The key, he reasoned, was making these optics much thinner, lighter, and less expensive to manufacture. If the individual mirror segments were thick and heavy, like those employed by NASA's Chandra X-ray Observatory, fewer mirrors could fly,

Continued on page 4

Volume 16 • Issue 1 • Fall 2019



IRAD Innovator of the Year William Zhang and his team succeeded in developing a new type of X-ray mirror. Team members include (from left to right): Michael Norman, Michal Hlinka, John Kearney, Kim Allgood-Puckett, Michael Biskach, James Mazzarella, William Zhang, Ryan McClelland, Raul Riveros, Ai Numata, and Peter Solly. Not pictured: Kai-Wing Chan and Timo Saha.

Photo Credit: Chris Gunn/NASA

limiting the observatory's collecting area and therefore its ability to discern details of an astronomical target.

Before Zhang set out to tackle the challenge, optics developers traditionally used glass, ceramics, and metals. However, these materials suffer from high internal stress, especially when cut or exposed to changing temperatures. These stresses become increasingly unpredictable as the mirror becomes thinner.

With support from Goddard's Internal Research and Development (IRAD) program, he and his team first experimented with glass slumping, a novel technique where he placed commercially available, super-thin glass segments on a mandrel, or mold, and heated the entire assembly in an oven (*Goddard Tech Trends*, Spring 2008, Page 2). As the glass heated, it softened and folded over the mold to produce a cylindrically shaped optic that was then coated with layers of silicon and tungsten to maximize their X-ray reflectance.

Though Zhang proved the technique and produced 10,000 modest-resolution mirrors ideal for NASA's Nuclear Spectroscopic Telescope Array mission, Zhang realized he had taken this technique to the limit. He concluded that they were inadequate for achieving the desired performance of future X-ray telescopes.

Turns to Silicon

He turned to single-crystal silicon, a material never polished and figured for lightweight X-ray optics. The material itself intrigued him. Inexpensive and abundantly available because the semiconductor industry uses it to manufacture computer chips, crystalline silicon has little, if any, internal stresses, making it ideal for creating super-thin X-ray optics.

Leveraging his experience with glass slumping, Zhang started with blocks of silicon. With standard machining tools, he and his team produced the approximate mirror shape and then used precision machining tools and chemicals to further grind and refine the blocks' surfaces. Like slicing cheese, he then cut thin substrates measuring less than a millimeter in thickness and polished their surfaces. Any surface defects larger than several nanometers were removed with a special ion-beam polishing tool.

Zhang prevailed.

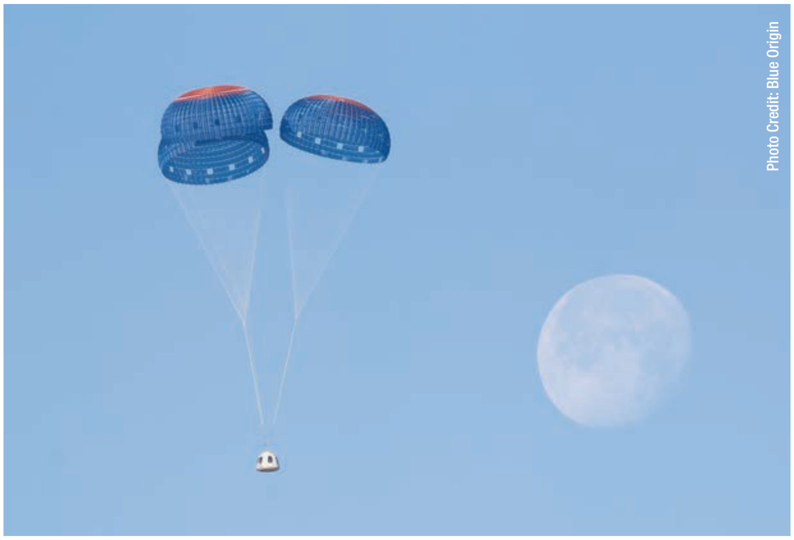
As part of a mission-concept study evaluating the proposed Lynx X-ray Observatory, a NASA-commissioned panel of 40 experts found that Zhang's optics could provide sub-arcsecond resolution, which is the same quality as the larger, much heavier mirrors flying on Chandra. Furthermore, because the mirrors are 50 times lighter and less costly to build than Chandra's, next-generation observatories can carry literally tens of thousands of mirror segments, improving sensitivity over even Chandra, the world's most powerful X-ray observatory.

Baselined on Lynx

Due to these findings, Zhang's optics are baselined for the conceptual Lynx X-ray Observatory. Furthermore, the European Space Agency's Athena X-ray Observatory Study Science Team recently

Continued on page 9

Microgap-Cooling Technology Immune to Gravity Effects and Ready for Spaceflight



The reusable Blue Origin New Shepard crew capsule makes its descent. It carried the microgap-cooling technology.

A groundbreaking technology that would allow NASA to effectively cool tightly packed instrument electronics and other spaceflight gear is unaffected by weightlessness and could be used on a future spaceflight mission.

During two recent flights aboard Blue Origin's New Shepard reusable launch vehicle, Principal Investigator Franklin Robinson and University of Maryland professor Avram Bar-Cohen proved that their microgap-cooling technology not only removed large amounts of heat, but also carried out this job in low- and high-gravity environments with nearly identical results.

The demonstration, funded by NASA's Space Technology Mission Directorate, opens the doors for the technology's use on a future spaceflight mission, Robinson said.

"Gravity effects are a big risk in this type of cooling technology," Robinson said. "Our flights proved that our technology works under all conditions. We think this system represents a new thermal-management paradigm."

With microgap cooling, heat generated by tightly packed electronics is removed by flowing a coolant — in this case, a fluid called HFE 7100 that doesn't conduct electricity — through embedded, rectangular-shaped microchannels within or between heat-generating devices. As the coolant flows through these tiny gaps, it boils on the heated surfaces, producing vapor. This two-phase process offers a higher rate of heat transfer, which keeps high-power devices cool and less likely to fail due to overheating.

The embedded cooling approach represents a significant departure from more traditional cooling technologies where designers create a "floor plan" that positions the heat-generating circuits far from one another. The heat travels into the printed circuit board, where it is directed eventually to a spacecraft-mounted radiator.

Robinson and Bar-Cohen began developing the microgap technology about four years ago to cool next-generation 3-D circuitry. Unlike more traditional circuits, 3-D circuits are created by literally stacking one chip atop another. Interconnects link each level to its adjacent neighbors. With shorter wiring linking the chips, data can move quickly both horizontally and vertically, improving bandwidth, computational speed, and performance, all while consuming less power and occupying less space (CuttingEdge, Fall 2015, Page 17).

Despite its advantages, 3-D circuitry presents a particular challenge: the smaller the space between the circuits, the harder it is to remove the heat. Because not all of the chips are in contact with a circuit board, traditional cooling techniques wouldn't work with 3-D circuitry. The emerging technology avoids this problem by running coolant within and between the stacked circuits.

In addition to 3-D circuitry, microgap cooling could help other electronic devices, including power electronics and laser heads. They, too, are shrinking in size and need an effective system for removing heat. "We see an application for microgap cooling in any power-dense electronic device," Robinson said. "I think we're now at the right technology-readiness level to implement embedded cooling on flight projects."

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Volume 16 • Issue 1 • Fall 2019

A Space First

NASA to Demonstrate New Star-Watching Technology with Thousands of Tiny Shutters

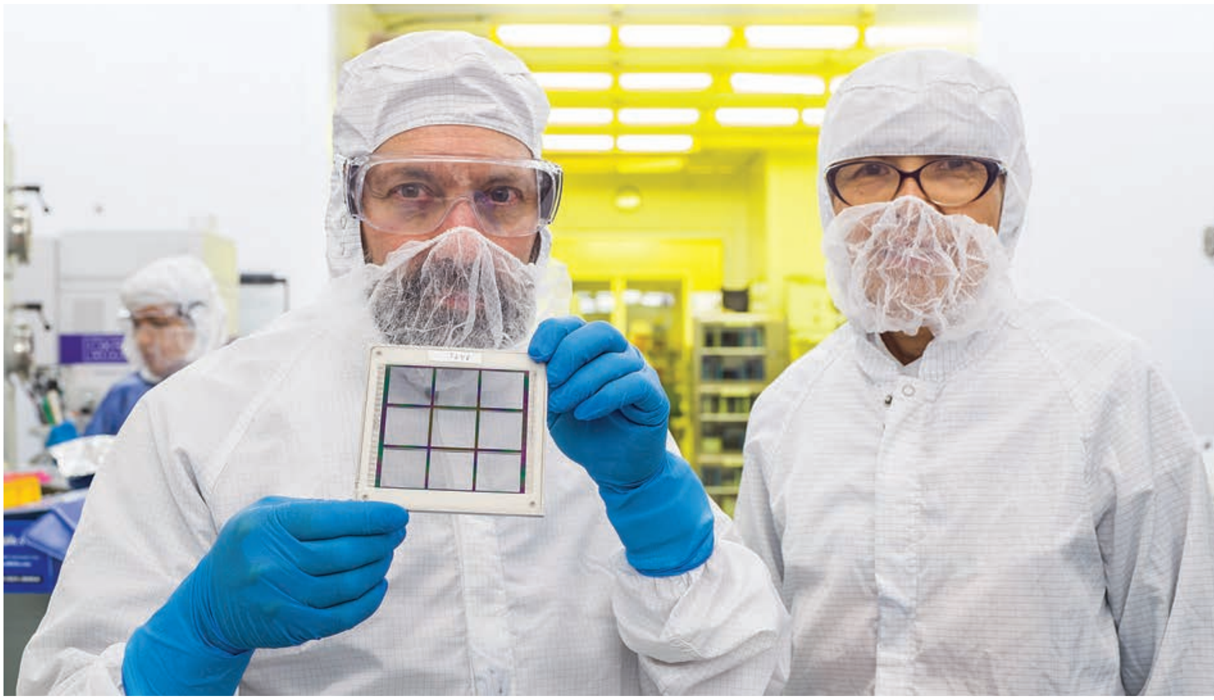

Photo Credit: Chris Gunn/NASA

Matt Greenhouse (left) and Mary Li (right) are developing the Next-Generation Microshutter Array, which will fly for the first time on a sounding rocket mission in late October. This enabling technology includes 8,125 tiny shutters, each about the width of a human hair, that open and close as needed to focus on specific celestial objects.

Scientists plan to demonstrate for the first time in space a vastly simplified, more efficient technology for studying hundreds of stars and galaxies at a time — a revolutionary capability originally created for NASA's James Webb Space Telescope.

The technology, called the Next-Generation Microshutter Array (NGMSA), will fly on the Far-ultraviolet Off Rowland-circle Telescope for Imaging and Spectroscopy (FORTIS) mission in late October. The array includes 8,125 tiny shutters, each about the width of a human hair, that open and close as needed to focus on specific celestial objects.

Led by Johns Hopkins University Professor Stephan McCandliss, FORTIS will launch aboard a Black Brant IX sounding rocket from White Sands Missile Range in New Mexico to study the star-forming galaxy, Messier 33, or M33. Located about 3 million light-years from Earth in the Triangulum constellation, M33 is the third largest member of the Local Group of galaxies that includes the Milky Way and Andromeda.

"FORTIS needed our new microshutter technology for science. We benefit from a test platform to advance the readiness of this design for use in space. It's a great synergy," said Matt Greenhouse, a Goddard scientist, who with technologist Mary Li, is advancing the next-generation technology with support from NASA's Strategic Astrophysics Technology program.

The sounding rocket mission is expected to retire a wide range of technology risks associated with operating this new technology and helping to lay the foundation for even larger arrays needed by several next-generation astrophysics missions that are currently being ranked by the National Academy of Sciences Decadal Survey on Astronomy and Astrophysics, also known as Astro2020.

Divining Structures Surrounding Emerging Hot Star Clusters

M33 is a spiral-disk galaxy littered with clusters of massive hot stars that have emerged within the past few million years from collapsing natal clouds of cold gas and dust. To study these bright clusters, which emit copious amounts of light at ultraviolet wavelengths, the FORTIS telescope will first locate

Continued on page 7

the brightest clusters with its imager and an on-the-fly targeting algorithm will close all the tiny shutters except those coincident with the bright targets.

This will allow light to flow to the spectrograph where it will be broken into component wavelengths to reveal details about the physical conditions of the clusters and their surrounding material.

The Goddard-developed, next-generation microshutter array technology has evolved since its initial development in the 1990s for the James Webb Space Telescope. Here are images of its various incarnations. A Next-Generation Microshutter Array will fly in space for the first time in late October 2019.

The microshutter technology gives scientists the ability to produce multiple spectra at once. This capability improves productivity on both sounding rocket missions, which offer only six minutes of observing time, or large space-based observatories, which can take up to a week to observe faint, far-away objects and gather enough light to obtain good spectra. With observing time at a premium, the ability to gather light from multiple objects at once is paramount.

Webb, scheduled to launch in 2021, will carry NASA's first-generation microshutter technology — four 365-by-172 microshutter arrays that together total 250,000 shutters. They will allow Webb to obtain spectra of hundreds of objects simultaneously.

What distinguishes the next-generation array on FORTIS from the one flying on Webb is how the shutters are opened and closed. Webb's arrays employ a large magnet that sweeps over the shutters to activate them. However, as with all mechanical parts, the magnet takes up space and adds weight. Furthermore, magnetically activated arrays can't be easily scaled up in size. As a result, this older technology is at a disadvantage for supporting future space telescopes larger than Webb.

Magnet Eliminated

To accommodate future missions, Goddard's microshutter-development team eliminated the magnet. The shutters in the pilot 128-by-64 array that will fly on FORTIS open and close through electrostatic interactions. By applying an alternating-current voltage to electrodes placed on the frontside of the microshutters, the shutters swing open. To latch the desired shutters, a direct current voltage is applied to electrodes on the backside.

Without a magnet, the next-generation array can be dramatically scaled up in size — and that's precisely what the team is attempting to accomplish. Particularly, Greenhouse and Li are using advanced manufacturing techniques to create a much larger, 840-by-420 array equipped with 352,800 microshutters, dramatically increasing an instrument's field of view.

"The array that is flying on FORTIS is a technology-development prototype for the big one," Greenhouse said.

Other Sciences Could Benefit

Next-generation astrophysics missions aren't the only potential beneficiary of the magnet-free array. Heliophysicist Sarah Jones is considering implementing the FORTIS-type array on a sounding rocket mission called Loss through Auroral Microburst Precipitation, or LAMP. LAMP will for the first time directly measure microbursts in pulsating aurorae, colorful light shows that occur 60 miles above Earth in a ring around the magnetic poles.

In addition, Jones said she could measure particle velocities in Earth's upper atmosphere with this technology and determine in which direction upper atmospheric winds are blowing just by opening one shutter at a time. Scientists are interested in obtaining these measurements because these winds can create an atmospheric drag on low-Earth-orbiting satellites.

"We want to use this technology as soon as we can and are excited to use it. We haven't measured these winds directly in 30 years," she said, adding that NASA's Dynamics Explorer mission used a similar, but more difficult-to-execute technique when it measured the winds in the 1980s and early 1990s.

Jones's enthusiasm is understandable, Greenhouse said. "Everyone wants this technology," he said. ❖

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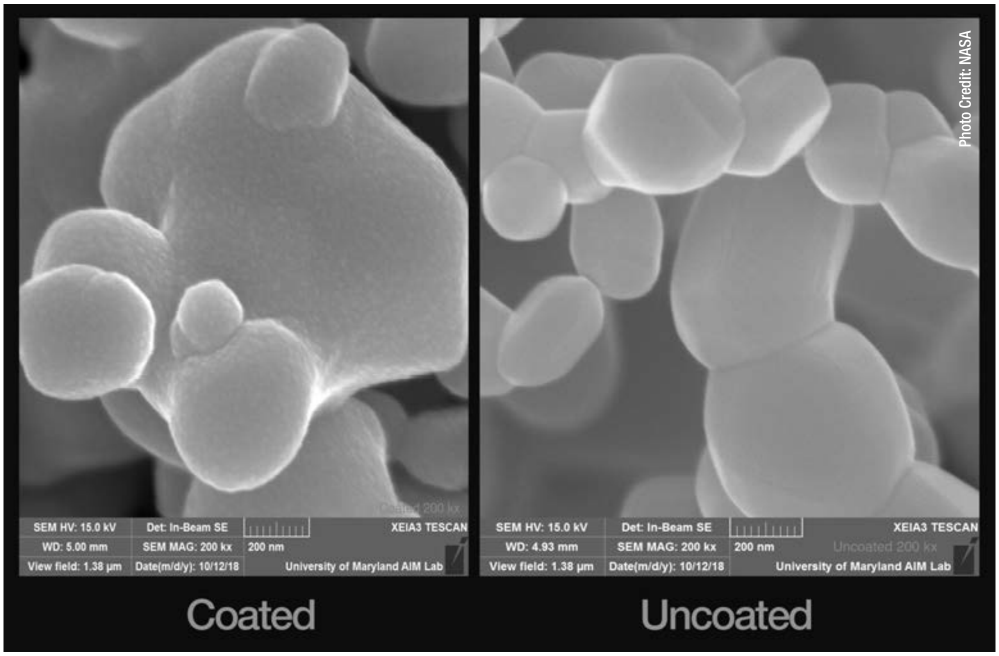
Busting the Dust

New Coating Technology Could Help Resolve Lunar Dust Challenge

An advanced coating now being tested aboard the International Space Station for use on satellite components could also help NASA solve one of its thorniest challenges as it plans to return astronauts to the Moon: how to keep the Moon's irregularly shaped, razor-sharp dust grains from adhering to virtually everything they touch, including astronauts' spacesuits.



A team of Goddard technologists are experimenting with coated pigments to solve one of NASA's thorniest challenges: how to keep the Moon's irregularly shaped, razor-sharp dust grains from adhering to virtually everything they touch, including astronauts' spacesuits. The uncoated pigment on the right looks smooth, while the coated pigment includes distinct features.

Although the coating wasn't originally conceived for lunar dust busting, "it's compelling for this application," said Goddard scientist Bill Farrell, who heads a NASA research organization, Dynamic Response of the Environments at Asteroids, the Moon, and moons of Mars, or DREAM2, which studies the lunar and Martian environments. NASA considers lunar dust to be among the top challenges to mitigate as it aims to establish sustainable exploration of the Moon by 2028 under the Artemis Program.

Mitigating Electrical Build-Up

Goddard technologists Vivek Dwivedi and Mark Hasegawa originally created the coating for an equally important job: they wanted to create a coating that would help "bleed off" the build-up of electrical charges that can destroy spacecraft electronics. These potentially mission-ending build-ups occur when spacecraft fly through plasma found within Earth's magnetosphere. Plasma contains trapped charged particles that conduct electricity, contributing to the build-up.

Hasegawa's idea was to use an advanced technology called atomic layer deposition, or ALD, to apply super-thin films of indium tin oxide — an effective compound for dissipating electrical charges — onto dry pigments of paint. Once mixed, the paint could then be coated on radiators and other spacecraft components to help mitigate the build-up.

Used ubiquitously by industry, ALD involves placing a substrate or sample inside a reactor chamber, which is like an oven, and pulsing different types of gases to create an ultra-thin film whose layers are literally no thicker than a single atom. The beauty of ALD is the fact that it can be applied on virtually anything, including three-dimensional objects.

To test the effectiveness of the pigment-treated paint, Dwivedi and his team then prepared a handful of coated coupons or wafers, which are now being exposed to plasma from an experiment pallet aboard the International Space Station. Hasegawa and Dwivedi expect to get their samples later this year for analysis.

Same Plasma, Same Trouble

As it turns out, the plasma that can damage electronics as spacecraft fly through Earth's magnetosphere is also the source of the Moon's dust problem.

Continued on page 9

The Moon's dust is made up of ultra-tiny grains formed by meteorite impacts that repeatedly crushed and melted rocks into glass, creating tiny shards of glass and mineral fragments. Not only can they travel at hurricane-like speeds, but they also cling to all types of surfaces not only because of their jagged edges, but also because of their electrostatic charge.

On the day side of the Moon, harsh, unshielded ultraviolet radiation from the Sun kicks electrons off the dust particles in the upper layers of the lunar regolith or soil, giving the surface of each dust particle a net positive charge. On the dark side and in the polar regions, the situation is a little different. Plasma flowing out from the Sun also charges the lunar surface, but, in this case, it deposits electrons, which create a net negative charge. It gets more complex at the terminator where the two sides meet. There, even stronger electric fields develop — all of which could affect humans and technology that land on the Moon.

For astronauts, the situation will be made worse because they carry their own charge and, as the Apollo missions proved, will attract dust as they rove about the Moon. Because NASA has eyed the Moon's south pole for possible human habitation, it's especially important that NASA develop efficient ways to dissipate these charges, Dwivedi said.

That got Dwivedi thinking. Why not apply the coating to Moon rovers and even habitats, or use ALD to treat the fibers in spacesuit material?

"We have conducted a number of studies investigating lunar dust. A key finding is to make the outer skin of the spacesuits and other human systems conductive or dissipative," Farrell said. "We, in fact, have strict conductivity requirements on spacecraft due to plasma. The same ideas apply to spacesuits. A future goal is for the technology to produce conductive materials, and this is currently being developed."

Working in collaboration with Farrell, Dwivedi and his team, including University of Maryland researcher Raymond Adomaitis, now plan to further enhance their ALD capabilities with funding from Goddard's Internal Research and Development program. This year, the team plans to construct a larger reactor, or oven, to increase the yield of the charge-mitigating pigment, which they would then apply to coupons and spacesuit material for testing. ❖

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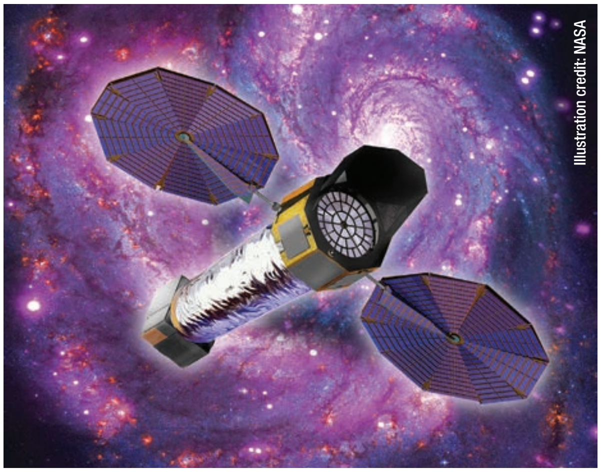
Zhang, *continued from page 4*

took notice of these achievements and is investigating the technology's potential use on ESA's Athena X-ray telescope, scheduled to launch in late 2031. Even if Lynx isn't selected as NASA's next flagship astrophysics mission, other NASA missions could benefit in the future, Zhang said.

In the nearer term, Zhang will be flying his optics on a suborbital sounding rocket mission called OGRE in 2021. This flight opportunity will represent the technology's first demonstration in space. For OGRE, which is short for the Off-plane Grating Rocket Experiment, Zhang is developing a 288-segment mirror assembly.

Moments of Doubt

"I had many moments when I thought I had bitten off more than I could chew," Zhang said, reflecting on his technology-development effort, which continues as he works with his engineering team to design an improved technique for aligning and bonding these fragile mirror segments inside a protective canister. "With technology development, you never know if you'll achieve what you set out to achieve."

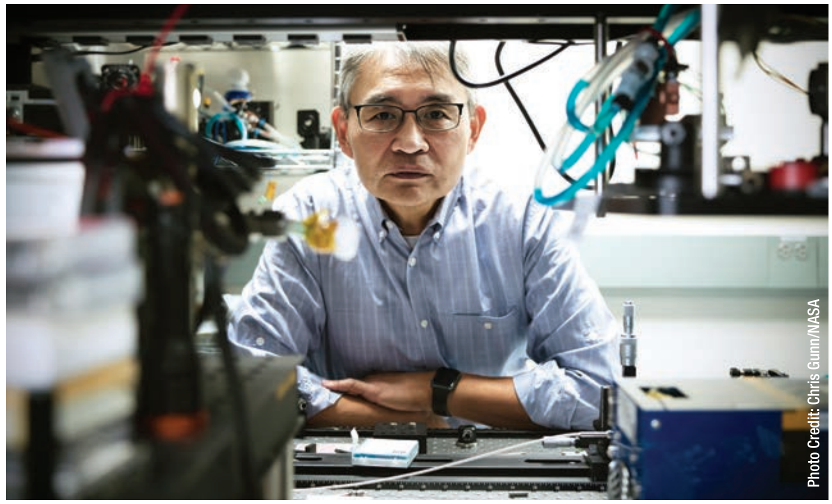


This is an artist's rendition of the conceptual Lynx X-ray Observatory, a potential user of a new X-ray mirror developed by Goddard astrophysicist William Zhang.

"But I'm fortunate that I work with a team of people who are really, really good. Teamwork isn't an empty word. It's precious and very, very important." As is moral support. "The IRAD makes a big difference. You have no idea if your idea will work — especially when most people are saying your idea is crazy. IRAD allows you to pursue your idea." ❖

Telecommunications Technology Tapped to Develop More Capable, Miniaturized Spectrometer

A technology that has enabled ever-faster delivery of voice and data over the Internet and other telecommunications platforms could play a front-and-center role in the development of a super-small instrument for gathering unprecedented details about extraterrestrial planets, moons, comets, and asteroids.



Goddard technologist Tony Yu is applying technology created by the telecommunications industry to develop a super-small instrument for gathering unprecedented details about extraterrestrial planets, moons, comets, and asteroids.

Although its critical component is the size of a computer chip, the instrument promises to exceed the performance of a similar-type, but significantly larger instrument installed at a ground-based observatory in Hawaii. Since its installation at the summit of Mt. Haleakala in 2014, the Japanese-developed Mid-Infrared Heterodyne Instrument, or MILAHI, has gathered extraordinarily detailed, continuous measurements of the atmospheric dynamics, thermal structure, and surface compositions of Mars and Venus.

As good as MILAHI is, it's too big and heavy to fly on a traditional satellite, let alone a less-expensive CubeSat whose small size and lower cost would allow scientists to fly multiple, similarly equipped platforms for multipoint observations, said Principal Investigator Tony Yu, who recently won technology-development funds from NASA's Planetary Concepts for the Advancement of Solar System Observations (PICASSO) program to mature a smaller MILAHI-type instrument.

"We want to do similar science, but we need to reduce the instrument's size," Yu said, adding that his team's goal is to create a small, lightweight instrument that consumes significantly less power and operates without moving parts, making it ideal for flying on CubeSat platforms.

PICTURE Perfect for Planetary Studies

Like MILAHI, the Photonic Integrated Circuit Tuned for Reconnaissance and Exploration, or PICTURE, would be tuned to the mid-infrared wavelengths — the spectral or frequency range ideal for remotely sensing water, carbon dioxide, methane, and many other compounds in extraterrestrial atmospheres and surfaces. And also like MILAHI, PICTURE would split mid-infrared light into its component colors — a method called spectroscopy — to reveal a wealth of information about an object's composition and other physical properties.

But shrinking the instrument to fit inside a CubeSat, which is often no larger than a loaf of bread, will require that Yu and his team, including the Naval Research Laboratory and the University of California-Santa Barbara, adopt techniques originally created by the telecommunications industry. "Basically, what we're doing is applying telecom technologies for use in space," Yu said.

Under his PICASSO award, Yu and his team are focusing on one of PICTURE's most critical subsystems: the PIC spectrometer, the chip-sized device inspired by the telecom industry's arrayed waveguide gratings, or AWGs.

In telecommunications and computer networks, AWGs serve a couple functions. In a process called multiplexing, they combine multiple analog or digital signals with varying wavelengths into a single optic fiber. At the receiver end of an optical communications network, a reverse process — known as demultiplexing — occurs. The waveguides then retrieve the individual channels.

With this two-step process, multiple channels can share a resource — in this case, typically a fiber-op-

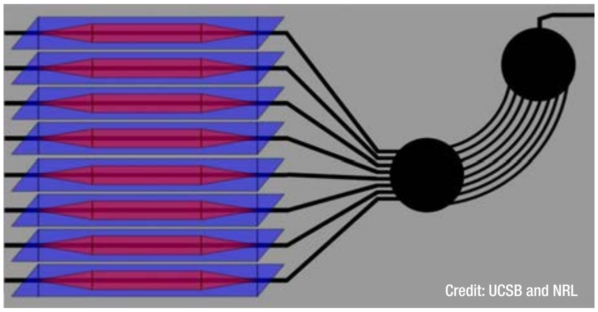
Continued on page 11

tic cable — and experience greatly reduced interference and crosstalk while dramatically increasing the efficiency and speed of telecommunications signals.

"Its Day Has Come"

The team plans to adopt the same general principle. The chip-sized PIC spectrometer, equipped with the telecommunications-inspired waveguides, would separate the light into its individual mid-infrared wavelengths — an important step in ultimately determining the molecular composition of planetary atmospheres and surfaces. These individual channels would then be mixed with laser light, also tuned to a specific wavelength, in a process called heterodyning — a commonly used technique to amplify signals.

Under this effort, the team will develop a PIC spectrometer that focuses on the spectral band ideal for detecting carbon monoxide. The goal under the PICASSO is to raise the device's technology readiness level (TRL) — the scale that NASA uses to determine a technology's readiness for use in space — from its current TRL of two to TRL of four and then to advance the instrument's other subsystems as well



This schematic shows an application of arrayed waveguide gratings, a technology developed by the telecommunications industry, combining eight laser arrays (left) to a single waveguide (far right) that would deliver specific infrared wavelengths ultimately to a detector.

as its ability to detect other molecular compounds beyond carbon monoxide.

"We're really excited about this instrument," said Mike Krainak, the former head of Goddard's Laser and Electro-Optics Branch and a PICTURE team member, who now holds the post of Emeritus engineer at Goddard. "It's a technology with a tremendous future in all types of applications. Its day has come." ❖

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Can BurstCube Detect Gamma-Ray Bursts and Talk with TDRS?

An enhanced miniaturized radio developed for the BurstCube mission is undergoing testing to determine if it can communicate with NASA's geosynchronous-orbiting Space Network — a development that could create new opportunities for science done on SmallSats.

Expected to be launch-ready by the fall of 2021, this CubeSat mission will monitor the sky for gamma-ray bursts and notify astronomers within 30 seconds of an event via text (*CuttingEdge*, Winter 2018, Page 12). Astronomers will then be able to alert ground- and space-based observatories so that they can point and focus on the event.

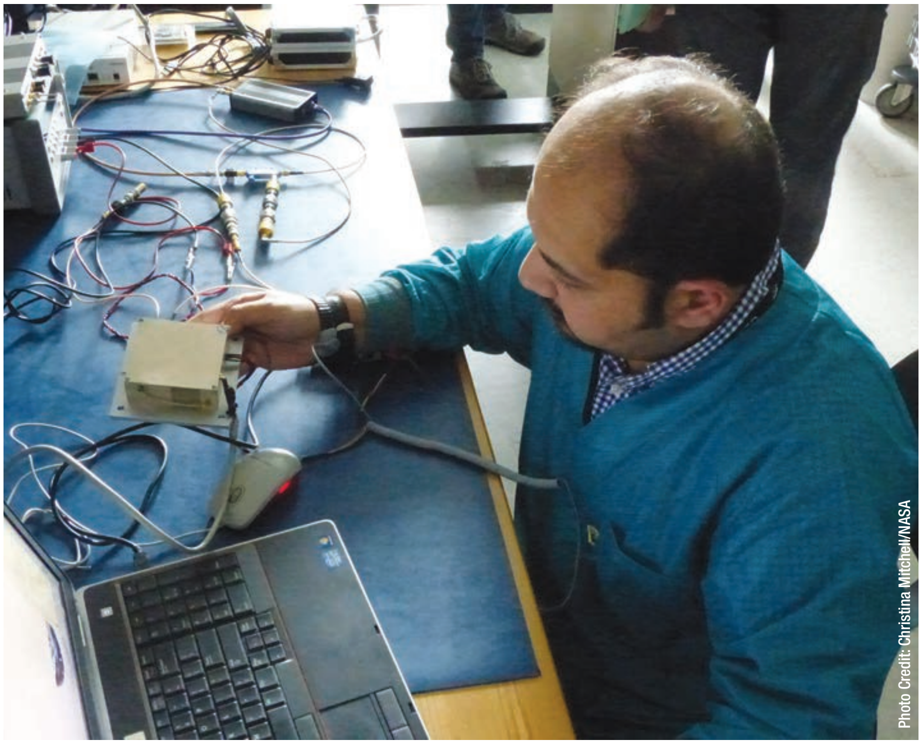
Once BurstCube launches, scientists' view of the gamma-ray sky will increase from 60 percent with the current suite of NASA gamma-ray-burst-detecting telescopes to about 90 percent, Perkins said. The ability to detect these powerful events will become more important as other missions, like the Laser Interferometer Gravitational Wave Observatory, or LIGO, make more detections that can be paired with observations in gamma-ray light or other wavelengths.

Currently, existing CubeSat missions relay data with the same commercially available radio, which communicates with NASA's Near-Earth Network, or NEN. NEN consists of ground stations located at sites around the world that provide space communication and tracking services to missions operating in the near-Earth environment.

These communication services, however, are only available when a ground station is within range. Given BurstCube's job of rapid communication with astronomers on the ground, the low-cost, low-power mission needs access to NASA's Tracking Data Relay Satellite (TDRS) network to ensure 24/7 connectivity.

Continued on page 12

To provide this connectivity, Goddard engineers used Goddard Internal Research and Development program and other funding to develop an engineering test unit consisting of commercial radio hardware equipped with revised operating firmware that allows the radio to use TDRS protocols. They also set up a test bench to test the radio. If proven in testing, the enhanced radio would be the first CubeSat-compatible radio capable of communicating with both the NEN and TDRS networks. The NEN tests were successfully completed in September, and the team plans to re-test for TDRS in January of 2020.



Radio engineer Benham Azimi holds the BurstCube radio module, which will use NASA'S Tracking Data Relay Satellite network to alert astronomers to gamma-ray burst events in less than a minute.

"A Really Great Benefit"

"From our scientific standpoint it's a really great benefit," said BurstCube Principal Investigator Jeremy Perkins. "TDRS is the gold standard for coverage and connection. If we get CubeSats up there that have access to communications networks 24/7, it opens up what we can do with networks of CubeSats."

The tiny radio had significant challenges to overcome, said Chuck Clagett, branch head of Goddard's computation and hardware division. "Most commercial off-the-shelf radios don't have the right kind of encoding/decoding protocols to communicate with TDRS," he said. "Second, TDRS is pretty high up, while BurstCube would be in low-Earth orbit. It takes one watt of power to communicate to the ground through NEN, but four watts to communicate with TDRS. We're also trying to keep it in a small package."

Radio signals attenuate — or weaken over long ranges — so engineers either have to increase the power or the size of the antenna, Perkins said. Neither of those options are particularly feasible in a CubeSat's small package.

With the new TDRS-enabling technology developed by Goddard radio engineer Benham Azimi, the modified radio would be able to transmit one kilobyte of data per second, enough bandwidth to send a standard text message. That's all the mission needs to text the coordinates of a gamma-ray burst. The radio has two antennas and can switch communications modes to contact both TDRS and ground stations.

Other CubeSat Missions Interested

In addition to BurstCube, other small satellite missions are interested in the radio technology, including the Plasma Enhancements in the Ionosphere-Thermosphere Satellite (petitSat), Geostationary Transfer Orbit Satellite (GTOSat), and SigNals of Opportunity: P-band Investigation (SNoOPI), Perkins said. "It opens up what we can do with networks of CubeSats. They can talk to each other about events that are happening right now, and they can talk directly with other big missions. You could even have a CubeSat early-warning system for space weather events."

For now, BurstCube's radio is a one-way transmitter. Next year, Perkins plans to obtain research-and-development support to develop a capability that would allow engineers to talk to the radio in addition to receiving signals from it. That would be necessary for CubeSats in a network to communicate with each other or another spacecraft. ❖

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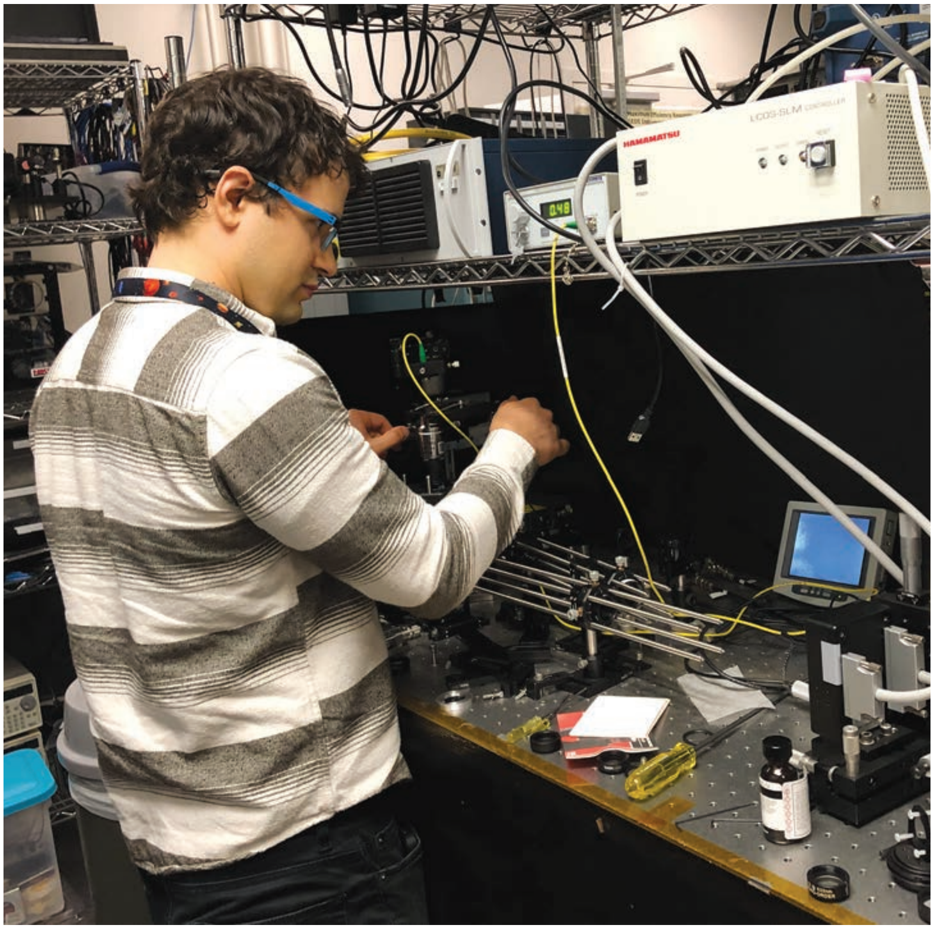
The Force is With You

Early-Career Innovator Experiments with Force Fields to Move Matter



Early-career optical engineer Aaron Yevick is using Goddard Fellows Innovation Challenge funding to advance a technology that moves particles via laser-induced force fields. The technology could be applied to planetary science.

On a metal work bench covered with tools, instruments, cords, and bottles of solution, Aaron Yevick is using laser light to create a force field with which to move particles of matter.

Yevick is an optical engineer who came to Goddard full-time earlier this year. Despite being in his current position with NASA less than a year, Yevick received funding from the Goddard Fellows Innovation Challenge (GFIC) — a research and development program focused on supporting riskier, less mature technologies — to advance his work.

His goal is to fly the technology aboard the International Space Station, where astronauts could experiment with it in microgravity. Eventually, he believes the technology could help researchers explore other planets, moons, and comets by helping them collect and study samples.

A native of Toronto, Yevick found his passion for research early. As a 17-year-old, Yevick attended Yeshiva University in New York City to study physics and published a scientific paper on measuring nanoparticles in his sophomore year. After graduating with a bachelor's degree, he attended New York University (NYU) to earn a doctoral degree in physics — an academic path that ultimately led him to NASA as a Goddard summer intern in 2016 and Pathways intern in 2018. He became a full-time optical engineer in February 2019.

"Aaron is well trained in optical trapping," said Paul Stysley, a laser engineer. "Bringing his expertise to Goddard allows us to partner more effectively with entities like NYU and NASA's International Space Station in the near term," he said, adding that in the longer term Yevick plans to partner with other organizations that want to study planetary environments. Stysley, who has studied laser manipulation (*CuttingEdge*, Fall 2011, Page 8), is mentoring Yevick as he attempts to complete a system that can generate complex light fields and perform scientific experiments benefitting planetary exploration.

Research Impacts

The GFIC-funded project will help Yevick bring complex light and related micromanipulation technologies, like optical trapping, to NASA. In optical trapping, a focused laser beam uses radiation pressure to push and pull small physical objects.

The underlying principle of optical trapping won American scientist Arthur Ashkin half of the 2018 Nobel Prize in Physics. This principle, developed in the 1980s, has been used to capture living bacteria

Continued on page 14

without harming them, leading to various researchers using this technology to probe the building blocks of life.

Complex light is the ability to shape the amplitude and phase of light in three dimensions, to form lines, knots, spirals, and arrays of points. These fields may involve a strongly focused beam of light with a very small amount of force to move tiny particles that range in size from tens of nanometers (smaller than the width of a strand of hair) to many micrometers (about the size of a human red blood cell).

The system includes a spatial light modulator to precisely control the three-dimensional pattern of the light, which in turn controls the motion of the particles. The modulator allows a user to independently adjust the phase of the incoming light beam across its profile at every point along a grid of pixels.

Development of the modulator, back in the 2000s, and other adaptive optics that can create complex light have unlocked new possibilities in the precision and customization of the force fields that can be applied to microscopic objects.

Space Application

Currently, researchers like Yevick are trying to adapt this complex light technology for space applications, particularly as a component for the Light Microscopy Module (LMM), which is a state-of-the-art light imaging microscope aboard the space station.

Astronauts use the LMM to pursue new research into microscopic phenomena in microgravity. On the space station, without the force of gravity, which could potentially overpower the delicate radiation pressure, researchers would be able to conduct experiments in self-assembly and space biology as well as study fine particles suspended in a fluid.

"Aaron brings much needed youth and enthusiasm to this project," Stysley said. With backing from management, "he has the drive to get the job done," Stysley said. ❖

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New Simulation Technology Helps Determine Best Way to Measure Snow from Space

A new simulation tool will help identify the best combination of satellite sensors to detect snow and measure its water content from space.

Snow's water content, or snow water equivalent (SWE), is a "holy grail for many hydrologists," said Bart Forman, a University of Maryland professor and principal investigator who is developing the tool with Earth Science Technology Office, or ESTO, funding.

Forman's team, which includes Goddard remote-sensing and modeling researcher Sujay Kumar and ESTO Technical Manager Jacqueline Le Moigne, is developing a tool that uses machine learning — the process of training algorithms to detect patterns in data — and physical models to simulate the performance of different satellite sensors to pinpoint how best to combine them to measure SWE and get the most "scientific bang for your buck," Forman said.

Why Measure?

This data is critical to people around the globe. In the U.S., for example, those living in the western U.S. get 70-90 percent of their drinking water from snow and its availability can affect hydroelectric generation and agricultural production, Forman said.

"We would love to have a global map of SWE," which can be obtained from Earth-orbiting satellites, said Edward Kim, a Goddard research scientist who has helped organize SnowEx, a NASA field campaign that gathers snow data with aircraft instruments. However, there is no single technique that can measure SWE globally because snow looks different depending on where it lands, Kim said.

It often forms a deeper layer in forests, where it's sheltered from the Sun, but maintains a shallower profile in the tundra and prairie, where it's exposed to wind and higher temperatures. Snow also changes its shape as it falls to the surface and then continues to change in its resting place. Its shape can specify which sensor is able to observe it, Kim said.

"The simulation tool will show us the kinds of tools we need to be able to make intelligent choices about how to combine sensors," Kim said.

Continued on page 16

Goddard Technologist Seeks a Better Prognosis for Spacecraft Lifespans

It's not easy knowing when a spacecraft will call it quits and end up in that big parking lot in the sky. The big unknown usually involves uncertainty about the spacecraft's critical subsystems — like batteries and power systems — and, more specifically, when they will fail.

Harry Shaw, a technologist with Goddard's Space Communications and Navigation (SCaN) Division, wants to unmask the unknown through machine learning — teaching a complex set of algorithms to identify incidents that could help predict the last days of spacecraft batteries.

This is an artist's concept of TDRS-13, NASA's Tracking Data Relay Satellite used for communication. A Goddard engineer used TDRS data to teach a complex set of algorithms to identify incidents that could help predict the last days of spacecraft batteries.

"My goal is to do hypothesis-driven analyses," Shaw said. "For instance, if I believe that the batteries on a given spacecraft are going to fail in five years, I want to test against the data to get an answer."

With support from SCaN, Shaw is studying many years of battery lifecycle and power-system data from NASA's Tracking and Data Relay Satellite, or TDRS, system. He wants to better predict the lifetime of a typical battery. Ultimately, he wants to extend the lives of valuable spacecraft to avoid unexpected and premature failures.

"All the TDRS satellites (and other communication satellites) fly in the geosynchronous arc, which is the most valuable real estate in near-Earth space," Shaw said, referring to that position 22,236 miles above sea level where an orbiting satellite maintains the same position relative to Earth's surface. "If a satellite is lost in the geo arc, meaning it fails and can't be kicked out into a safer orbit, it could possibly collide with other satellites causing massive damage to the world's telecommunications systems," Shaw added.

The use of TDRS data is ideal for improving battery prognoses, said Dave Israel, SCaN communications architect at Goddard. "Many orbital and deep space missions have one-off battery or power systems tailored to the particular needs of the spacecraft," he said. "TDRS, however, flies multiple satellites with minor changes from generation to generation, and NASA keeps a massive wealth of data from their entire lifespans."

The similarities of TDRS batteries eliminates many variables, Israel added. That gives NASA a high degree of confidence that what engineers learn can be applied to other systems.

Last year, Shaw began analyzing TDRS data, initially using machine learning. Working with a data scientist from Aerospace Corp., Shaw fed the algorithms data from cases where spacecraft batteries performed outside expected parameters, tripping an alarm and requiring ground engineers to react to maintain spacecraft functionality.

"It's not humanly possible to analyze all that data in real time," he said. "It's not even really possible to go back and pull the relevant data out without AI (artificial intelligence)."

Once Shaw and his team develop the machine-learning algorithms, Shaw said they can take the next step: bringing in a cloud data service like Amazon Web Services to use these tools on data from the current TDRS fleet. ❖

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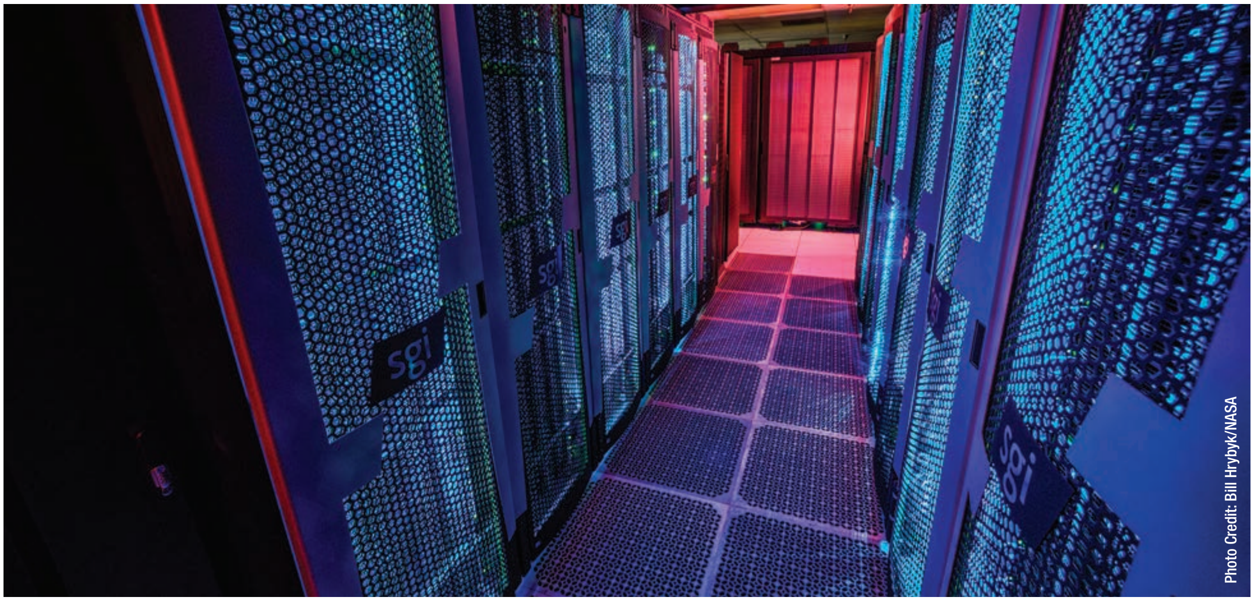

The Discover Supercomputer sits in the NASA Center for Climate Simulation at Goddard. The supercomputer allows researchers to do 100 to 1,000 calculations in the same time as a regular computer. This computing facility is being used to run different SWE-measuring scenarios.

Snow, *continued from page 14*

A Tale of Different Sensors

Given the fact that one technique can't effectively gather snow data to calculate SWE across the globe, the simulation tool includes data gathered by three different types of microwave-sensitive instruments: radiometer, radar, and lidar. So far, only radiometers and radar instruments have flown in space as part of a snow-centric observing mission to measure snow.

Scientists have limited lidar snow-specific measurements to aircraft campaigns, including NASA's SnowEx. However, Forman's team can use this airborne information to hypothesize a range of errors that might result from using lidar onboard a satellite, and then use the tool to run experiments with those assumptions, he said.

The simulation also uses a constellation simulator called TAT-C that Le Moigne and her team at Goddard and other institutions developed. "TAT-C helps us locate where the satellite would be and what part of the Earth it would see," Forman said.

Once all the sensors are together in the simulation tool, the team is able to run different experiments that include different scenarios, like putting a satellite into one orbit versus another or having a satellite look at a wide swath of Earth versus a narrow one. With this suite of experiments, they can gauge the "scientific bang" based on a common benchmark scenario. "We're really trying to systematically narrow down the pool of options we might want to consider," Forman said.

"In order to do all this, you have to use supercomputers," Forman said, adding he's using the Discover Supercomputer at the NASA Center for Climate Simulation at Goddard and the Deepthought2 High-Performance Computing cluster at the University of Maryland.

As sensors evolve and satellites change, the tool's creators plan to stay in the game. The team intends to continue working on the tool until the end of 2019 and then continue to tweak it so that it represents the current mix of satellites in orbit, Forman said. The tool "will continue to ask questions of what should be next and how we should be planning in 20 years or more out into the future," Forman said.❖

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Cutting edge Goddard's Emerging Technologies

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