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Cutting edge

Goddard's Emerging Technologies

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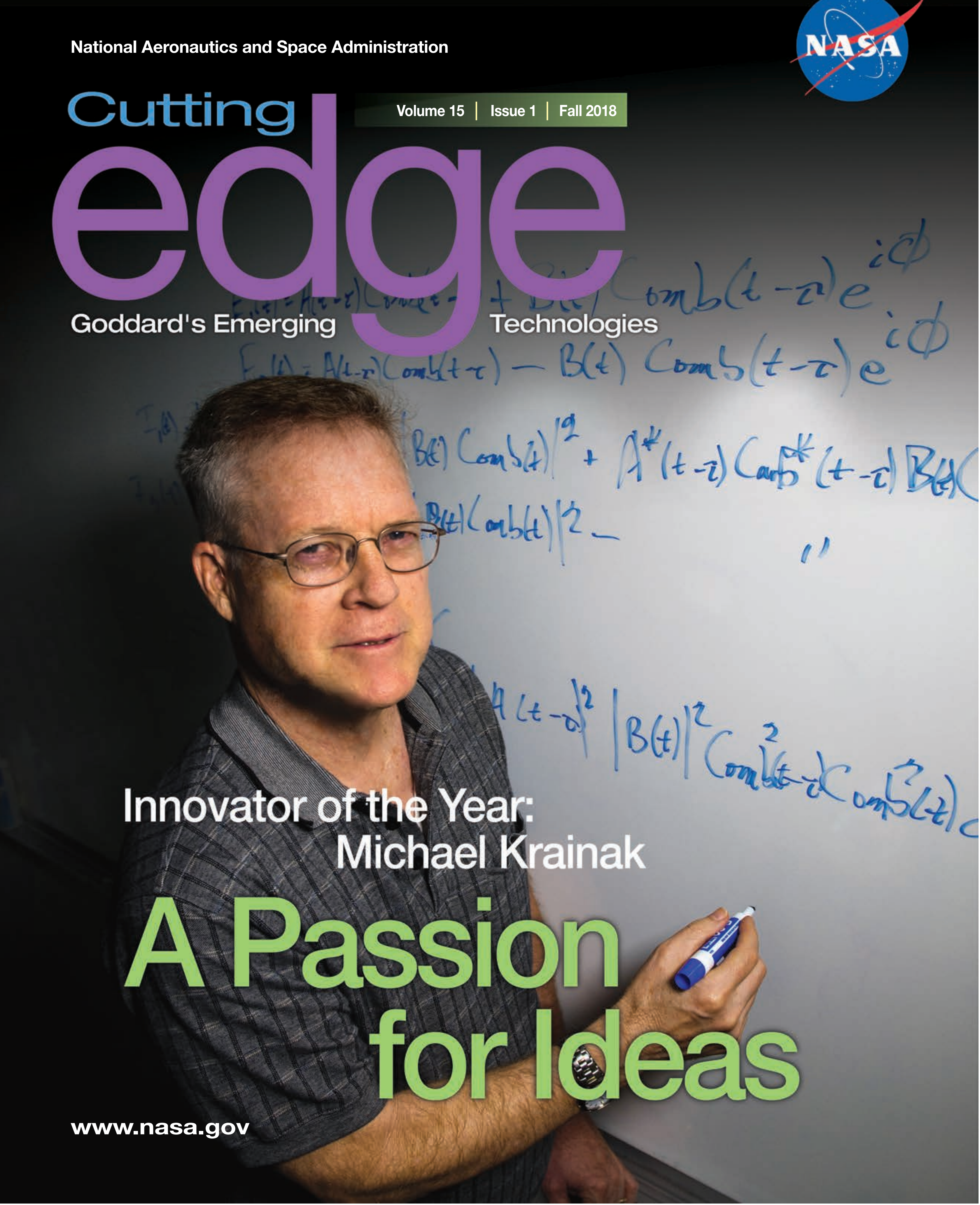

Innovator of the Year: Michael Krainak

A Passion for Ideas

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Office of the Chief Technologist Announces FY18 Innovators

Each year, the Office of the Chief Technologist recognizes individuals and/or teams that demonstrate the best in innovation. This year, the office is awarding its IRAD Innovator of the Year individual award to Michael Krainak, the head of Goddard's Laser and Electro-Optics Branch, and a team award to the group that conceived and developed the Dellingr CubeSat mission. We profile these winners on pages 2 and 5.

A Passion for Ideas

Michael Krainak Demonstrates Rare Combination of Skills

Mention integrated photonics, optical transistors, artificial guide stars, or any other emerging laser or electro-optical capability — topics that certainly aren't a part of most people's everyday lexicon — and this year's IRAD Innovator of the Year, Michael Krainak, more than likely has familiarized himself with the topic and invented ways that NASA could benefit from the technologies.

So innovative and wide ranging is his mind that many have trouble keeping up as he jumps from one technical subject to the next. His ideas have resulted in a prodigious number of technical articles in peer-reviewed journals as well as in multiple patents, the most recent awarded for a recirculating etalon spectrometer in late 2017.

Krainak says he's passionate about ideas — spending at least an hour each day perusing technical literature — but his greatest skill is his ability to apply his vast knowledge and orchestrate the development of new laser-and electro-optical-based capabilities that help keep NASA at the forefront, said Goddard Chief Technologist Peter Hughes, announcing Krainak's selection.

"Mike is an innovator. He understands NASA's toughest challenges and sees how to apply emerg-

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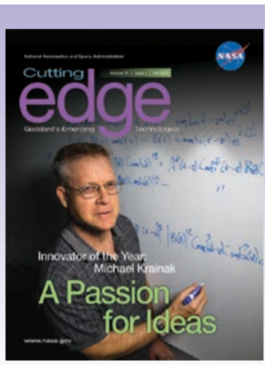

About the Cover

With the selection of Goddard technologist Michael Krainak as the FY18 IRAD Innovator of the Year, the center's Office of the Chief Technologist celebrates a rare combination of skills that NASA values — technical acumen, visionary thinking, and inspirational leadership. The office recognized Krainak for his unparalleled ability to apply emerging, potentially revolutionary technologies to spaceflight needs.

Photo Credit: Bill Hrybyk/NASA

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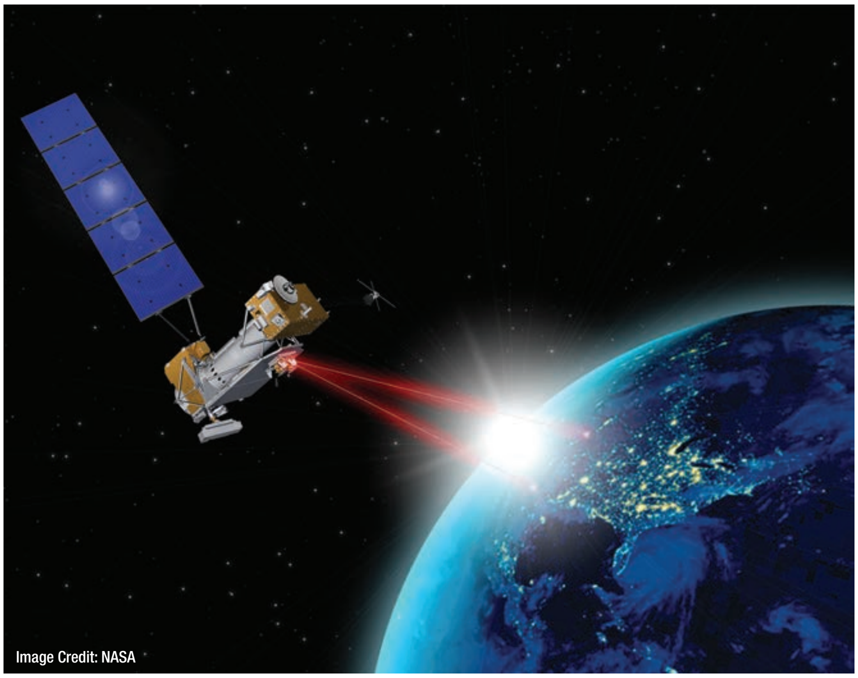
ing technologies to solve them. He then uses his management acumen to not only secure funding to further advance the idea, but also pull together the right mix of people to work on the effort," Hughes said. "With this choice, we celebrate a rare combination of skills that NASA values — technical acumen, visionary thinking, and inspirational leadership."



Among the many projects that Michael Krainak worked on was NASA's Laser Communications Relay Demonstration, which is now under development.

Successes Run the Gamut

Krainak's successes have affected virtually every area of science and technology.

As the head of Goddard's Laser and Electro-Optics Branch, he played an important role in NASA's Laser Communications Relay Demonstration, or LCRD. This mission will show a fully operational laser-communications system involving a hosted payload and two ground stations capable of relaying data at more than a gigabit per second via laser light, using significantly less mass and power.

Understanding that laser communications is the future, Krainak directed his organization to develop and demonstrate a low-cost optical communications ground station, with the hope that the system would help lay the foundation for widespread adoption of optical communications (CuttingEdge, Summer 2018, Page 10). He also guided the development of NASA's first low-Earth-user modem, which will fly on the International Space Station where it will serve as a low-Earth terminal for LCRD (CuttingEdge, Winter 2016, Page 2).

Furthermore, he is also considered an expert in photonic integrated chips, which are similar to integrated circuits except they use light rather than electrons to perform a variety of optical functions. Leveraging this technology will lead to a revolution in communications and in science instruments, Krainak has said.

His leadership in the field is one of the reasons NASA appointed him as its representative to the American Institute for Manufacturing Integrated Photonics, a non-profit, Defense Department-funded consortium that brings together the nation's leading talent to establish global leadership in the field. He also serves as the integrated-photonics lead for NASA's Space Technology Mission Directorate's Early Stage Innovation, Early Career Faculty, and Space Technology Research Grants Programs.

"Mike really understands the value of research — even in those areas where there isn't an immediate application," said Robert Lafon, an optical physicist who is researching, at Krainak's direction, the use of ultrafast lasers for different spaceflight applications (see related story, page 12). "He keeps up on the latest research. And, of course, he's really sharp. He has this ability to go through the literature and identify applications to benefit NASA."

One of those potential applications is a patent-pending custom laser crystal that could promote more widespread use of artificial guide stars in laser-communications ground stations and space-based observatories.

Astronomers use guide stars and a technique called adaptive optics in ground-based observatories to correct aberrations in telescope imaging. These distortions are caused as light from an astronomical target travels through Earth's turbulent

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FY18 Innovators

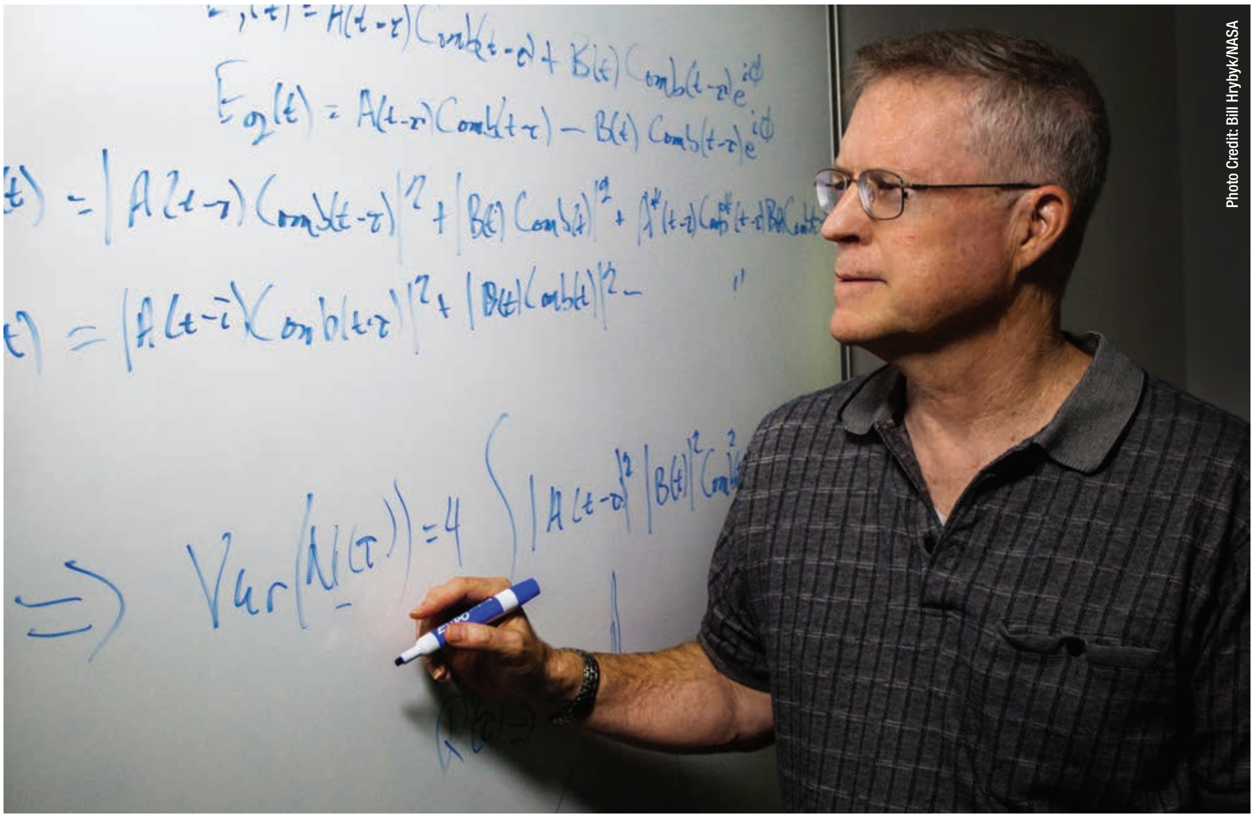

Photo Credit: Bill Hrybyk/NASA

Michael Krainak, a native of Wheaton, Maryland, credits his family and faith for his professional successes.

atmosphere and becomes blurred. The same technologies could assist in laser communications. By using a laser to probe the atmospheric turbulence, an adaptive-optics system could correct the aberrations and focus the beam more tightly as it travels to and from space and ground terminals.

Scientists have also identified an artificial laser guide star as a potential solution for easing highly demanding requirements for several conceptual space missions searching for Earth-like planets around Sun-like stars. The optical components of these systems can't move or distort by more than the size of an atom during an observation. Otherwise, the movement will jeopardize the telescope's ability to gather and focus enough light to image and characterize the exoplanet. The crystal could enable a laser guide star that works in space much like it does for ground-based observatories. The laser guide star would allow the telescope to better focus exoplanet light, thereby relaxing in-orbit, system-stability requirements by orders of magnitude.

In other mission-enabling efforts, Krainak and his team developed a patent-pending, ultra-low-noise laser to detect cosmic gravitational waves that ripple across space-time after cataclysmic events in the universe. He has also developed a quantum sensor and an optical transistor — technologies for which Krainak has already submitted patent applications.

"These technology developments are groundbreaking and potentially transformational," Hughes said. "I'm awed by the breadth and scope of his technical knowledge and ability to envision how NASA might use emerging technology to bring about breakthrough capabilities. Mike is well overdue for recognition."

Though Krainak's colleagues may speak highly of his intelligence and vision, he remains humble, giving credit to his family and faith for modeling honor, integrity, and even grit. The Wheaton, Maryland, native and graduate of Catholic and Johns Hopkins Universities sees himself as an orchestra leader or coach. "I've worked with many geniuses over my career and I'm not one," he said. "I am passionate about ideas, but I want my people to be smarter than me. I personally want to be inspired and I want to inspire others." ❖

FY18 Innovators

Accomplishing Much with Little

Team Awarded for Dellingr-Development Effort

Photo Credit: Bill Hrybyk/NASA

Dellingr team members include (first row, from left to right): Traci Rosnack, Juan Rodriguez, Blair Carter, Manohar Deshpande, Luis Santos, Chuck Clagett, Michael Johnson, Larry Kepko, Nick Paschalidis, Ken McCaughey, and Paulo Uribe; second row (left to right): Wendy Morgenstern, Eftyhia Zesta, Todd Bonal-sky, Jaquelyn Snell, Eric Smith, Dennis Chornay, John Lucas, Dan Berry, Tim Cameron, and Marcello Rodriguez; third row (left to right): Allison Evans, Dean Chai, Matt Colvin, Tom Plummer, Todd Bently, Eric Bentley, James Marshall, Kris Heefner, Giriraj Nanan, and Behnam Azimi.

The road to launch wasn't always smooth, but the scientists and engineers who built the Dellingr spacecraft proved they could develop a more capable and resilient CubeSat platform, and in the process, advance the state-of-the-art in this increasingly more important mission class.

For the group's efforts, the Office of the Chief Technologist awarded its FY18 IRAD Team Award to the engineers and scientists who created and now operate Dellingr and its payloads, including an advanced time-of-flight Ion-Neutral Mass Spectrometer, or INMS, two miniaturized magnetometer systems, a release mechanism called DANY, short for Diminutive Assembly for Nanosatellite Deployables, and a miniaturized thermal-control technology (*CuttingEdge*, Summer 2017, Page 4).

Since Dellingr's deployment from the International Space Station in November 2017, the shoebox-sized spacecraft and its miniaturized science and engineering payloads have demonstrated new capabilities and gathered high-quality data about the densities of ionized atom species in Earth's upper atmosphere.

Just as important, lessons learned from the Dellingr effort retired considerable cost and schedule risks for future SmallSat missions. It matured the skills of Goddard personnel and contributed to the win of three additional CubeSat missions, including petitSat, GTOSat, and BurstCube, said Michael Johnson, the chief technologist of Goddard's Engineering and Technology Directorate and one of the Dellingr project founders. Efforts are now underway to create a follow-on SmallSat architecture — DellingrX — which will extend capabilities beyond CubeSats and be capable of operating outside the relatively benign radiation environment found in low-Earth orbit.

"When our team began developing Dellingr about four years ago, the goal was to build a relatively inexpensive and more reliable CubeSat platform. The goal was to advance the state-of-the-art in small-satellite capabilities," said Goddard Chief Technologist Peter Hughes. "Despite a tight budget and aggressive schedule, this team accomplished this and more. The team inaugurated a new era for scientists wanting to use small, highly resilient

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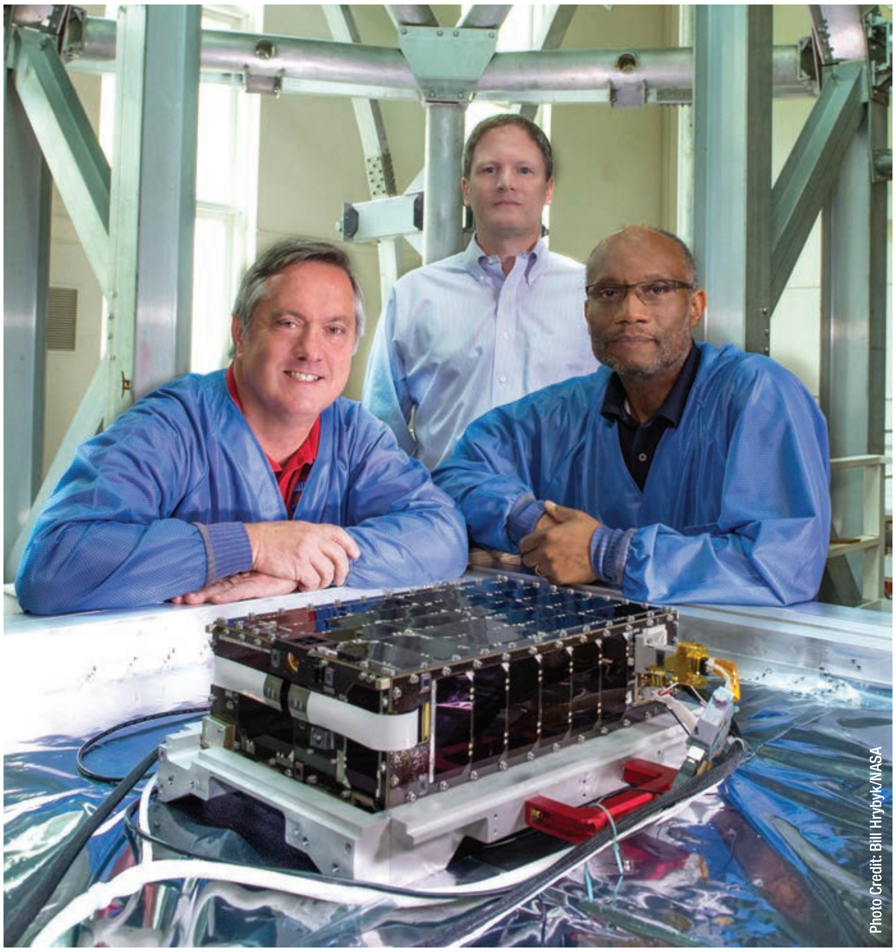
satellites to carry out important, and in some cases, never-before-tried science."

Driven by Need

The quest to build a more resilient CubeSat platform was driven in response to growing interest among NASA and other government scientists. They sought a low-cost platform on which to fly instruments, as well as the ability to fly constellations of these tiny craft to gather simultaneous, multi-point observations — a technique not financially possible with more traditional spacecraft.

Unfortunately, many low-cost commercially available CubeSat platforms, subsystems, and components used by universities mainly for classroom instruction had proven unsuitable for NASA-class science. "It was a matter of reliability. In many cases, our desired level of performance just wasn't there," Johnson recalled.



Chuck Clagett, Larry Kepko, and Michael Johnson — part of the team that conceived and built the Dellingr spacecraft and instruments — are shown here with the Delllingr bus.

Developing a new platform, however, proved challenging. Although the team had planned to use commercial components to reduce costs, these parts didn't always play well together or work as advertised, requiring additional engineering and technical effort. The team learned that to minimize costs, it would also have to change the way it managed CubeSat missions, eliminating or modifying some standard processes and tests.

System Approach

"Resilience is just as important as reliability," Johnson said. With larger missions, designers incorporate redundant systems in the event of a system failure. Small satellites, however, typically don't have the resources to support backup systems. "It's easier to design in redundancy," Johnson added. "It's more difficult to build single-string systems that will work even if something goes wrong. You really have to look at the challenge from a system perspective. The CubeSat has to work as a resilient unit."

As a result, the team had to leverage its knowledge of ground and flight systems and rely more heavily on software to correct problems should they occur on orbit.

That philosophy proved vital shortly after Dellingr was deployed. The platform's command-and-data-handling subsystem experienced an upset and began rebooting every 64 seconds for 10 days. One of the team's engineers, Behnam Azimi, however, had incorporated a hardware capability that allowed Dellingr to recover from the terminal loop, which the team ultimately traced to a one-line bug in a vendor-supplied software driver, Johnson said.

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Forty Years in the Making

Goddard Team to Fly First-Ever Coronagraph Capable of Determining the Formation of the Solar Wind

An observational technique first proposed more than four decades ago to measure three important processes necessary for the formation of the solar wind — the source of disturbances in Earth's upper atmosphere — will be demonstrated for the first time next year.

Goddard heliophysicists Nat Gopalswamy and Jeff Newmark plan to demonstrate BITSE — short for the Balloon-borne Investigation of Temperature and Speed of Electrons in the corona — aboard a high-altitude scientific balloon from Ft. Sumner, New Mexico, next fall. BITSE will detect the density, temperature, and speed of electrons in the corona.

A New Type of Coronagraph

BITSE, which also involves the Korea Astronomy and Space Science Institute, is equipped with a coronagraph. These devices block the Sun's bright surface to reveal its faint, but very hot upper atmosphere called the corona.

However, the BITSE coronagraph has added features that can measure some very important properties of the solar wind, which can travel as fast as a million miles per hour as it flows off the Sun carrying charged particles or plasma and embedded magnetic fields outward across the solar system. Although scientists know that the solar wind originates in the corona, they don't know precisely how it forms or accelerates.

"This flight will mark the first time we've flown a coronagraph to detect the density, temperature, and speed of electrons in the corona. No coronagraph has ever done this before," said Gopalswamy, who used Goddard's Internal Research and Development program funding to advance BITSE. According to him, previously flown coronagraphs measured only the density of electrons in the Sun's corona. "We need all three physical properties to understand how solar wind forms," he said.

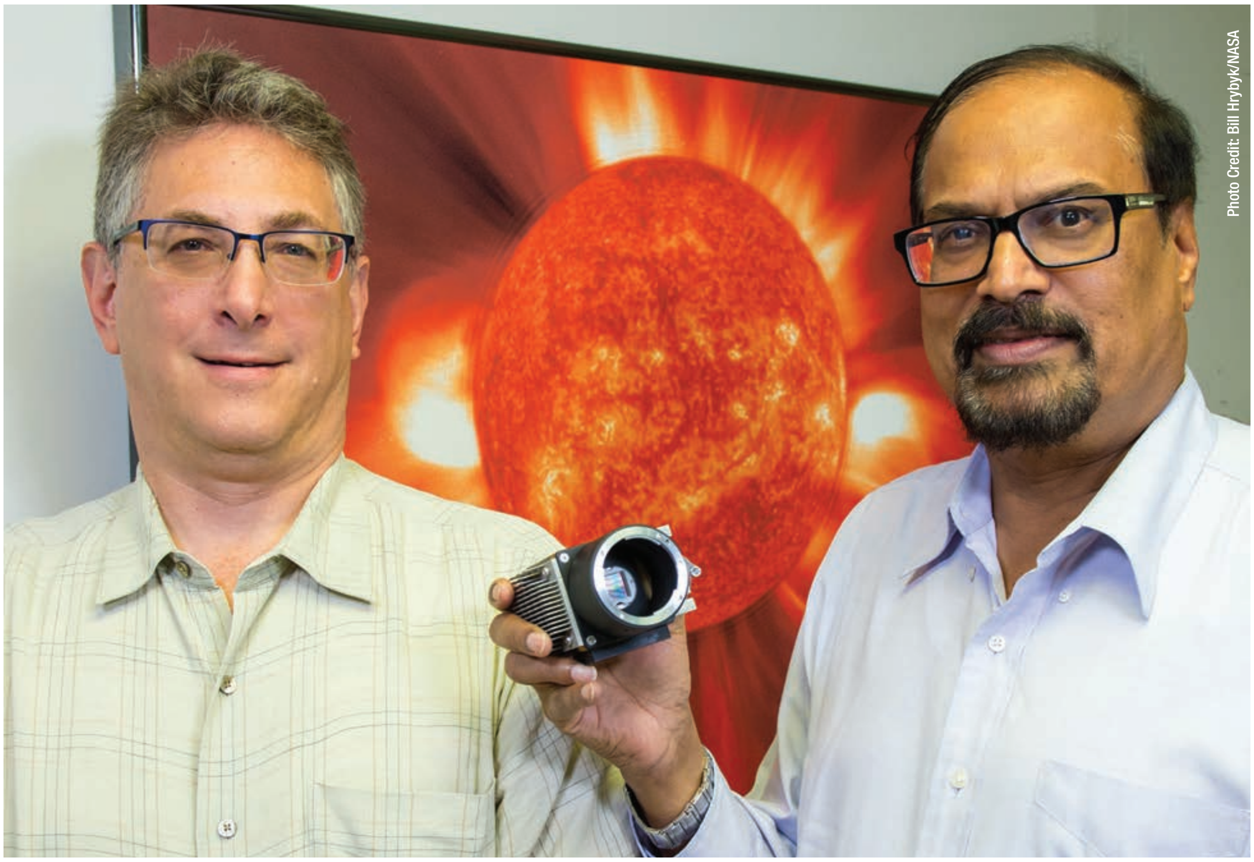
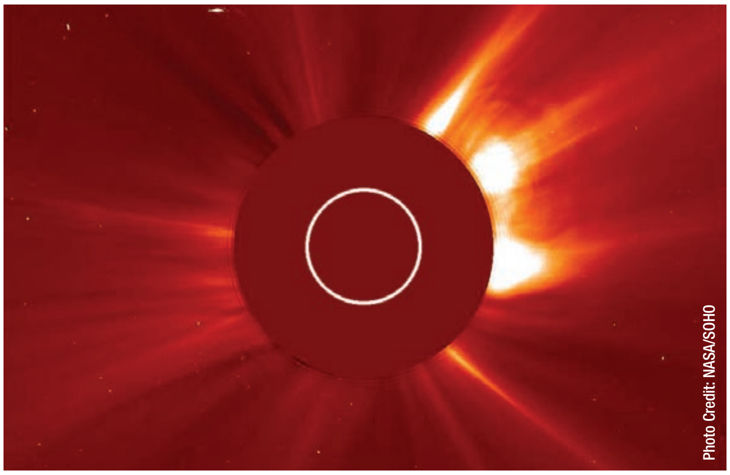


Photo Credit: Bill Hrybyk/NASA

Goddard heliophysicists Jeff Newmark (left) and Nat Gopalswamy, who is holding the polarization camera he used to gather 50 images during the total solar eclipse in August 2017, plan to fly a new coronagraph on a balloon-borne mission next year.

Understanding the source of the solar wind, which determines how space weather-causing coronal mass ejections, or CMEs, propagate between the Sun and Earth, can help improve space-weather forecasts, particularly in the near-Earth environment where changes can sometimes interfere with radio communications or GPS. During particularly strong geomagnetic storms, sparked by the release of tons of charged particles during a CME, particles that make up the solar wind can flow along magnetic fields through Earth's protective magnetosphere onto the surface where they can disrupt power grids and electronics.



This image from the Solar and Heliospheric Observatory shows streaks of bright light. This represents material streaming out from the Sun, which is obscured in this picture by the central red disk so that its light doesn't overwhelm the fainter material around it. Scientists want to better understand what causes this regular outflow, known as the solar wind.

During its sojourn 25 miles above Earth's surface, BITSE will spend up to 10 hours imaging the Sun's corona. In addition to an occulter that blocks light from the Sun's surface — much like how the Moon blocks the bright light during a solar eclipse — BITSE carries two other important technologies.

The filters block all wavelengths of visible light except for those in four specific bands in the violet range — 3850, 3987, 4100, and 4233 Angstroms. And the polarization camera, which serves as BITSE's detector, is able to directly collect polarized light — that is, light where the electric and magnetic fields oscillate in specific directions. Scientists need the polarized light to derive the electron properties. Because the camera can collect polarized light, BITSE doesn't require an extra mechanism to carry out the same task as do more traditional detectors.

Together, these payload components will allow the team to execute an observational technique called passband ratio imaging — an approach originally proposed in 1976. This technique determines electron temperature and speed, along with the density information that coronagraphs traditionally gather.

It works like this: "The visible light we're seeing is actually light from the Sun's disk that scatters from the electrons in the solar wind," Newmark explained. "This scattering 'smears out' the light from the disk, which is actually lots of individual spectral lines or wavelengths. If we choose the right wavelengths to look at, then the amount of smearing tells us the temperature and speed the electrons must exhibit to smear the light in that way."

"Anyone can make a filter wheel tuned to four individual visible wavelengths, but we put this technology together to make our instrument do what we want it to do. It's cool. It's the first time we've done this," Newmark added.

The team plans to test the full-up BITSE system at the vacuum facility at the National Center for Atmospheric Research in Boulder, Colorado, in the spring of 2019. However, Gopalswamy did mount the polarization camera on a telescope and obtained 50 images in all four filters during the total solar eclipse in August 2017.

ISS Instrument Sought

The field campaign during which Gopalswamy imaged the solar eclipse proved that the BITSE camera and filter technique work. The balloon flight, however, is critical for validating the system in a near-space environment where Gopalswamy and Newmark hope to gather at least eight hours of data, which Gopalswamy likens to observing 150 solar eclipses.

The team hopes the balloon mission won't be the last hurrah for the coronagraph. "We really want to put a version of this instrument on the International Space Station," Newmark said. The team's methodical approach — from the first field campaign observing the solar eclipse to the balloon fight in 2019 — paves the way for a longer-term mission in low-Earth orbit, Newmark said. "We can fly the instrument for six months on the station," Gopalswamy added. "Literally, we're going from minutes, to hours, to months gathering these much-needed solar wind parameters that will feed into our space-weather models." ❖

CONTACTS

Natchimuthuk.Gopalswamy-1@nasa.gov or 301.286.5885

Jeffrey.Newmark@nasa.gov or 301.286.6806

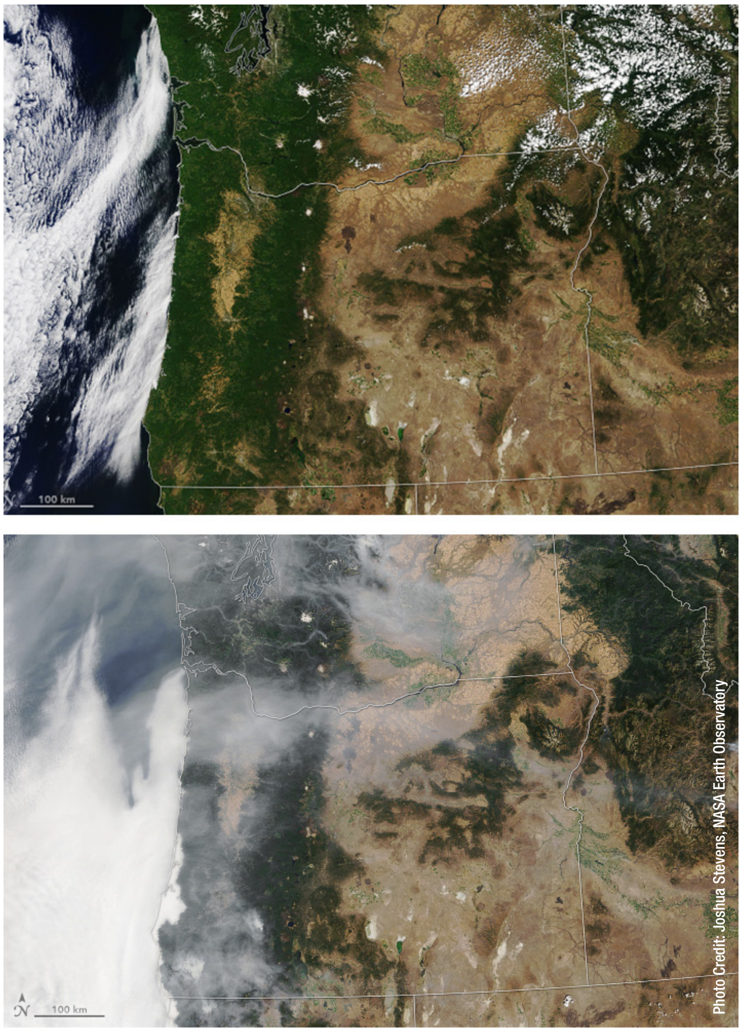
Teaching Machines to "See"

Goddard Teams Investigate Advanced Algorithms for Identifying Patterns in Data

Your credit card company contacts you asking if you've purchased something from a retailer you don't normally patronize or spent more than usual. A human didn't identify the atypical transaction. A computer — equipped with advanced algorithms — tagged the potentially fraudulent purchase and triggered the inquiry.

Goddard researchers think scientists and engineers could benefit from the same technology, often referred to as machine learning or neural networks.

Considered a subset of artificial intelligence, machine learning and neural networks are actually in the avant-garde. Instead of programming a computer to carry out every task it needs to do, the philosophy behind machine learning is to equip ground- or space-based computer processors with algorithms that, like humans, learn from data, finding and recognizing patterns and trends, but faster, more accurately, and without bias.



The Moderate Resolution Imaging Spectroradiometer, or MODIS, on NASA's Terra satellite acquired these natural-color images. The photo on the bottom shows the enormous amount of smoke produced during fires in Oregon last summer. The image on the top was taken on a clear day. A Goddard computer engineer, James MacKinnon, has used MODIS data to train algorithms how to detect wildfires.

Wide-Ranging Applications

"The benefits are many and the applications are wide ranging," said Goddard Senior Fellow and Assistant Chief for Technology Jacqueline Le Moigne, who has been working in artificial intelligence since her graduate school days in France several years ago.

"Scientists could use machine learning to analyze the petabytes of data NASA has already collected over the years, extracting new patterns and new correlations and eventually leading to new scientific discoveries," she said. "It could also help us monitor the health of a spacecraft, avoid and recover from catastrophic failures, and prevent collisions. It could even assist engineers, providing a wide range of knowledge about past missions — information they would need in designing new missions."

With funding from several NASA research programs, including the Earth Science Technology Office, or ESTO, Goddard engineers and scientists are researching some of those applications individually or in partnerships with academia and private industry. Their projects run the gamut, everything from how machine learning could help in making real-time crop forecasts or locating wildfires and floods to identifying instrument anomalies and even suitable landing sites for a robotic craft.

"People hear artificial intelligence and their minds instantly go to science fiction with machines taking over, but really it's just another tool in our data-analysis toolbox and definitely one we shouldn't neglect because of preconceived notions," said James MacKinnon, a Goddard computer

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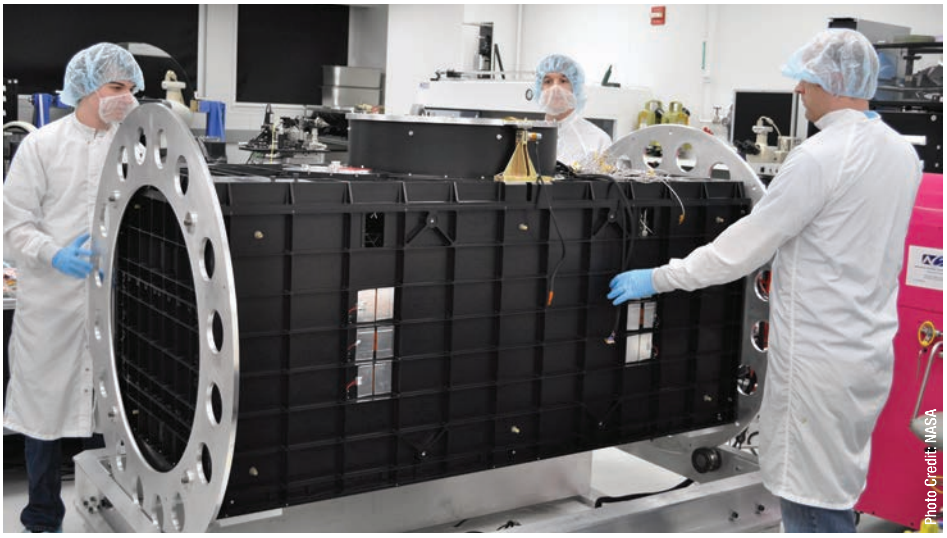
engineer who is involved in several projects involving artificial intelligence.

Finding Fires

Since joining Goddard a couple years ago, MacKinnon has emerged as one of the technology's most fervent champions. One of the first projects he tackled involved teaching algorithms how to identify wildfires using remote-sensing images collected by the Terra spacecraft's Moderate Resolution Imaging Spectroradiometer. His neural network accurately detected fires 99 percent of the time. He has since expanded the research to include data gathered by the Joint Polar Satellite System's Visible Infrared Imaging Radiometer Suite.



Data gathered by Goddard's Cloud-Aerosol Transport System, a refrigerator-sized instrument shown here, is being used to advance machine-learning algorithms under a Goddard-industry partnership.

His dream is to ultimately deploy a constellation of CubeSats, all equipped with machine-learning algorithms embedded within sensors. With such a capability, the sensors could identify wildfires and send the data back to Earth in real time, providing firefighters and others with up-to-date information that could dramatically improve firefighting efforts. "The key here is processing the data onboard, not only for wildfires but for floods. There are a lot of things you could do with this capability," he said.

He is also developing machine-learning techniques to identify single-event upsets in spaceborne electronic devices, which can result in data anomalies, and compiling a library of machine-learning computer models, dataset-generation tools, and visualization aids to make it easier for others to use these techniques for their missions, he said.

"A huge chunk of my time has been spent convincing scientists that these are valid methods for analyzing the massive amounts of data we generate," he said.

Cutting Through the Noise

Goddard scientist Matt McGill doesn't need convincing. An expert in lidar techniques to measure clouds and the tiny particles that make up haze, dust, air pollutants, and smoke, McGill is partnering with Slingshot Aerospace. This California-based company is developing platforms that pull data from many types of sensors and use machine-learning algorithms to extract information.

Under the ESTO-funded effort, McGill is providing Slingshot with data he gathered with the Cloud-Aerosol Transport System, or CATS, instrument, which retired late last year after spending 33 months aboard the International Space Station. There, CATS measured the vertical structure of clouds and aerosols, which occur naturally during volcanic eruptions and dust storms or anthropogenically through the burning of oil, coal, and wood. A Slingshot-developed machine-learning algorithm is ingesting that data so that it can learn and ultimately begin to recognize patterns, trends, and occurrences that are difficult to capture with standard processing algorithms.

McGill is particularly interested in seeing whether machine-learning techniques can filter out the noise that is common in lidar measurements. Although humans already cull noise from data, current techniques are time-consuming and can take days to accomplish — antithetical to the goal of distributing intelligence in real time. "The idea is that algorithms, once trained, can recognize signals in hours rather than days," McGill said.

Just as important, at least to McGill, is the need to miniaturize CATS-like lidar systems. While CATS was roughly the size of a refrigerator, future systems must be much smaller, capable of flying on a constellation of SmallSats to collect simultaneous, multipoint measurements. However, as instruments get smaller, the data can potentially be noisier due

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to smaller collection apertures, McGill explained. "We have to get smarter in how we analyze our data and we need to develop the capability to generate true real-time data products."

Photo Credit: iStock

A Goddard team, led by heliophysicist Antti Pulkkinen, is investigating machine-learning techniques to find a causal relationship between dolphin strandings and strong winds during the winter months in Cape Cod, Massachusetts.

Dolphin Stranding

Getting smarter in data analysis is also driving Goddard heliophysicist Antti Pulkkinen and engineer Ron Zellar.

A couple years ago, Pulkkinen began investigating whether solar storms were causing otherwise healthy whales, dolphins, and porpoises — collectively known as cetaceans — to strand along coastal areas worldwide (CuttingEdge, Winter 2017, Page 14). While he and his team found no correlation, they did find a link between stranding events in Cape Cod, Massachusetts, and wind strength.

Is it possible that strong winds, which occur during the winter months when dolphins are more likely to beach, stir ocean phytoplankton and other nutrients that feed fish? Are the dolphins simply following their food source? "We can't assume a causal relationship," said Zellar, who, when not working on this project, serves as a mission-systems engineer on the Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, or OSIRIS-REx, mission. "That's what we're trying to find."

With funding from the Goddard Fellows Innovation Challenge, a program that funds the development of potentially revolutionary technologies, the team is applying machine-learning techniques to delve more deeply into environmental data to see if they can prove a cause.

Cutting the Umbilical Cord

In November, the OSIRIS-REx mission is scheduled to begin a series of complex maneuvers that take the craft closer to asteroid Bennu so that it can begin characterizing its surface and snapping images that will inform the best location for collecting a sample and returning it to Earth for analysis. This will require thousands of high-resolution images taken from different angles and then processed manually by a team of experts on the ground.

Scientists want to simplify and hasten the processing time.

Under a NASA-funded research effort involving Goddard scientists, Dante Lauretta, a University of Arizona professor and OSIRIS-REx principal investigator, and Chris Adami, a machine-learning expert at Michigan State University, a team is investigating the potential of networked algorithms. The goal is to teach onboard sensors to process images and determine an asteroid's shape and features — information needed to autonomously navigate in and around an asteroid and make decisions on where to safely acquire samples.

"The point is to cut the computational umbilical cord back to Earth," said Bill Cutlip, a Goddard senior business-development manager and team member. "What we're trying to do is train an algorithm to understand what it's seeing, mimicking how the human brain processes information."

Such a capability not only would benefit future missions to asteroids, but also those to Mars and the icy moons of Jupiter and Saturn, he said. With advances in field-programmable gate arrays or circuits that can be programmed to perform a specific task and graphics-processing units, the potential is staggering, he added.

In Its Infancy

Le Moigne agrees. "I suspect that with the rapid development of these technologies, these advances will come very soon. The artificial intelligence and machine-learning landscape at Goddard will be extremely different in probably less than five years," she said. ❖

CONTACTS

William.E.Cutlip@nasa.gov or 301.286.0438
Jacqueline.J.LeMoigne-Stewart@nasa.gov or 301.286.8723
James.MacKinnon@nasa.gov or 301.286.4785
Matthew.J.Mcgill@nasa.gov or 301.614.6281
Ronald.S.Zellar@nasa.gov or 301.286.7219

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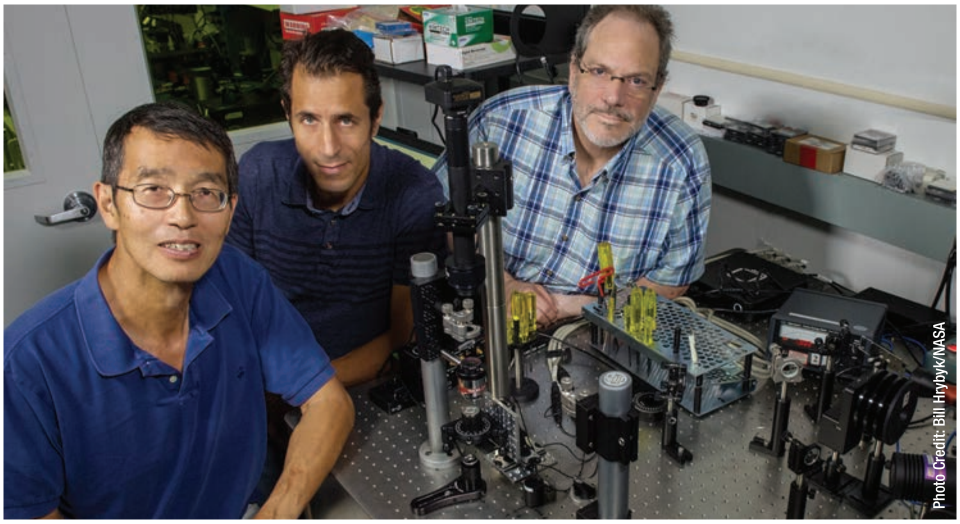
Goddard Team Investigates Ultrafast Laser Machining for Multiple Spaceflight Applications

An ultrafast laser that fires pulses of light just 100 millionths of a nanosecond in duration could potentially revolutionize the way that technicians manufacture and ultimately assemble instrument components made of dissimilar materials.

A team of Goddard optical physicists is experimenting with a femtosecond laser and has already shown that it can effectively weld glass to copper, glass to glass, and drill hair-sized pinholes in different materials.



Steve Li (left), Frankie Micalizzi (middle), and Robert Lafon (right) are using an ultrafast laser to bond dissimilar materials and etch microscopic channels or waveguides through which light could travel in photonic integrated circuits and laser transmitters.

Now the group, led by Robert Lafon, is expanding its research into more exotic glass, such as sapphire and Zerodur, and metals, such as titanium, Invar, Kovar, and aluminum — materials often used in spaceflight instruments. The goal is to weld larger pieces of these materials and show that the laser technology is effective at adhering windows onto laser housings and optics to metal mounts, among other applications.

With support from the Space Technology Mission Directorate's Center Innovation Fund program, the group is also exploring the technology's use in fabricating and packaging photonic integrated circuits, an emerging technology that could benefit everything from communications and data centers to optical sensors. Though they are similar to electronic integrated circuits, photonic integrated circuits are fabricated on a mixture of materials, including silica and silicon, and use visible or infrared light, instead of electrons, to transfer information.

But important differences exist between the two types of circuits. Traditional information-carrying circuitry slows down electrons, which is why electronics heat up and limit the amount of data that can be transmitted. In contrast, photons or particles of light move at light speed with no interference. Furthermore, they don't heat, allowing greater amounts of information to be transmitted at once at only a fraction of the energy they carry.

For these reasons, researchers are excited about the potential of integrated photonics and believe NASA could benefit enormously from their use.

"This started as pure research, but now we hope to start applying what we have learned to the fabrication of instruments here at Goddard," Lafon said, referring to the work that he, Frankie Micalizzi, and Steve Li are executing with a used ultrafast laser and setup. "We already see what the applications could be. In this case, research for research's sake is in our best interest," Lafon said.

The Technology's Virtues

Central to advancing these applications is the laser itself. By virtue of its short pulses — measured at one quadrillionth of a second — an ultrafast laser interacts with materials in a unique way, Lafon said. The laser energy doesn't melt the targeted material. It vaporizes it without heating the surrounding matter.

As a result, technicians can precisely target the laser and bond dissimilar materials that otherwise couldn't be attached without epoxies. "It's not possible to bond glass to metal directly," Lafon said. "You have to use epoxy, which outgases and deposits contaminants on mirrors and other sensitive instrument components. This could be a serious application. We want to get rid of epoxies. We have already begun reaching out to other groups and missions to see how these new capabilities might benefit their projects."

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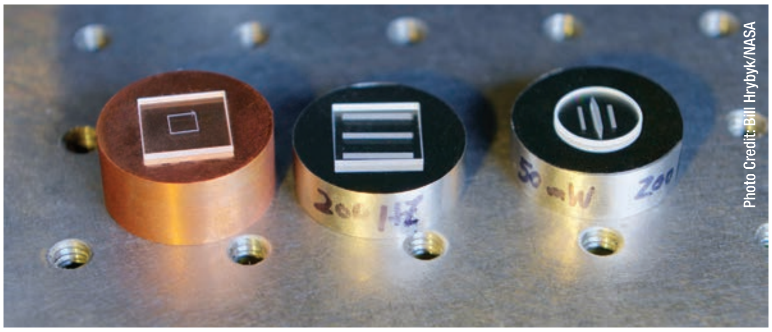
Another important application is in the area of micromachining. “The ability to remove small volumes of material without damaging the surrounding matter allows us to machine microscopic features,” Lafon added.

Microscopic features include everything from drilled, hair-sized pinholes in metals — an application the team already demonstrated — to etching microscopic channels or waveguides through which light could travel in photonic integrated circuits and laser transmitters. The same waveguides could allow liquids to flow through microfluidic devices and chips needed for chemical analyses and instrument cooling.



A Goddard team is using an ultrafast laser to bond dissimilar materials, with the goal of ultimately eliminating epoxies that outgas and contaminate sensitive spacecraft components. Shown here are a few samples (from left to right): silica welded to copper; silica welded to Invar; and sapphire welded to Invar.

Widespread Applicability to NASA Projects

“Ultrafast lasers offer fundamental changes in how we can microprocess materials,” said Ted Swanson, senior technologist for strategic integration at Goddard. “The team’s work on this research effort will allow Goddard to adapt this emerging technology to a wide variety of flight applications.”

To that end, the team — between working on several of NASA’s high-profile laser-communications projects, including the Laser Communications Relay Demonstration mission — plans to compile a library of micromachining and welding capabilities. “Once we are able to demonstrate this capability reliably, we will attempt to apply it to existing challenges here at Goddard. Our initial research is showing that this technology could be applied to a large number of projects across NASA,” Lafon said. ❖

CONTACT

Robert.Lafon@nasa.gov or 301.286.4409

It Takes a Village

New Exoplanet Collaboration Seeks to Answer Age-Old Question: Are We Alone?

Answering the age-old question — are we alone in the cosmos — isn’t a challenge that will be done alone. It will take an interdisciplinary village.

That’s why NASA funded the Sellers Exoplanet Environment Collaboration, or SEEC, last year. This Goddard-run, multi-disciplinary research program is leveraging existing expertise and applying knowledge of solar-system bodies to improve analytical tools that could help scientists better understand the physical conditions on an alien world, and more profoundly, discover if life exists there.

Tearing Down the Stovepipes

“We all need to work together, especially with the flood of data coming down from existing planet-finding spacecraft and those planned for the future,” said SEEC Director and Research Scientist Avi Mandell, adding that Goddard is the logical choice for such a program because it’s home to experts in all pertinent scientific disciplines — planetary, Earth science, heliophysics, and astrophysics.

“SEEC is focused on enabling scientists to break out of stovepipes so that they can pool their knowledge and expertise relating to planetary systems and the search for life,” Mandell said. “When it comes to exoplanet discovery and characterization, these topics intersect.”

Since the discovery of the first extra-solar planet in 1995, ground- and space-based observatories have found thousands of candidates. NASA’s exoplanet hunter, the Kepler Space Telescope, alone has confirmed about 2,327, most of them ranging between the size of Earth and Neptune in our region of the Milky Way — a planet size not found in the solar system. Earlier this year, NASA launched its most recent exoplanet finder — the Transiting Exoplanet Survey Satellite, or TESS. As a follow-on to Kepler, TESS will scan nearly the entire sky and is expected to uncover thousands of additional exoplanets.

“The planetary zoo has become amazingly diverse in the 23 years since the first discovery,” Mandell

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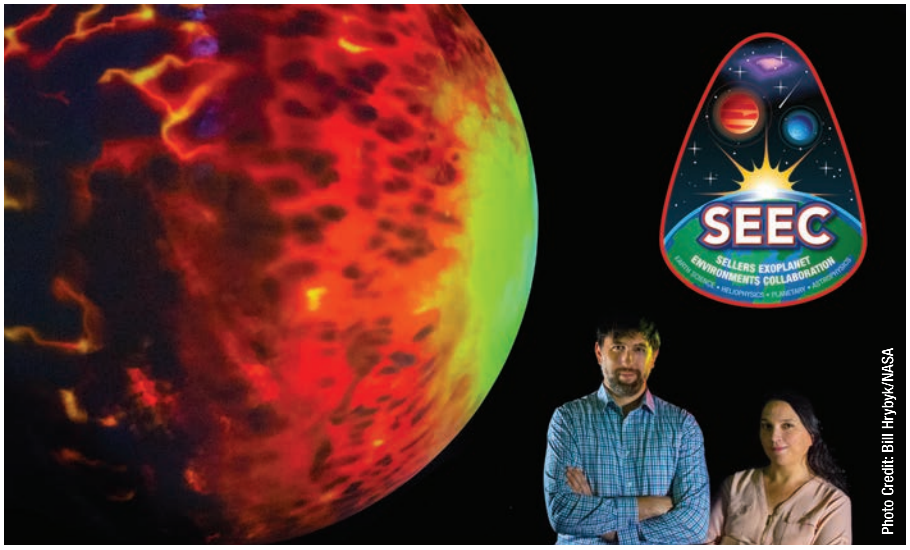
continued. With a new crop of more advanced observatories slated to launch over the coming decade, including the James Webb Space Telescope, the quest will be to not only identify additional exoplanets, but characterize them and, perhaps, detect chemical signatures of life in their atmospheres.



Goddard scientists Avi Mandell and Elisa Quintana are among the scientists participating in the Sellers Exoplanet Environment Collaboration, a cross-disciplinary research effort named after the late Piers Sellers. The collaboration is now funding 16 cross-disciplinary research teams that are working with already-existing analytical tools, such as 3-D general-circulation and stellar-outflow models, to see how they could be adapted or modified to run simulations that would advance exoplanet science.

But to conclusively determine if life exists on an alien world, scientists will need to know what to look for to make sure they recognize the signatures of a life-bearing planet and also avoid a false positive. They will need to tap into the expertise of all scientific disciplines to assure they have the analytical tools and knowledge needed to accurately interpret data and determine if they've found a truly inhabited world.

Sixteen Cross-Disciplinary Teams

Named after preeminent astronaut and NASA science champion, the late Piers Sellers, SEEC is now supporting 16 cross-disciplinary research teams that are working with already-existing analytical tools, such as 3-D general-circulation and stellar-outflow models, to see how they could be adapted or modified to run simulations that would advance exoplanet science — a field that has literally exploded since the discovery of the first extra-solar planet.

With a set of integrated and well-tested tools, institutional knowledge, and collaborative relationships among scientists who may not necessarily work together under other circumstances, NASA thinks it will be better equipped to dive into data from exoplanet missions over the next 10 to 20 years. Mission planners could also use the tools to set observational requirements and science goals for next-generation telescopes.

The Exoplanet Modeling and Analysis Center, or EMAC, plays a central role in the SEEC research effort. Modeled on the Community Coordinated Modeling Center, which NASA and the National Science Foundation created to provide space weather-related models to researchers, EMAC houses community modeling and analytical tools. By tapping into the EMAC cloud server, users can access tools and combine or add modules, enabling previously impossible cross comparisons and multi-modal analyses.

High-Quality Science Shown

"We are showing that we can do high-quality science with SEEC teams," said Bill Danchi, deputy SEEC director, who himself is interested in planet habitability and the role of stellar explosions, such as coronal mass ejections, that influence prebiotic atmospheric chemistry and atmospheric loss.

Another SEEC researcher, Goddard planetary scientist Scott Guzewich, is working with astrophysicists Giada Arney and Ravi Kopparapu to adapt ROCKE 3-D — short for Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics. Developed by the NASA Goddard Institute for Space Studies in New York, the tool models the atmospheres of solar system and exoplanetary terrestrial planets. The goal is to expand the model's capabilities to handle a broader range of atmospheric conditions that, among other things, could help scientists determine exoplanet rotation rates and the role that oceans and continents may play in an exoplanet's climate.

"SEEC is bringing together all the science disciplines to address questions that we couldn't address alone," Guzewich said. "It is opening up new areas of exoplanet science." ❖

CONTACTS

Avi.Mandell@nasa.gov or 301.286.6293
William.C.Danchi@nasa.gov or 301.286.4586

Goddard Teams Study Probe-Class Missions

Many astrophysicists think it's time to create a new class of astrophysics missions that would fill the niche between Small- or Medium-Class Explorers and the multi-billion-dollar flagship missions that on average take nearly two decades to develop.

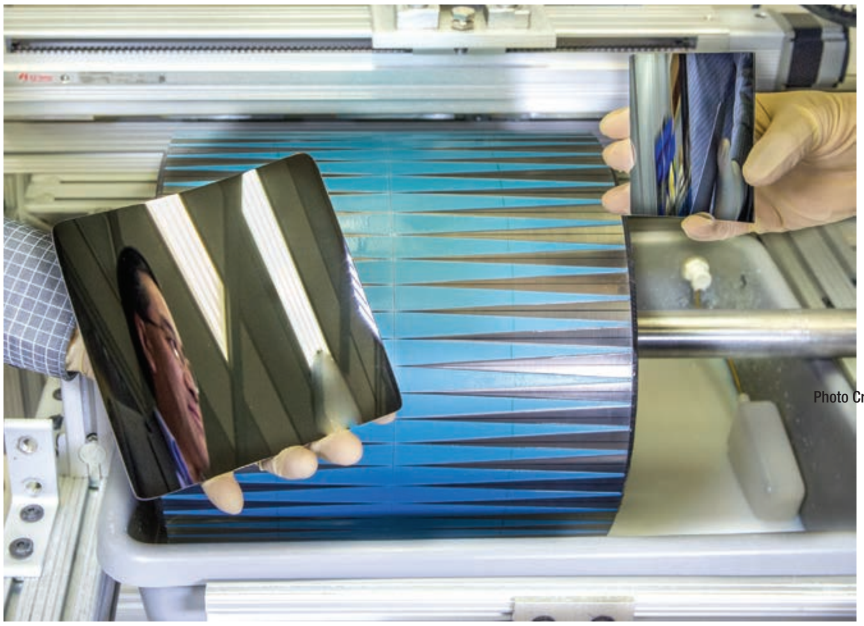


Photo Credit: Bill Hrybyk/NASA

The conceptual Advanced X-ray Imaging Satellite is envisioned as a Probe-Class successor to the Chandra X-ray Observatory. It relies on Goddard technology — in particular, the low-cost, lightweight, high-resolution X-ray mirrors that scientist Will Zhang (shown in the mirror reflection) has advanced for nearly 15 years with Goddard IRAD and other funding.

At the end of 2018, several teams — many of them involving Goddard experts — will complete studies of concepts that could qualify as potential "Probe-Class" missions — a proposed classification that many in the astrophysics community support. To qualify as a Probe, these missions can't exceed more than $1 billion to complete and launch.

The 2020 Astrophysics Decadal Survey, which evaluates new missions and recommends those it believes NASA should pursue in the next decade, is expected to consider the creation of a new astrophysics classification that would mirror the New Frontiers missions that NASA awards to planetary investigations and possibly recommend one or more of the concepts now under study.

Transformational Science

"There's excitement in the astrophysics community for a Probe Class," said Goddard's Astrophysics Division Director Rob Petre, who, along with hundreds of others, attended a session about Probe mission concepts at the annual American Astronomical Society conference in January. "The quality of the science across the board was astounding. Each of the proposed Probes would produce transformational science. It's pretty clear that there is a huge amount of science we're missing because we don't offer a mission class between smaller Explorer missions and our flagships."

Last year, NASA's Science Mission Directorate — understanding that "exciting science could be done" with $1-billion missions — selected 10 teams from around the U.S. to carry out detailed studies of possible Probes, Petre said. Two are led by Goddard scientists; several others include significant participation from Goddard scientists. The Center's Internal Research and Development, or IRAD, program also provided funding to three other Goddard-led studies beyond those selected by NASA.

"The key point here is that we at Goddard are deeply involved in many of these concepts," Petre said, adding that many of these concepts would have been impossible to propose as Probe-Class missions just a few years ago. Technological improvements, many of them advanced by Goddard experts, now make them feasible. "We've been key players in concept and technology development. This has been an exciting venture for us," he added.

The 10 NASA-selected concepts will be submitted to NASA decisionmakers at the end of 2018. Once independently evaluated for costs, NASA will then present the concepts to the Decadal Survey for consideration in 2019. The concepts being studied internally by Goddard will be submitted directly to the Decadal Survey sometime in 2019.

Cover the Gamut

According to Petre, the concepts cover the gamut in compelling questions, everything from the polarization of the cosmic background radiation to the electromagnetic counterparts of gravitational waves. And another proposes to develop a starshade to rendezvous with NASA's Wide Field Infrared Survey

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Telescope. The starshade's job would be to block starlight to reveal faint exoplanets in orbit around their parent stars.

A couple concepts are conceived as follow-on missions to current missions, Petre added. One such concept is the NASA-funded Cosmic Evolution Through UV Spectroscopy, or CETUS, mission. "This is basically like a mini-Hubble," said Goddard senior scientist and CETUS Principal Investigator Bill Danchi. CETUS, through its multi-target ultraviolet spectroscopy, would study why galaxy formation peaked about 10 billion years ago, Danchi said.

One of its enabling technologies is the Goddard-developed microshutter array, which features tiny shutters that open or close to block all light except that of targeted stars or galaxies. This allows scientists to observe 100 or more targets simultaneously, depending on the field being observed. Developed originally for the James Webb Space Telescope, the technology is now lighter and simpler — in other words, ideal for a $1-billion-capped mission, Danchi said.

The conceptual Advanced X-ray Imaging Satellite, or AXIS, is envisioned as a Probe-Class successor to the Chandra X-ray Observatory. It would study X-ray binary-star systems, galaxy mergers, and black holes, said Goddard scientist Andy Ptak, a member of the AXIS team. It, too, relies on Goddard technology — in particular, the low-cost, lightweight, high-resolution X-ray mirrors that scientist Will Zhang has advanced for nearly 15 years with Goddard IRAD and other funding (*CuttingEdge*, Winter 2017, Page 3).

"To fit in the $1-billion Probe cost cap, AXIS mirrors have to be very inexpensive, yet provide 10 times the collecting area as Chandra, yet weigh a third of what Chandra's optics weighed," Zhang said. "I know it sounds like it's too good to be true, but our new optics are on the way to making this dream come true." ❖

CONTACT

Robert.Petre-1@nasa.gov or 301.286.3844

FY18 Innovators

Accomplishing, *continued from page 6*

Innovative thinking was also on display shortly after ground controllers recovered Dellingr from the reset loop. Due to a bug in the attitude-control system, which includes torquers and reaction wheels that rotate a satellite in small amounts, the spacecraft began to spin, preventing the INMS from collecting data. Unable to slow down the spacecraft with the existing attitude-control system, the team wrote a new software application, uploaded it, and used one of Dellingr's two miniaturized onboard magnetometers as an attitude sensor, which provided data needed to activate Dellingr's torquers to help stabilize the spinning.

"Thanks to the heroic efforts of the Dellingr team, the spacecraft recovered from a fast spin, tumbling once every five seconds, to once every 50 minutes," said INMS Principal Investigator Nick Paschalidis. The instrument team turned on the instrument's ion mode and collected mass spectra for hydrogen, helium, and oxygen. "We have collected excellent data," Paschalidis said.

The now patented and licensed DANY, which released Dellingr's magnetometer boom and UHF antenna, also "worked perfectly and is a huge success," said Dellingr Project Manager Chuck Clagett. And Principal Investigator Allison Evans also reported success with her CubeSat Form Factor Thermal Louver Experiment, a miniaturized thermal-control system whose louvers successfully opened or closed depending on whether heat needed to be conserved or shed. Meanwhile, Eftyhia Zesta, the principal investigator on the two magnetometer systems, is still analyzing her data, but considers the flight of the miniaturized instruments a success onto themselves.

"The team has tackled issues head on, is collecting and analyzing data, and has moved CubeSat capabilities from rudimentary, unreliable spacecraft to highly capable science platforms, all while enhancing workforce skills," Hughes said. "I think we'll be enjoying the fruits of the team's labor for years to come." ❖

Cutting edge Goddard's Emerging Technologies

CuttingEdge is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Maryland. The publication describes the emerging, potentially transformative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, *Peter.M.Hughes@nasa.gov*. If you wish to be placed on the publication's distribution list, contact Editor Lori Keesey, *Lori.J.Keesey@nasa.gov.* NP-2018-10-2281-GSFC