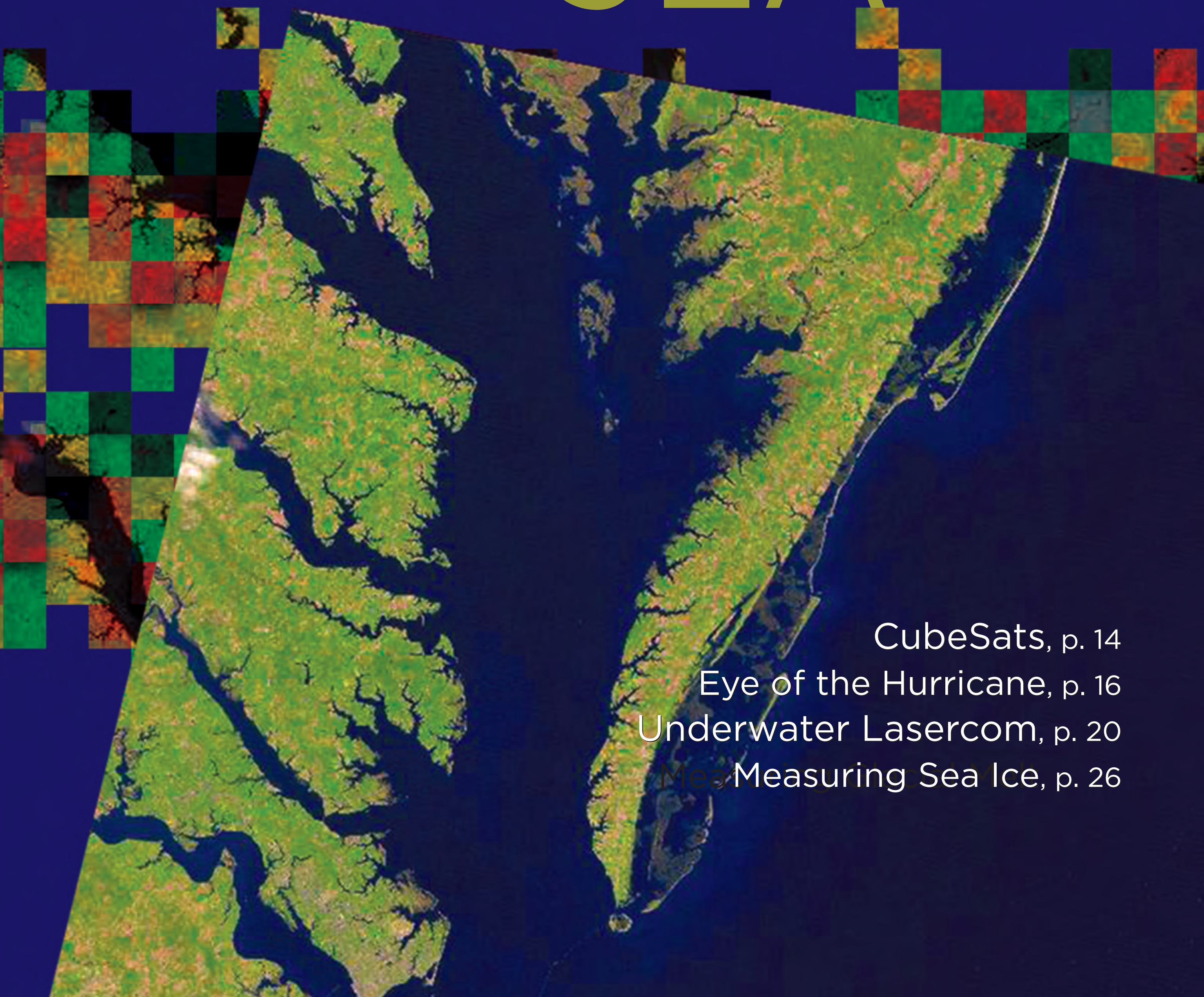
SPIE. Professional

July-September 2019

LAND AND SEA



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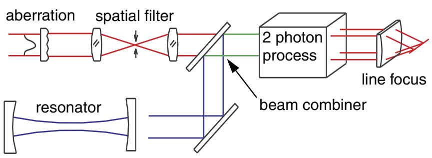

GLAD uses a general description of intensity and phase to perform full diffraction propagation through the most complex systems including detailed treatment of laser gain, nonlinear optics, stable or unstable resonators, diffractive optics, waveguides, fibers and coupling, fiber lasers, photolithography, excimers, optical integrators, etc.

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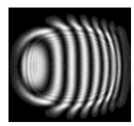
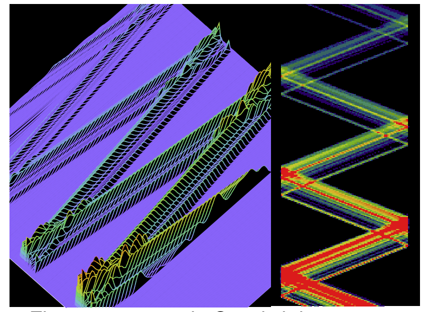
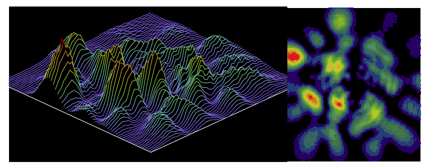
- Lens and mirror arrays
- Binary optics and gratings
- 3D waveguides and fibers

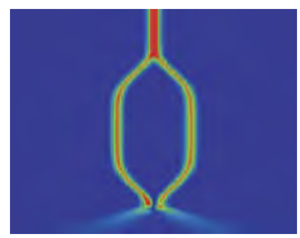




Zigzag resonator in Q-switch laser showing amplification from top to bottom and self-interference at side mirrors.



Transient Q-switch laser mode at 2ns



Photonic switch in the *off* position

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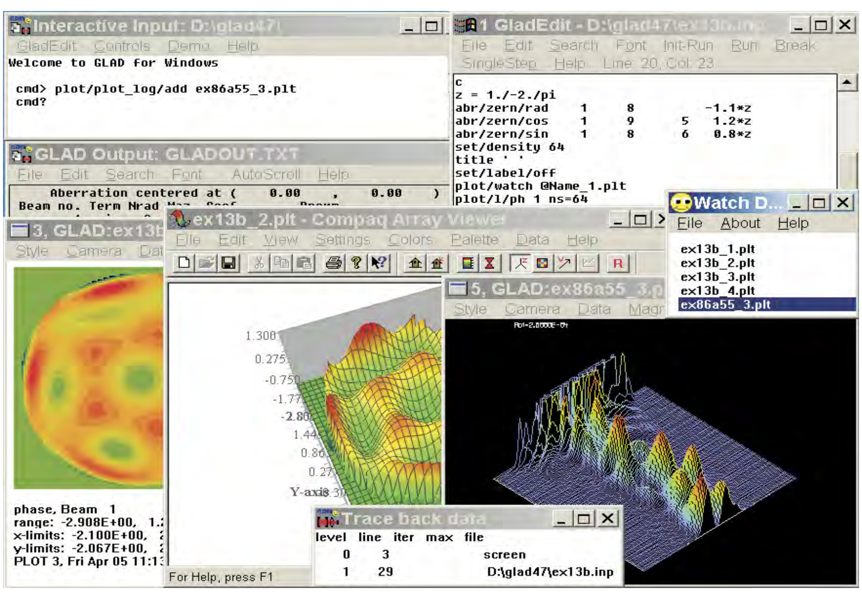

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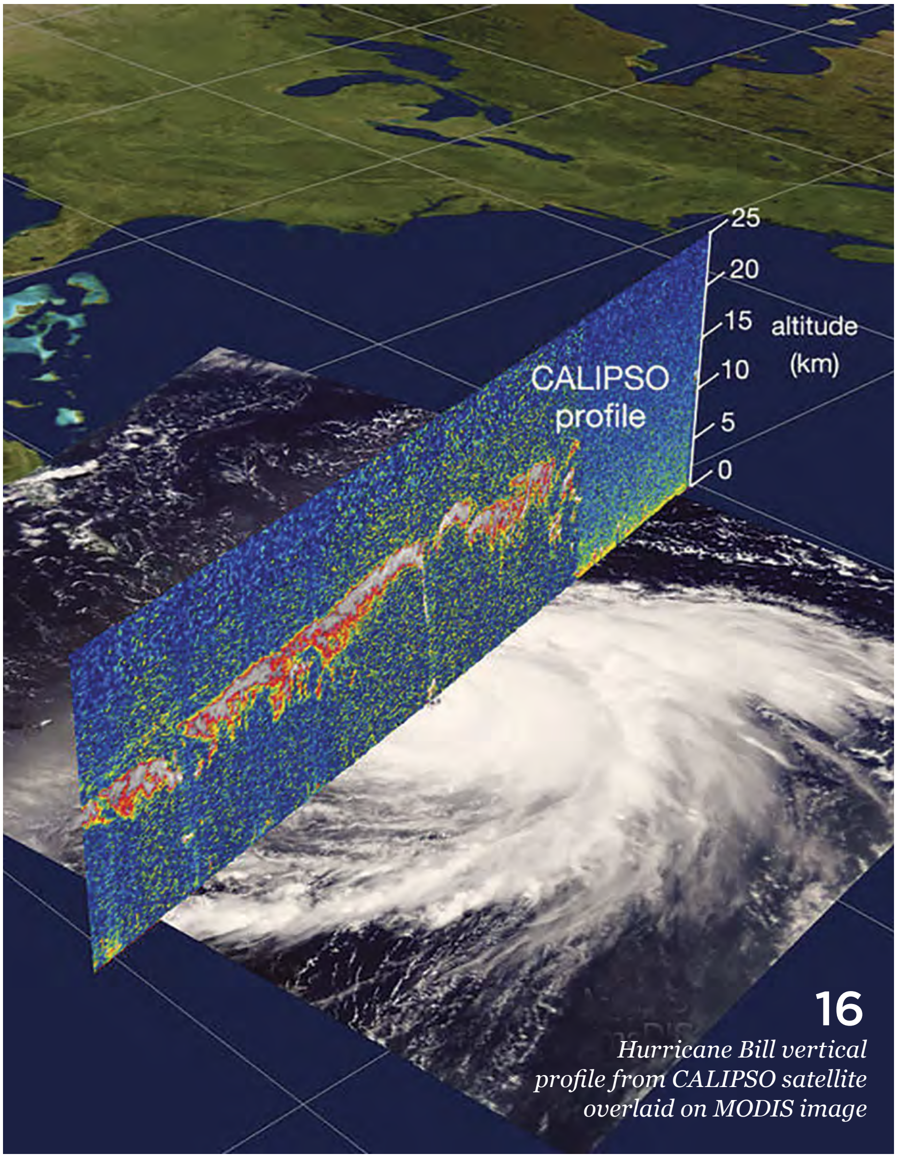
SPIE Professional

Volume 14, Number 3 (ISSN 1817-4035)



16
Hurricane Bill vertical profile from CALIPSO satellite overlaid on MODIS image

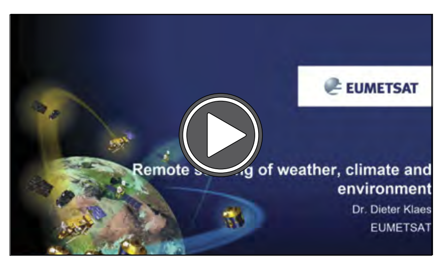
Credit: NASA

FEATURES

ONLINE OPTICS + PHOTONICS 2018 PLENARY RECORDINGS IN THE SPIE DIGITAL LIBRARY

Metasurface flat optics: Unifying semiconductor manufacturing and lens making
Federico Capasso
» spie.org/OP18_DL1

Making smart windows smarter
Yueh-Lin (Lynn) Loo
» spie.org/OP18_DL2



Remote sensing of weather, climate, and environment
K. Dieter Klaes
» spie.org/OP18_DL3

Credit: *Planet Labs Inc.*

Credit: *Tina Jaskolski*

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SPIE Professional

JULY-SEPTEMBER 2019

Volume 14, Number 3
ISSN 1817-4035

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SPIE.

ON THE COVER
Landsat-7 image courtesy of the US Geological Survey

Connecting Minds, Advancing Light through Remote Sensing

By **Jim Oschmann**

SPIE President Jim Oschmann "field testing" marine navigation apps that utilize satellite imagery and data.

This issue of *SPIE Professional* highlights optical systems looking at or working in land and water. Recently retired from a long career as an aerospace engineer, I would like to highlight one of my favorite optical technologies in this arena, remote sensing.

It is now a given that app-based navigation systems like Google Maps include images of terrain and features at increasing resolution. In less than 20 years, this information has expanded from a few specialized uses to an assumption that everyone will have it available at our fingertips through our smartphones.

Over the water, information from satellites guides navigation, much like it is used on land. I personally use marine navigation apps that include satellite remote imaging for planning and following routes on our boating vacations. (Speaking of which, I need to plan our next boating vacation…have I mentioned that I'm retired?)

In addition to navigating the open waters, knowing the weather in advance is a critical safety issue for boaters, as it is over land. How many people know that the vast majority of the data behind ever-improving weather forecasting around the globe come from satellites? Microwave sensors, imagers, and spectral data combine to provide the core data to detect, track, and predict the path of major storms. They can image, measure temperature, humidity, and precipitation profiles differentiating between rain, snow, and hail. The data and data analysis from these systems, produced by a number of countries, is shared worldwide.

Increasingly often, these systems are being produced through international collaborations, such as the NASA/JAXA Global Precipitation Measurement Satellite. Sharing and understanding the data from these satellites has become an international scientific journey. Even in regional forecasts to the public, a range of US and European models are used to explain potential paths for severe storms. This data comes almost exclusively from satellites with optical, infrared, and microwave sensors onboard.

Further improvements to forecasting ability are underway. Beyond weather satellites, a number of existing and planned scientific Earth remote sensing instruments have increased our capabilities to study ice, water properties (such as salinity, wave states, etc.), atmospheric pollution transport, ozone, and clouds. These and many other properties feed into our evolving understanding of our Earth as a system.

Often, these scientific instruments prove useful in obtaining further improvements to forecasting weather and environmental quality, leading to future weather and environmental remote sensing systems. For example, articles in this issue describe the recent launch of ICESat-2, which is delivering impressive data about the melt rate of glaciers and floating sea ice; the role of lidar aboard the National Oceanic and Atmospheric Administration's Hurricane Hunter aircraft; and the rapid Earth-mapping capabilities of yet-to-launch TanDEM-L.

What we have learned from space-based observations of Earth helps us know what to look for in our search for life elsewhere in the Universe. Many believe that some of these methods are technologically advanced enough, when combined with future large observatories and coronagraphs being planned, to detect the life-supporting elements of water and atmosphere around other planets, and possibly answer the question of life existing elsewhere in the Universe.

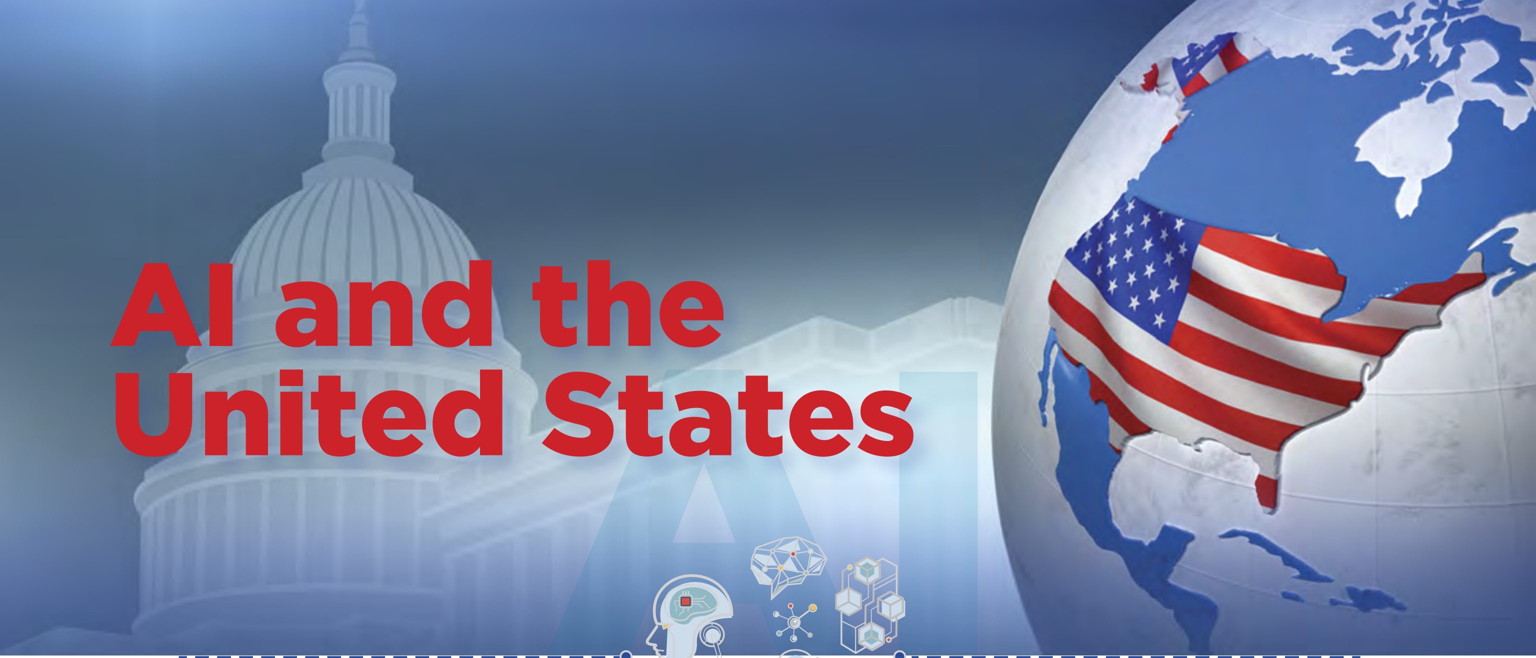
In the meantime, international partnerships have been expanding to join our collective ideas and capabilities to produce larger and more capable observatories in space and on the ground. The James Webb Space Telescope, European Extremely Large Telescope, Thirty Meter Telescope, and Giant Magellan Telescope are the (near) future generation of high-power observatories currently under construction with significant international partnerships. Not only countries, but scientists and engineers from government labs, academia, and industry are collaborating on these projects, and their cooperation is essential to enable these very challenging systems. Complex systems are sometimes required to answer complex questions.

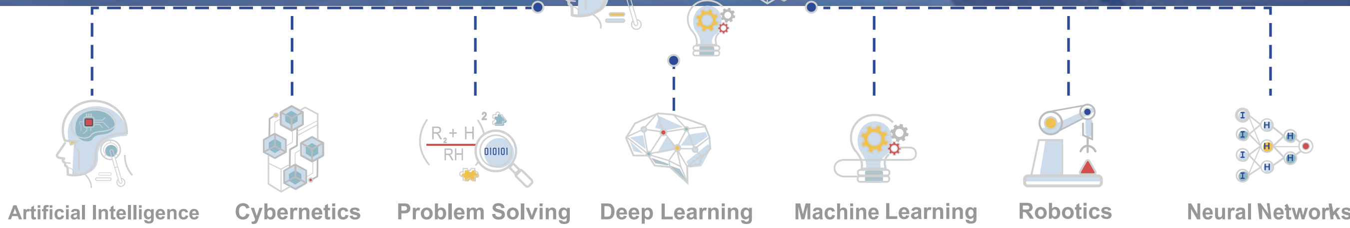
Take a look at the articles within to explore the myriad ways photonic technology operates in air and water, including laser communication, solar-powered water pumps in developing countries, commercial CubeSats, and more. I bet you and I will learn something new.

Many people working in photonics are "Connecting Minds" and "Advancing Light." These are just a few of their stories. Enjoy! ■

Jim Oschmann, 2019 SPIE President

AI and the United States





There may be a path, but it's not straight and it's not clear

By **Benjamin Isaacoff**

In February, US President Trump issued an executive order (**bit.ly/AmericanAI**) laying out the "American Artificial Intelligence Initiative" (AAII). This executive order appears to be an aspirational start to a full-fledged US AI national strategy. However, unlike the AI plans of peer and competing countries, the US AAII is not a detailed substantive plan that will, in and of itself, meaningfully move the nation forward on AI.

The last several years have seen countries across the world racing to get out in front of AI technologies and ensure that their companies, researchers, and/or militaries have the strategic advantage and aren't left behind in the (presumably) forthcoming AI revolution. No two countries have identical AI national strategies, but most feature large investments in AI R&D, efforts to boost a computer science–literate workforce balanced with policies aimed at helping workers displaced by automation, and calls to increase public and private sector uptake of AI-based tools.

The substance of the AAII covers most of the important areas that a comprehensive AI national strategy should. The AAII covers AI R&D by directing federal research funders to prioritize funding AI R&D. The critical issues of data availability and computing resources are similarly addressed, though somewhat broadly, by directing federal agencies to work on these areas while balancing countervailing privacy concerns. The AAII also mentions the often-overlooked issue of technical standards development for AI tools, in this case directing the National Institute of Standards and Technology (NIST) to issue a plan. The workforce section of the AAII focuses on traditional education support, though it does not delve into worker retraining or any "future of work" considerations. Finally, the AAII calls for balancing the need to keep international markets open for US AI industries, while still protecting and prioritizing US companies.

However, the AAII executive order omits some information as well. For example, it directs various federal agencies to make and implement their own plans to achieve these goals. And, although the AAII calls for investments in AI R&D, it doesn't specify that Congress should fund these initiatives. Instead, much of the funding language suggests that R&D funders should reallocate existing funds, as opposed to growing the overall R&D investment. The AAII also doesn't provide detail about the R&D investments the White House is calling for, an approach in contrast to many foreign AI National Strategies that are more strategic about the types of AI R&D they fund. Finally, the AAII does not mention directing public sector uptake of AI-based tools, something that AI policy experts and foreign governments believe to be a win-win approach to spurring AI development and deployment while increasing good governance.

Executive orders are often light on the

details, and this usually isn't a problem when they represent just one piece of an overall policy agenda. However, the AAII has left many observers unclear about White House priorities. For instance, the AAII calls for increasing AI R&D, however White House budget requests submitted to Congress have included large cuts to federal R&D funding. The US Congress has thus far chosen to increase R&D funding for the last several years, despite the budget requests to decrease it.

The AAII is also very interested in promoting and protecting the United States' current leading position in AI relative to other countries. One of the most effective strategies to ensure US leadership—one that has been wholeheartedly employed for the last century—is to attract the best and the brightest from around the world to study and work in the US. However, current immigration policies are making it more difficult for immigrants to come to the United States for work or study. Excluding foreign researchers and entrepreneurs will likely harm US prospects and grow those of other countries.

MANY POSSIBLE PATHS FORWARD

Congressional interest in a wide variety of AI policy topics has grown steadily. This independent congressional interest combined with the AAII out of the White House may lead to numerous meaningful individual AI policies being enacted. For example, it is likely that congressional appropriators will continue to generously fund federal R&D on AI. Alternatively, it's possible that Congress and the White House could come together to develop an actual full-fledged AI national strategy for the US.

With the newly formed Senate AI Caucus, and the already established House AI Caucus, Congress is organizing itself to write and pass meaningful AI legislation. Many of these bills address shortcomings of the AAII. The FUTURE of AI Act, for example, seeks to create an advisory committee in the Department of Commerce that would effectively develop recommendations for an AI national strategy. The AI in Government Act is focused on promoting public sector use of AI tools. The Growing Artificial Intelligence Through Research Act is focused on funding AI R&D and is both generous with the amount funding and is very specific about where the funding would go. The AI Jobs Act of 2019 directs the Department of Labor to study how the rise of AI will affect the United States workforce. H.Res.153 is a resolution supporting the development of guidelines for ethical issues in AI.

At this point it's unclear what the future will hold for federal AI policy in the United States. Will Congress lead on AI policymaking, and if so, will it be with the current approach of a bevy of individual policies focused on specific issues, or will Congress try and put together something more comprehensive? Or, possibly, is the AAII truly an aspirational start to a government-wide effort to craft and implement a full-fledged AI national strategy? What we do know now is that it's clear that everybody—the White House, US Congress, and foreign governments—recognizes the importance of AI policy. The only question is what they're going to do about it. ■

*–**Benjamin Isaacoff** is the 2018-2019 OSA & SPIE Arthur H. Guenther/AAAS Congressional Science and Engineering Fellow.*

The SPIE/OSA Arthur H. Guenther Congressional Fellow works in the office of a US Senator or Representative or with a Congressional Committee to gain first-hand knowledge of congressional operations, contribute to the policy-making process, and forge links between the engineering, scientific, and public policy communities. Fellows also gain a perspective that will enhance industrial, academic, and government careers. The Fellowship is an ideal way to spend an academic sabbatical or leave of absence from a company.

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For more information, go to (**spie.org/policy-fellowship**)

High Stakes Year for Research and Development Funding

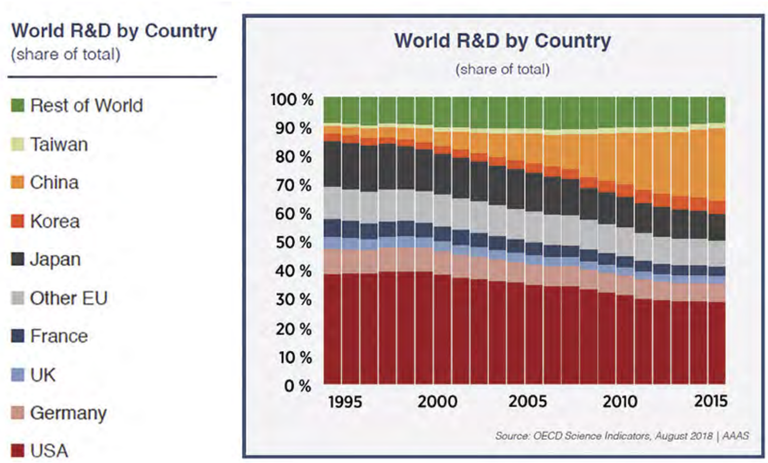
Benchmark report highlights increased challenges to US scientific leadership

Once again, the US faces an uncertain appropriations year, as mandated cuts in government spending loom, and a deal to prevent those reductions from going into effect is yet to materialize.

Passed into US law back in 2011, the Budget Control Act (BCA) mandates cuts in both defense and nondefense spending totaling $1.3 trillion from FY2012–2021. In 2018, Congress agreed to a two-year budget agreement that raised those mandatory caps in spending for FY2018 and FY2019. Without another budget agreement, the US will be looking at about a 13% cut to defense spending and 11% cut to nondefense spending in FY2020. Should this happen, it would mean significant cuts for research and development funding across the federal government, and no hope for the increases sought after in many critical, growing areas of science and technology.

This also comes at a time of increased international competition. According to a recently released benchmark report by the Task Force for American Innovation (**bit.ly/Benchmarks_2019**), the US share of global R&D has declined from 38.3% in 1995 to 28.5% as of 2016. This is largely due to the significant increased investment by Taiwan, South Korea, and China. According to the report, China is likely to catch up to the US in terms of "R&D expenditures within the next few years."

While other countries are increasing their investments,



the US is among only a handful of countries who have seen a decrease over 15% relative to gross domestic product (GDP) since 1995. Another country cited to have declining investment relative to GDP during this time period is the United Kingdom (UK). However the UK government has announced intentions to raise the UK investment in research and development (R&D) to 2.4% of GDP over the next ten years.

Additionally, in the US there is an evident shift from engineering and physical sciences to medical and life science. This can be seen in terms of publications and in federal financial investment. "In engineering alone, the US share of article production decreased from 23% to 12% during the 2003–2016 period," states the report. During that same time, China far surpassed the US in terms of publications.

Though the US called for the doubling of the budgets of NSF, NIST, and DOE via legislation titled America COMPETES Act, this authorization bill was unable to obtain the support necessary to reach the funding goals called for in the bill. Alternatively, the 21st Century CURES bill, which called for a large increase in investment at the National Institutes of Health (NIH), has received broad support, resulting in the NIH budget increasing 30% since 2015.

A 2018 white paper published by the Center for Innovation Policy at Duke Law cited that physical sciences and engineering research "represented 41% of the [US] federal science budget. Thirty-five years later its share had fallen to 28%. The life sciences had picked up the entire difference." However, as the paper highlights, the solution is not to simply shift funding back to the physical sciences, but to treat all science as a national priority and increase both budgets.

The final indicator highlighted in the report is triadic patents, which is a patent filled at "European Patent Office, Japan Patent Office, and the United States Patent and Trademark Office that share one or more priorities" according to the Organisation for Economic Co-operation and Development (OECD). Triadic patents are generally seen as representing higher quality. The largest economies to file triadic patents are in East Asia, which includes Japan (the largest), South Korea, Taiwan, China, Hong Kong, and Singapore. Though the US has increased its triadic patents between 1990 and 2019 by 21.7%, this does not compare to the increases seen by East Asia.

Put this in the context of the FY2020 debate on research and development spending, and it is very clear that a deal to raise the mandated budgetary caps on spending is coming at a critical time for the United States. In order to maintain its leadership standing in research and technology, increased investments in the US cannot be delayed over political battles.

We will likely not know how the budget debate will end until sometime in the fall of 2019, when the necessity of increasing the debt ceiling puts pressure on Congress and the White House to negotiate. If spending is allowed to increase, it will then be up to appropriators in Congress to prioritize R&D investment. ■

*–**Jennifer Douris-O'Bryan** is the SPIE Director of Government Affairs*

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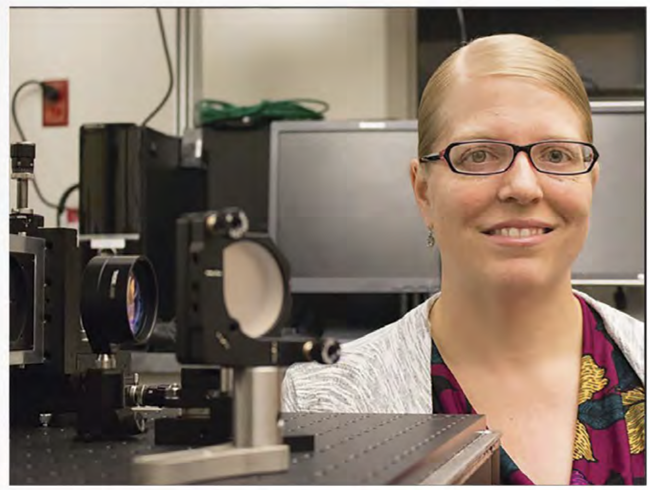
Learn more: spie.org/conferences

A Day in the Life of an SPIE Professional

In 2019, the #FacesofPhotonics series in *SPIE Professional* will focus on people who have taken different career paths in optics and photonics, from industry, to starting a new company, to academia, to government. These profiles will give SPIE Members a glimpse at a day in the life of an SPIE Professional.



Amy Oldenburg

Associate professor of physics,
University of North Carolina at Chapel Hill

SPIE Fellow Dr. Amy Oldenburg started the Optical Coherence Imaging Laboratory at UNC Chapel Hill in 2008. Her research focuses on the use of coherent optical and acoustic properties for imaging tissue viscoelastic properties, and developing novel contrast mechanisms for biomedicine.

Describe a typical recent day at the office.

In my vintage Miata, I enjoy the route to Chapel Hill, with wisteria, cherry, and redbud in full bloom. Climbing hills and stairs to my office, I first catch up with email: one student is finalizing a journal paper; another student has sent me his preliminary exam paper for review. I organize some laboratory tours, and plan a meeting to work on an FDA investigational device-exemption application for our airway endoscopy instrument. Then comes grading and preparing a lecture for my optics course: today's topic is an introduction to semiconductor optics. I adopt a strategy of making analogies between the rate equations for emission and absorption in semiconductors to those for two-state systems, a topic that we studied the previous week. I head upstairs to my laboratories, catching up with students' different projects: optical imaging of nasal cavities, ultrasound imaging of thrombosis, and optical detection of biological magneto-receptors. In the afternoon, I present the optics lecture. Finally, I meet with my most senior graduate student to go over her latest results in measuring airway wall compliance after burn injury. There are some very good results, as well as some problems. We brainstorm about how to troubleshoot the problems, and go over what she will present in her thesis and final exam.

What are three skills necessary to do your job?

First, communication skills, particularly writing. Managing a laboratory requires you to be an effective communicator on a daily basis. And the ability to communicate your research in publications and grant proposals is crucial. Next, the ability to analyze a complex problem—for example, understanding at a fundamental level all of the dependencies that affect the signals you are measuring in an experiment—is key. These skills are a baseline before you can develop a good sense for how to troubleshoot problems, or the ability to recognize something new and exciting hidden in your data. Finally, grit and determination! This includes being able to work in an area outside of your expertise. It also means being undaunted by boring or repetitive tasks that make up the lion's share of academic work. As I like to say, if it's not boring and repetitive, you haven't "gotten it down to a science" just yet.

What is the most interesting challenge you've worked on recently?

While I hate to play favorites with the research projects in my lab, the most interesting one currently is my student's project on developing a parallel-plate rheometer that can be accessed by optical coherence tomography for real-time imaging of shear within the bulk of the fluid. There is a lot of rich theory in describing viscoelastic materials—including wave propagation and particle diffusion—that I enjoy learning about. The challenge is to try to best adapt the device to extract meaningful materials properties, within a range that is of biological interest for fluids such as mucus.

How did you end up working in academia?

I enjoyed math early, gravitated (pun intended) toward physics in high school, and, as an applied physics major at Caltech, took an elective in optical electronics that interested me in lasers and optics. When I knew I wanted to pursue a PhD in optical physics, I joined an atomic, molecular, and optical (AMO) physics lab at the University of Illinois at Urbana-Champaign. Toward graduation, I explored job opportunities at Intel to work on excimer lasers, and at GE as a scientist. But there was a postdoc opening at Illinois doing biomedical optical imaging with a relatively new professor, Dr. Stephen Boppart.

> "There was this big, muddy hill that we would slide down on the seat of our pants. Once you started, there was no way to stop, but you could guide your direction by leaning one way or the other. You just have to accept the speed with which things come at you, and make the best of it."

I knew nothing about biomedicine, but the position primarily required knowledge of a particular type of mode-locked laser I had worked with in the AMO lab, so I jumped on it. I enjoyed being a postdoc for many years, and was promoted to senior research scientist. Although I hadn't been looking for faculty positions, I learned of a position at UNC-Chapel Hill in Physics and Astronomy, with a co-appointment in the Biomedical Research Imaging Center. I recall looking at the ad and getting excited about how perfectly it matched my background and interests. Serendipity! I see my career as an evolving story: my lab at UNC Chapel Hill has reached its peak size, and my interests are increasingly geared toward translating our technologies into commercialized devices and applications that can impact human health.

How do you balance your research, teaching, and publishing obligations?

As a lab director, I would certainly add proposal writing to this list! The research cannot happen without funds coming in, so that's a priority. There is absolutely no way to keep on top of everything when running a large research group. My favorite analogy is my experience as a kid at camp: there was this big, muddy hill that we would slide down on the seat of our pants. Once you started, there was no way to stop, but you could guide your direction by leaning one way or the other. You just have to accept the speed with which things come at you, and make the best of it. ■

Affordable Photovoltaic Technology at the Nexus of Energy and Water

By **Fatima Toor, PhD**

Recent drastic cost reductions in the photovoltaic (PV) industry driven by technical innovations and oversupply have led to an enormous increase in solar power deployment around the globe, enabling access to electricity for the developed and developing world.

According to the *2019 International Technology Roadmap for Photovoltaic (ITRPV)*, the sale price of PV modules has been decreasing exponentially for the past several years due to both technology innovations across the PV value chain, and, since 2015, due to oversupply in the industry because of increased manufacturing capacity expansions in China.

Watt peak (Wp) is the value that specifies the output power achieved by a solar module under full solar radiation. Average spot market prices of monocrystalline silicon (c-Si) and multicrystalline silicon (mc-Si) modules at the beginning of 2019 were 0.24 US$/Wp, down from 0.60 US$/Wp in 2015, a drop of 60% in module price in a matter of just four years.

This significantly fast reduction in price has enabled an exponential growth in PV deployment around the globe. In terms of PV installations, Asia leads, followed by the Americas, Europe, and Africa.

The target of the Paris Agreement is a net zero emission society around the middle of the 21st century. This target is possible to achieve if solar PV power generation becomes the source of 69% of electricity globally by 2050—a viable target according to the LUT University's energy system transition model, which was used to simulate a transition pathway towards renewable energy in the power sector.

There have been a number of technical innovations that have enabled cost reductions in the PV industry. The leading PV material is silicon (Si), which is both abundant and cheap. The existing industrial large-scale manufacture of Si-based integrated circuit devices enabled the PV industry to expand Si-based manufacturing on a gigawatt scale in a matter of a few years. The key technical innovations that have enabled the $/W cost reductions involve various aspects of Si solar cell device design.

Black silicon. The use of vacuum-free low-cost wet chemistry-based metal assisted chemical etching (MACE) process that results in a highly absorbing (~99%) Si surface is known as "black Si." The MACE process results in increased solar cell efficiency with minimal increase in manufacturing costs, which is why it is increasingly adopted by Si solar cell manufacturers. According to the 2019 ITRPV report, MACE

for mc-Si solar cell texturing will continue to be adopted by Si solar cell manufacturers with an increase in its share from around 15% in 2019 to 60% in 2029.

Passivated rear contacts. In the conventional Si solar cell design, heavy doping of Si due to aluminum causes high surface recombination on the backside of the cells and results in significant efficiency loss. To eliminate this loss, a number of passivated rear contact cell designs have been introduced in commercial solar cells, such as the passivated emitter rear contact (PERC), passivated emitter with rear locally diffused (PERL), and passivated emitter rear totally diffused (PERT) cell structures. These cell designs approach higher than 20% efficiency at commercial manufacturing scale. The 2019 ITRPV report suggests that these passivated rear contact cell designs have reached 50% market share in 2019 with an expected increase to 70% by 2029.

Bifacial photovoltaics. The passivated rear contact cell designs can be modified so that light hitting from both sides of the solar cell contributes to the electrical current produced by the cell. When placed into modules designed with transparent backsheets or glass-glass construction, bifacial PV modules are formed. Commercial deployment of bifacial PV cell and module technology is growing fast. The 2019 ITRPV report suggests 13% market share for bifacial PV technology in 2019 which is expected to grow to 60% by 2029.

The drastic cost reductions in solar power generation has led to its use in low-resource applications such as electricity and water supply in rural areas. SPIE *Journal of Photonics for Energy* is publishing a special section on solar energy solutions for electricity and water supply in rural areas in 2019. One of the guest editors of the special section, Tina Jaskolski of The American University in Cairo, is actively developing solar-powered rural projects in Egypt. Her team's projects include solar-powered 7–10 hp water-pumping units for irrigation, small-scale solar-operated chicken incubators for 100–1000 eggs, and solar-powered drinking water stations that purify water using anodic oxidation and green sand filters operating at only 100 Watts.

Jaskolski has some insight on why solar power generation is growing in Egypt. "As the Egyptian government is rolling back state subsidies on diesel, pumping water is becoming significantly more expensive and increasingly unaffordable for small farmers. In Egypt's Western Desert, a significant number of farmers have had to abandon their farms as they simply cannot afford the pumping costs for irrigation," she says. "Solar-powered pumping systems are an alternative solution that have become increasingly affordable as prices for solar panels, controllers, pump drives, and pumps are coming down."

To learn about her team's work and the work of other PV engineers and scientists across the globe who are developing solar power generation solutions for rural applications, read the papers in the special section. (**spie.org/SolarEnergySolutions**) ■

*–SPIE Member **Fatima Toor** is a professor of electrical and computer engineering at the University of Iowa, with expertise in semiconductor optoelectronics, electromagnetic design, solid-state physics, and quantum optics.*

An Agariya family at their temporary shelter in the desert area of Little Rann of Kutch, India, where newly installed solar panels are used to lift ground water with the help of a motor to cultivate natural salt.

Credit: Sudipto Das

Should I Patent It?

Questions to ask before filing a patent for artificial intelligence

Artificial intelligence (AI) is a driver of innovation in imaging science. Scientists are developing AI methods to automate tumor identification, classify archeological sites, chart glacial melt, and uncover new drug indications. But are these AI applications even considered inventions? Can AI be patented? Even if it can be patented, should it be? Douglas Link and Curtis Vock from Lathrop Gage LLP (**lathropgage.com**) specialize in intellectual property, and they suggest answering a few questions before proceeding with that patent application.

1. Is it patentable? AI-related inventions are like any other invention and must be patent eligible (not an abstract idea), new, useful, and nonobvious to be successfully patented. Furthermore, the technology must be described so that (a) someone of ordinary skill in the art can make and use the invention without undue experimentation and (b) the inventor can prove, when the patent is filed, that she or he has "possession" of the invention, typically by including one or more examples on how to practically make the invention.

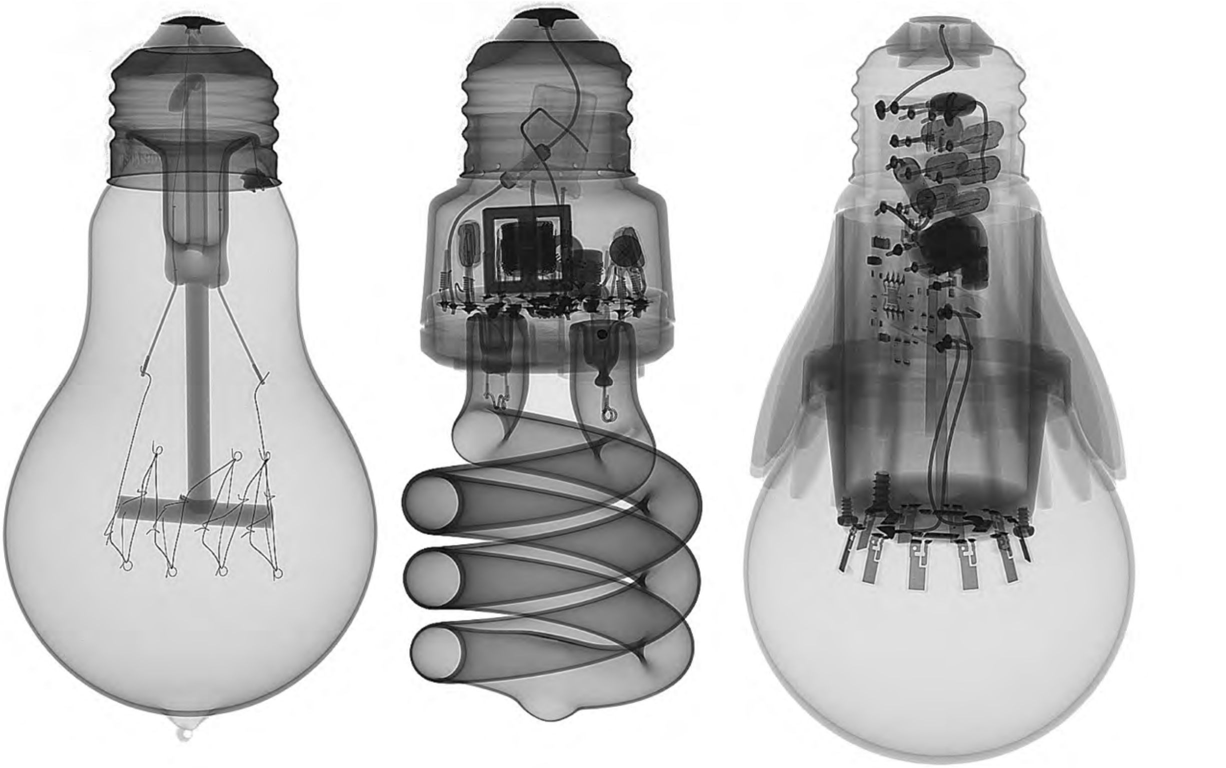
2. Are you improving a computer? If the invention is an advancement of AI techniques and/or the foundational AI computing structure, then the invention might fall within the category of an improvement to a computer itself. This provides a straightforward argument for patentability.

3. Does the AI invention use the computer as a tool or improve a technological field? Using standard AI models and techniques as a tool for a known application is likely ineligible under US patent law. However, the US Patent Office Guidance on this topic states that an improvement to technology is present and patentable when the claimed elements integrate an abstract idea (such as a mathematical algorithm) into a practical application. An example of a practical application could be improving an existing imaging platform using integrated AI technology to increase the clarity and efficacy (i.e., highlighting potential targets for treatment or further investigation) of the images obtained.

4. If yes, how should AI improvements be claimed? If you are using AI with a set of known components (e.g., a set of existing components knitted together by a "black box" executing AI), the AI improvements should be clearly articulated in the claims. The Federal Circuit has invalidated patents for not providing sufficient detail of how components process data. If the patent claims and describes inputs to and outputs from a black box, without execution detail of the black box, it will likely fail. There is limited Federal Circuit case law directly addressing AI inventions, but other cases suggest patentability based on how data is organized, how the AI model is trained, or how the AI engine outputs and effects an external system. How/what data is displayed in a GUI may also provide a road to patentability.

5. Is the invention detectable? Even if the AI invention is patentable, you must still assess whether it will even be possible to detect infringement by an unauthorized entity. Often AI tools and data-processing platforms are in the cloud and completely undetectable. If your sole purpose of patenting is to prevent infringement and pursue litigation, likelihood of proving unauthorized use of your AI should be determined prior to filing. Difficulty in proving infringement of your AI may be outweighed by other business concerns, for example owning patents for exit strategies or licensing purposes.

6. How else can I protect AI? If any of the above give pause for concern, consider trade secret and copyright protection. Trade secret protection prevents others, including employees, from stealing data behind the AI models (e.g., model training datasets or techniques). However, there are data security and notification requirements that must be met in order to have a valid trade secret: one cannot simply say "trade secret" and expect full protection. Copyrights, when coupled with a strong licensing agreement, may further provide control over software code. ■



Credit: Herminso Villarraga-Gomez, "The Evolution of Electric Lighting"

Move Over Alexa, These Smart Lights Don't Need You to Tell Them When to Shine

The role that light plays in regulating the 24-hour circadian rhythm is well understood by scientists, and so broadly accepted by the mainstream population that there is increasing commercial demand for more human-centric lighting in residences and offices.

Human-centric lighting (HCL) can be used to create dynamic indoor environments that mimic daylight patterns with respect to human circadian rhythms and physiology. For example, the stimulating effects of bluer frequencies are welcome during daytime hours, whereas amber and red frequencies are relaxing, and therefore more desirable in the evenings. HCL is enabled by the maturity of LED lighting, which enables finely tuned control over the color temperature of the light, as well as spectral power and brightness.

In addition to enhancing our sleep and wellbeing, solid-state lighting benefits are evident in the ongoing development of applications in medicine, imaging, agriculture, communication, transportation, and museum lighting. Some of these applications require highly precise light spectra that don't produce optical power variations or shifts in color over time.

But as a bulb ages or a junction heats up, the spectral distributions fluctuate. The amber spectrum may weaken before the blue spectrum. But wouldn't it be great if a bulb could recognize, by itself, that its amber channel was fading? And if, after recognizing this fact, it could increase the pulse-width modulation weight of the amber channel so that it continues to meet the spectral power distribution required for a specific setting?

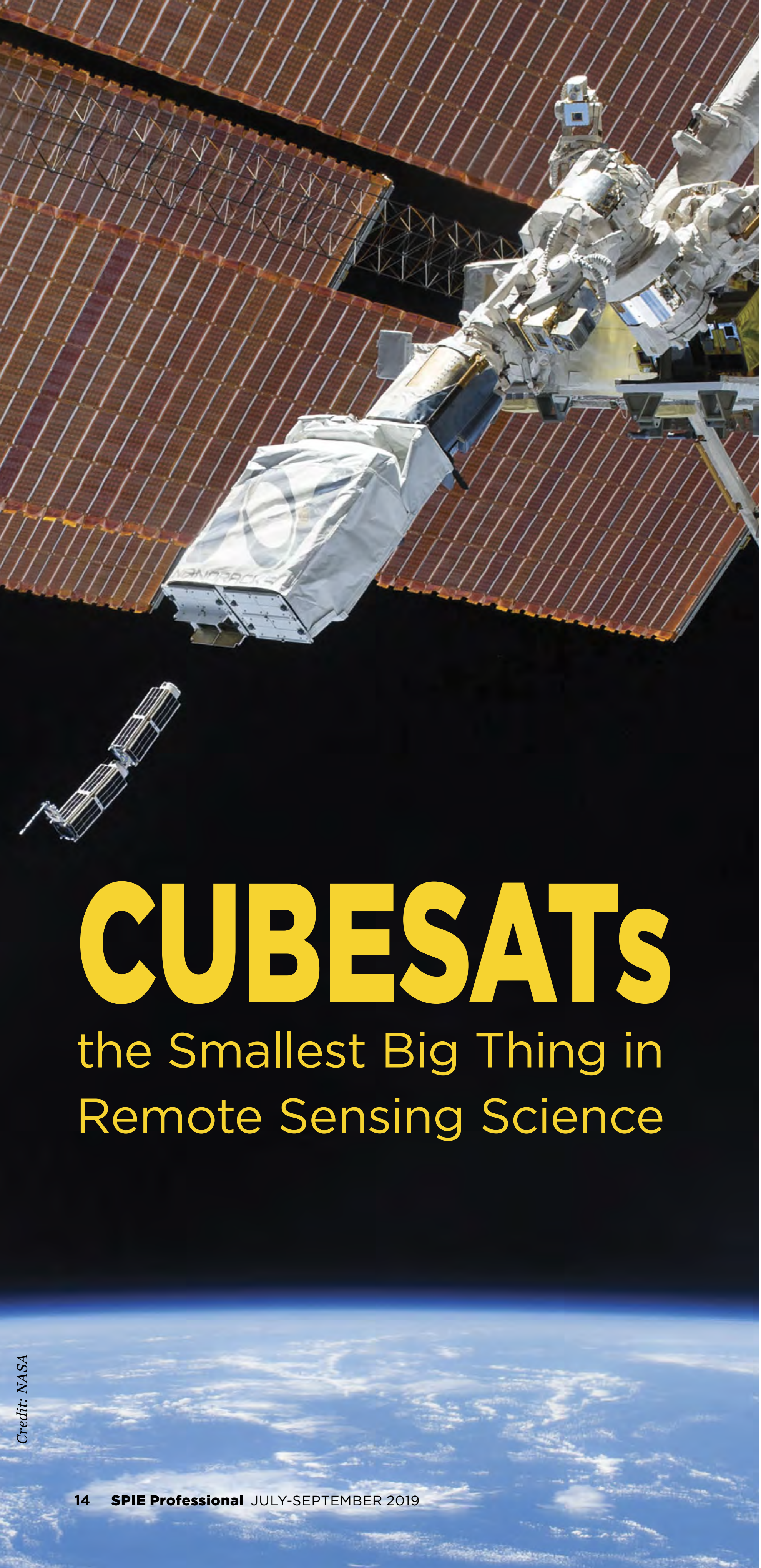
Researchers Aleix Llenas from Catalonia Institute for Energy Research (Spain) and Josep Carreras from Ledmotive Technologies (Spain) have done just that. Their work, recently published in the SPIE journal *Optical Engineering*, addresses two lighting challenges: how to keep temperature changes and age-based deterioration from impacting a light emission's strength, consistency, and color, as well as providing a reliable, internal, self-monitoring method.

They use a fast-computation annealing algorithm to determine channel weights of a targeted SPD, such as one designed for optimal lighting at 5 p.m. In conjunction, a microprocessor in the light provides a closed-loop control system that monitors and corrects the spectral output, compensating for shifts due to temperature changes or wear and tear on the LED. In effect, the light can keep an emitted spectrum constant and stable over time.

Daniel LeMaster, associate editor for *Optical Engineering*, believes that the research showcases significant advances in terms of lighting technologies. He says, "This method to monitor and quickly compensate for the colorimetric issues that arise from junction heating and LED aging will be of great utility in the global LED lighting market."

The intelligence and spectral awareness of these LEDs create new possibilities for healthier living spaces by giving lighting designers complete control over the visible spectrum, at any time of day. ■

Read the article: **spie.org/SmartLights**


Credit: NASA

CUBESATs

the Smallest Big Thing in Remote Sensing Science

It may well be that the biggest thing in the future of remote sensing will be the relatively small spacecraft known as a CubeSat.

"There is no doubt in my mind that, within the next few years, small spacecraft will be a regular and accepted capability for Earth remote-sensing measurements," observed Dr. Charles Norton, special advisor, Small Spacecraft Missions at NASA. "They are going to impact not just the quality of our existing science but also allow us to make new types of improved science measurements that otherwise would not be possible with other platforms," he said.

CubeSats emerged about 20 years ago as an academic engineering project. Conceived at Cal Poly and Stanford University in 1999, the project was intended to enable university students to gain design, manufacture, and test experience with small satellites intended for low Earth orbit (LEO) within the time and financial constraints of a graduate degree program. The first six CubeSats entered orbit in June 2003 from Russia's Plesetsk launch site.

Since then, more than 1,000 CubeSats have been launched into LEO, and small spacecraft have evolved into a significant global enterprise involving national space agencies as well as many commercial entities. Recently, CubeSats even ventured into deep space when two were launched in May 2018 to support the InSight mission to Mars.

While satellites of all types are big business, with global industry revenues exceeding $260 billion in 2017, the small satellites segment is the one driving significant growth, according to the Satellite Industry Association (SIA).

There were 1,738 satellites operated by entities from 62 countries orbiting the Earth at the close of 2017. Of those, almost one third were involved in Earth observation and meteorology. In terms of small and very small satellites (i.e., with mass of less than 1,200 kg), the SIA reports that small craft account for about half of the total 3,000 metric tons currently in orbit. Furthermore, the number of satellites in orbit increased 49% over five years (from 1,167 in 2013) mostly due to newly launched small systems into LEO.

The rapid growth of the small satellite segment is a direct result of the significant benefits they offer in terms of cost, flexibility, speed, and access to space. From the beginning, CubeSats were assembled with commercial off-the-shelf (COTS) parts, and most still are. That reduces costs while also allowing a high degree of design flexibly for both the platform and its instrument payload. Using COTS parts also means that assembly of the craft takes less time as compared to more traditional satellites.

Norton explains that there have been sustained ongoing efforts to miniaturize instrumentation—in terms of reducing size, weight, and power—for large strategic space missions, while maintaining accuracy in resolution and measurement quality. The miniaturization efforts have only intensified by the desire to utilize them on small satellites as well.

The relatively lower weight and complexity of these small craft, combined with the standardized small footprint, mean they can be launched with a much shorter lead time than traditional satellites. They can go into space via a ridesharing program with an already planned launch, with a supply mission to the International Space Station, which hosts a CubeSat launch system, or through dedicated launch capabilities. In addition, many of them can be launched simultaneously to operate together in space as a constellation.

Norton characterizes CubeSats as a disruptive technology likely to have a long-term impact, not unlike the cellphone camera. Initially, the capabilities were not great, but development over time has pushed the performance of CubeSats to the point where they can now deliver targeted high-quality remote sensing measurements, while CubeSat constellations will provide new types of observations and data products.

The Cyclone Global Navigation Satellite System (CYGNSS), for instance, is operated by NASA and uses eight CubeSats launched together in a single launch vehicle to make accurate measurements of ocean surface winds in and near the eye of the storm throughout the lifecycle of tropical cyclones, typhoons, and hurricanes.

The private sector holds the record for the most satellites launched at once from one rocket. The Dove satellite constellation has been deployed from both the International Space Station and conventional rockets to low earth orbit to take daily images of Earth. The constellation makes up history's largest fleet of Earth-imaging satellites and can image up to 250 million km^2 per day. Operated by Planet Labs Inc., the satellite constellation currently consists of more than 120 nanosatellites called Doves weighing only 11 pounds each, and providing 3-meter multispectral image resolution for a variety of mapping applications, ranging from monitoring deforestation and urbanization, to improving natural disaster relief and agricultural yields around the world. The constellation is capable of imaging the entire surface of the Earth each day with revisit rates that are more frequent than existing government or commercial satellites.

In fact, the small satellite private sector is one area where NASA has been very interested and is making investments, says Norton. NASA is looking at the quality of remote sensing data collected by industry and exploring how or if that data can be used scientifically (see sidebar).

Impromptu in-space experiments is another area enabled by the design and operation of small spacecraft, according to NASA. Their flexibility and responsiveness provide mission operators the ability to take advantage of opportunities to perform additional maneuvers and procedures not previously envisioned for a particular mission. In this context, NASA recently demonstrated that an optical crosslink between two orbiting CubeSats is feasible with proper pointing and alignment of the emitting and receiving spacecraft. This is an important stepping stone in terms of satellite-to-satellite communications, since most satellites currently rely on ground stations for their coordination.

Looking forward, Norton stresses that the large satellite missions are not going away. "They still have their role," he said.

"In fact instrument scientists in remote sensing are looking at ways in which they could combine and support large strategic missions with small spacecraft observations as well," he said. "Those types of combined measurements with data from multiple satellites and use of data analytics and fusion techniques will likely generate new insights into all types of remote sensing measurements." ■

*–**Stephen G. Anderson** is the SPIE Director of Industry Development.*

Getting Calibrated

Creating and selling high-res Earth images is the bread and butter of commercial CubeSat companies. Their images fill a missing spatial gap not available with MODIS or LANDSAT that gets down to the scale of a few meters. That range is close enough to visualize individual tree stands, an issue of importance to Dr. Brian Johnson from the Earth Lab at University of Colorado, Boulder. In 2018, he published a study [spie.org/Commercial_Sat] that investigated whether Planet Lab's Dove satellite imagery could be harnessed to collect accurate scientific data and monitor forest health. His conclusions weren't encouraging.

He noted that the imagery from commercial CubeSats is not calibrated on a standard radiance or reflectance scale, so comparing the resulting images with MODIS or LANDSAT imaging is a challenge. And, a constellation of Dove satellites has as many sensors as it does satellites, and not all of them are calibrated to each other. They each have their own characteristics, gains, and offsets. Johnson said, "You'd see differences in images, but you're not sure if it's the sensor characteristics or if it's a real difference in what you're seeing on the ground."

That distinction is obviously important to scientists conducting climate research. Sandra Cauffman is the acting director of NASA's Earth Science Division, and she's overseeing NASA's Earth science data-buy program, which has contracted with commercial satellite companies Planet, Digital Globe, and SPIRE. She agrees that preliminary reports are showing some problems, primarily with calibration, discrepancies between spectral reflectance of vegetation, and discontinuities with atmospheric correction.

Planet appears to be interested in understanding—and correcting—these problems. They recently calibrated a subset of their CubeSat flock by looking at invariant ground targets, like deserts, and comparing against other calibrated imagery. "If the same satellites—MODIS, LANDSAT, and Planet—are all looking at the same patch of ground, they ought to be looking at the same reflectance. If they don't, corrections can be made so that they all agree," explained Johnson.

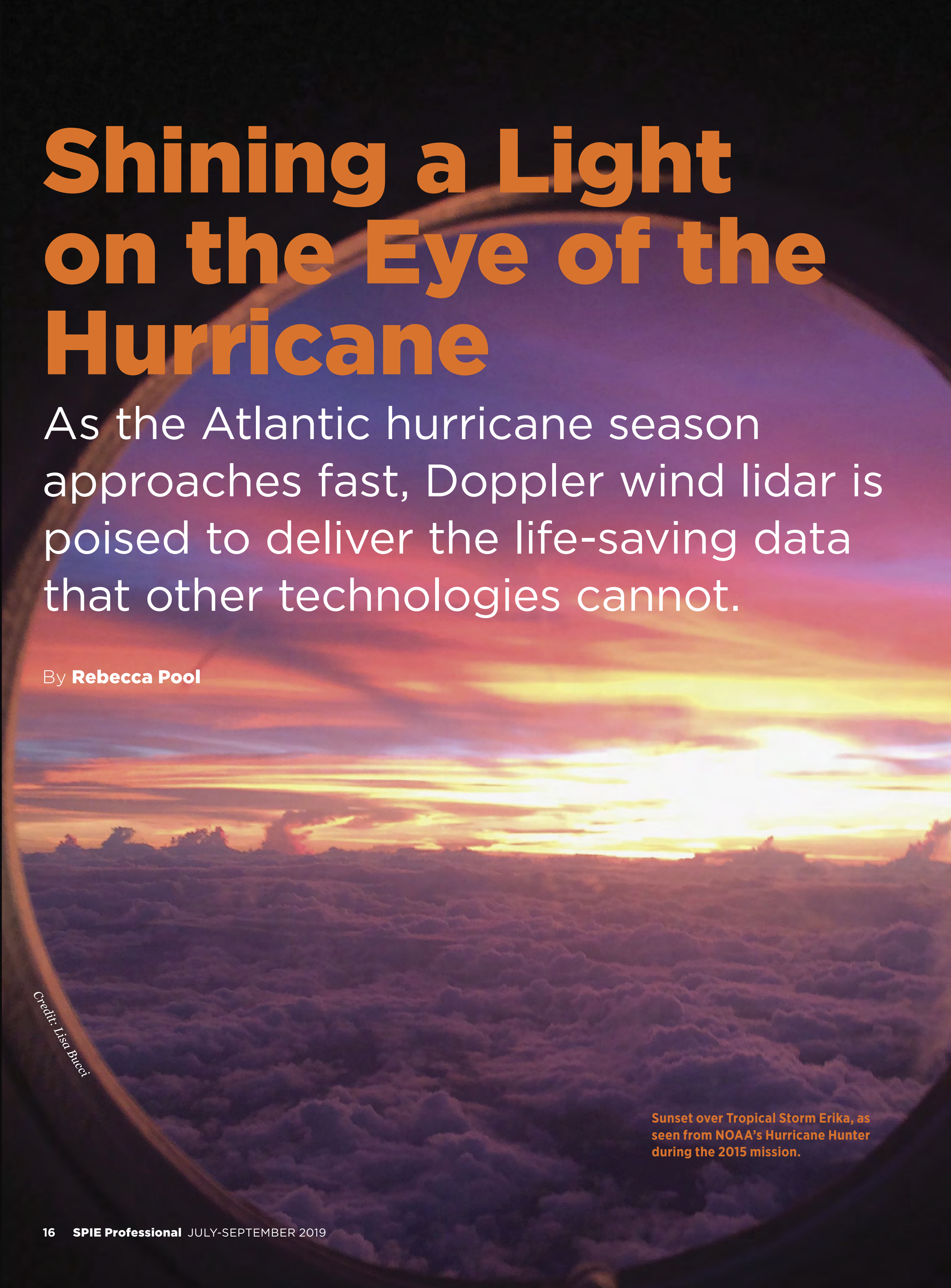
If the company chooses to continue this calibration practice, then they will eventually get a normalizing factor across the flock of satellites. But, these small and inexpensive units only have a lifetime of one to two years, so there's a constant turnover of the sensors. They would have to do this calibration routinely.

While CubeSats designed and calibrated for gathering scientific data—like JPL's RainCube and TEMPEST-D—are delivering game-changing results for earth science research, there's still work to be done by optical engineers and imaging experts before commercial CubeSats will be reliable for scientific data.

Shining a Light on the Eye of the Hurricane

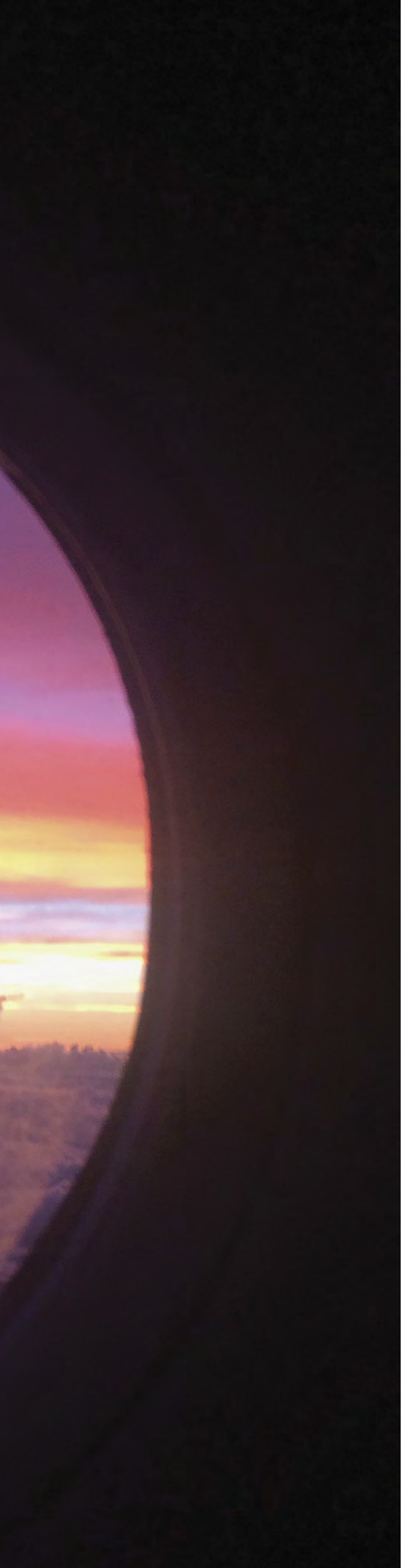
As the Atlantic hurricane season approaches fast, Doppler wind lidar is poised to deliver the life-saving data that other technologies cannot.

By **Rebecca Pool**



Credit: *Lisa Bucci*

Sunset over Tropical Storm Erika, as seen from NOAA's Hurricane Hunter during the 2015 mission.



As Hurricane Lane, the wettest tropical cyclone on record in Hawaii, barrelled towards the Aloha State in August 2018, US National Oceanic and Atmospheric Administration scientists were readying for a critical mission.

Lisa Bucci and Kelly Ryan were part of an all-female science crew flying aboard one of NOAA's Hurricane Hunters, set to gather data from within the storm itself. Hurricane Lane had formed from a region of low air pressure off the southern coast of Mexico, and crossing the Central Pacific Basin was on course for Hawaii, reaching catastrophic category 5 proportions and generating 160 mph wind speeds.

Although the NOAA scientists were scheduled to fly some 10,000 feet high in Earth's stormy lower atmosphere and directly into the eye of the storm, they were not fazed.

According to Ryan, "Flights tend to last up to nine hours, and we really get right into the thick of the storm, so we lose a few coffee cups along the way...but the data we collect helps us to understand the storm's physical processes and improve future hurricane forecasts."

For NOAA's National Hurricane Center, this is what it's all about. During hurricanes, its high-flying meteorological laboratories have typically relied on dropsondes fitted with a GPS receiver and sensors, as well as tail Doppler radar and fuselage radar systems and stepped frequency microwave radiometers, to detect atmospheric changes from the outer rim of the storm to the eye.

Dropped one by one from the aircraft, around 20 dropsondes per flight transmit pressure, humidity, temperature, wind direction, and speed measurements back to the plane while plummeting towards the sea. At the same time, radar systems scan the storm, providing real-time data on precipitation velocity and intensity. In addition, microwave radiometers measure over-ocean wind speed and rain rate, pointing to potentially deadly storm surges.

In the last decade, a relatively new technology—Doppler wind lidar—has also ridden the storm, probing previously uncharted regions that the established technologies couldn't reach.

While Doppler radar emits microwaves and receives the signal scattered from precipitation to determine motion and intensity, it doesn't work if it isn't raining. This poses clear problems for precipitation-free areas such as a tropical cyclone's boundary layer just above the ocean surface, as well as the 'moats' or light rain regions between its swirling eye-wall and outer spiralling rain bands.

But lidar can help. Instead of using water particles to scatter its receiving signal, Doppler wind lidar relies on the motion of aerosols, which is measured by the Doppler shift of the backscattered return pulse along its laser beam. Indeed, as Ryan points out, "A lot of aerosols exist close to the ocean surface so we can get a lot more information from lidar here."

Credit: NASA

Dropsonde, an expendable weather reconnaissance device.

And although dropsondes provide data in the precipitation-free regions that radar can't touch, lidar covers a much broader area, providing a continuous stream of data throughout the storm. Both Bucci and Ryan are excited.

Right now, their raison d'être at NOAA is to assimilate more and more lidar data into the organization's numerical models to improve hurricane forecasts. "Every time you kick out a dropsonde it costs around $700," says Ryan. "But with lidar we can [affordably] access new regions of data to really get to some of the questions that we just couldn't before."

And according to Bucci, "We have been able to resolve wind features and maxima in clear air that we couldn't have necessarily measured with the radar, and we also wouldn't have been able to extrapolate this information from a dropsonde."

Bucci recalls how lidar provided some key information during a 2016 flight. "Back in Hurricane Earl, we flew along a developing rain band and we could see how the wind increased as we went from the coast of Venezuela up into the north-east quadrant of the storm," she adds. "We just couldn't resolve this with the radar, so it was pretty cool."

ONBOARD SYSTEMS

Bucci and Ryan are hardly alone with their passion to measure hurricane processes with Doppler wind lidar. Dave Emmitt, president of Simpson Weather Associates, has worked with NOAA and other organizations on lidar projects for many years.

As early as 2008, he was flying through typhoons around Guam, a tiny island in the western Pacific Ocean, using lidar to augment radar and other standard measurements. And more recently, he was instrumental in setting up the lidar system that flew through Hurricane Lane on the NOAA Hurricane Hunter.

According to Emmitt, NOAA, NASA, and the US Navy all use airborne lidar for hurricane research, although NOAA is the only US-based organization working with the data for weather forecasting. "Lidar is so important for providing wind profiles where radar can't, and also for taking measurements near the ocean surface where a lot of the energy exchange between the water and hurricane is taking place," he says. "We've been striving to do this for many, many decades without the proper tools, but now we can visualize and quantify [cloud] structures within the boundary layer with lidar, and it's so exciting."

The Doppler wind lidar, developed by the US Army and used by NOAA aboard a Lockheed WP-3D Orion turboprop aircraft, comprises a laser and receiver, housed together within the transceiver, as well as a scanner and data processing system. The lidar system measures line-of-sight wind wherever its beam is pointed and operates at an eye-safe 1.6 micron wavelength with a low pulse energy of 1 mJ and pulse frequency of 500 Hz.

During flight, the system can take measurements from around the aircraft as close as 0.4 km and up to 25 km into the storm, depending on the amount of aerosol backscatter.

"The real secret to NOAA's system is its scanner, which actually sticks out of the side of the aircraft and allows us to point the beam up and down," says Emmitt. "It can be a huge challenge on an aircraft to scan the lidar beam in different patterns to derive your full wind profile—you really do need several perspectives to get this data.

"But we can do this with the NOAA scanner and it's been really critical to achieving our wind profiles," he adds. "For example, the aircraft usually flies at around 10,000 feet but we can 'look up' and retrieve profiles from deep within a hurricane."

Bucci and Ryan concur, pointing out how recent lidar data from Lane as well as other hurricanes and tropical storms, including Danny, Erika, Earl, Javier, Maria, and Nate are helping them

Emmitt will present his evaluation of airborne Doppler wind lidar sensitivity and accuracy during a convective storm at SPIE Optics + Photonics in San Diego. spie.org/DAWN

Doppler wind lidar scanner on the side of NOAA's Hurricane Hunter.

answer questions about hurricanes that have remained unanswered for years. For example, they are now getting closer to understanding how energy from relatively small-scale turbulence at the ocean surface, known as surface flux, can energize a hurricane.

And, in a similar vein, while high vertical wind shear typically causes a hurricane to become asymmetric and then dissipate, this isn't always the case, as witnessed during the deadly Hurricane Florence that hit the coast of the Carolinas in 2018.

"We can now begin to understand [such observations] with lidar as we can measure more of a storm than with radar alone," says Ryan. "These are some big questions that definitely have the potential to be answered now that we're using lidar."

Indeed, over the years, NOAA researchers and colleagues have worked tirelessly to prove that the airborne Doppler wind lidar is mechanically sound and provides viable data. As recently retired NOAA Atlantic Oceanographic and Meteorological Laboratory Director Bob Atlas points out, "We have found definitively that Doppler wind lidar complements the other observing systems on the aircraft and is able to fill in the gaps that we otherwise would have here."

What's more, Atlas is certain the technology will be instrumental to future hurricane research. A lack of frequent and accurate observations of the winds within hurricanes has contributed significantly to inaccurate forecasts, but thanks to lidar, this is changing. "We don't have all of the data right now, but lidar is helping," says Atlas.

Importantly, Ryan and Bucci are confident they have validated the technology after collecting and comparing vast swathes of data against dropsonde and

Credit: NOAA

radar measurements. During flight, lidar collects several gigabits of data an hour, so for the researchers a next critical step is to refine the algorithms that process this raw data.

After processing, the highest quality wind profiles can then be transmitted in real time to the forecasters at the National Hurricane Center, already working with dropsonde and radar data. "We really want to make this data available in a format that can be assimilated by our numerical models and used for further analyses," says Ryan.

Looking to the imminent 2019 hurricane season, the NOAA researchers want to experiment with new flying patterns so they can continue to collect data from within uncharted hurricane territory.

"In the past, the plane has been flown in predetermined patterns defined for radar, but with the lidar, we are now going to try flying along cloud-free, rain-free regions," says Ryan. "Radar can still collect data as we go along such a region, but the lidar can also collect data where the plane is as well as within the rain-free region. So we are getting this new, complementary coverage."

For Ryan and Bucci, the next Atlantic hurricane season can't come soon enough. Typically running from June to November, they will take to the skies in July this year, and they expect to fly in around eight storms throughout the season. As Bucci says, "We love everything about hurricanes and the lidar data helps us to understand a storm's physical processes so much more as we are seeing things that we haven't seen before... I got into meteorology to understand when and where dangerous weather would happen and how to stay safe."

But the story for NOAA, lidar, and hurricanes doesn't end here. Talks are already underway at NOAA to fit a second lidar system to its Gulfstream IV jet that flies higher than its Lockheed turboprop aircraft. The Gulfstream IV would collect data from the upper atmosphere.

However, Atlas envisions lidar reaching even greater heights. Following in the footsteps of the European Space Agency, he would like to see a satellite-borne lidar, which he says would provide a much larger coverage to truly define a hurricane and its environment.

Emmitt concurs. As he points out, he and Atlas have already carried out numerous simulations of wind lidar in space that sought to assess the impact of such an instrument on hurricane forecasts.

"I don't think we need to justify the need to make wind measurements from space anymore. If we were some 400 km in orbit, we could detect the presence of cyclones starting up and also predict where they were going to go and how intense they may be," he says. "In short, we'd have a much better chance of detecting and predicting the many, many cyclones that develop all over the world." ■

–***Rebecca Pool*** *is a science and technology writer based in Lincoln, United Kingdom.*

FREE-

-SPACE

Optical Communication Takes a Deep Dive

Lasercom research team celebrates successes in space and shifts focus to underwater communications

By **Gwen Weerts**

The world has an enormous appetite for communication bandwidth, which means that we're all competing for access to the radio frequency (RF) spectrum. Wireless gadgets from smartphones to smart kitchen appliances all jostle for bandwidth, and broadband connectivity has become a passport for education and commerce.

In the 1920s, the Federal Radio Commission (the predecessor to today's Federal Communications Commission) recognized a need to regulate bandwidth availability in the United States, so legislation that licensed bands of the RF spectrum to different regions was passed, guaranteeing the licensee interference-free communication over those wavelengths. But some bands go unused today, while others are completely overwhelmed.

A submersible vehicle emits a blue LED light to send information to the surface during the Nekton First Descent expedition.

Credit: Nekton

Radio frequency communication has been used in space communication since the Soviet Union launched Sputnik in 1957, and the rate of data transfer has been sufficient for low-bandwidth deep-space communication. During the Apollo 11 mission to the moon, Neil Armstrong was able to transmit his historic "one step" speech to Earth with just a 1.25 second delay.

While the technology surrounding radio transmission has remained fairly static since the early days of the space program, the quantity of data we're able to collect on space missions has increased exponentially. The radio frequencies are simply not adequate for transmitting large amounts of data from deep space back to Earth without using a prohibitively large terminal.

Unlike radio bands, the optical bands of the electromagnetic spectrum are unregulated, and they, too, can carry a signal. Laser beams are also much, much smaller than radio beams, which makes lasers uniquely capable of transmitting high data rates. Since the advent of the laser in the 1960s, optical engineers have been exploring the potential of optical communication. Every part of a radio communication system has a direct correlation in an optical system, such as a source, receiver, amplifier, and modulator.

NASA quickly recognized the tremendous potential of laser communications (lasercom) for space missions, and asked a research group at MIT Lincoln Laboratory to build a Lunar Laser Communication Demonstration (LLCD) to prove the concept. Lincoln Lab program manager Don Boroson was the principal investigator for the LLCD. "We wanted to show that it was not only possible, but feasible, to send high-data-rate communications on a laser from a spacecraft that was near the moon to a ground telescope on Earth, while keeping the space and ground terminals smaller than their radio counterparts," he says.

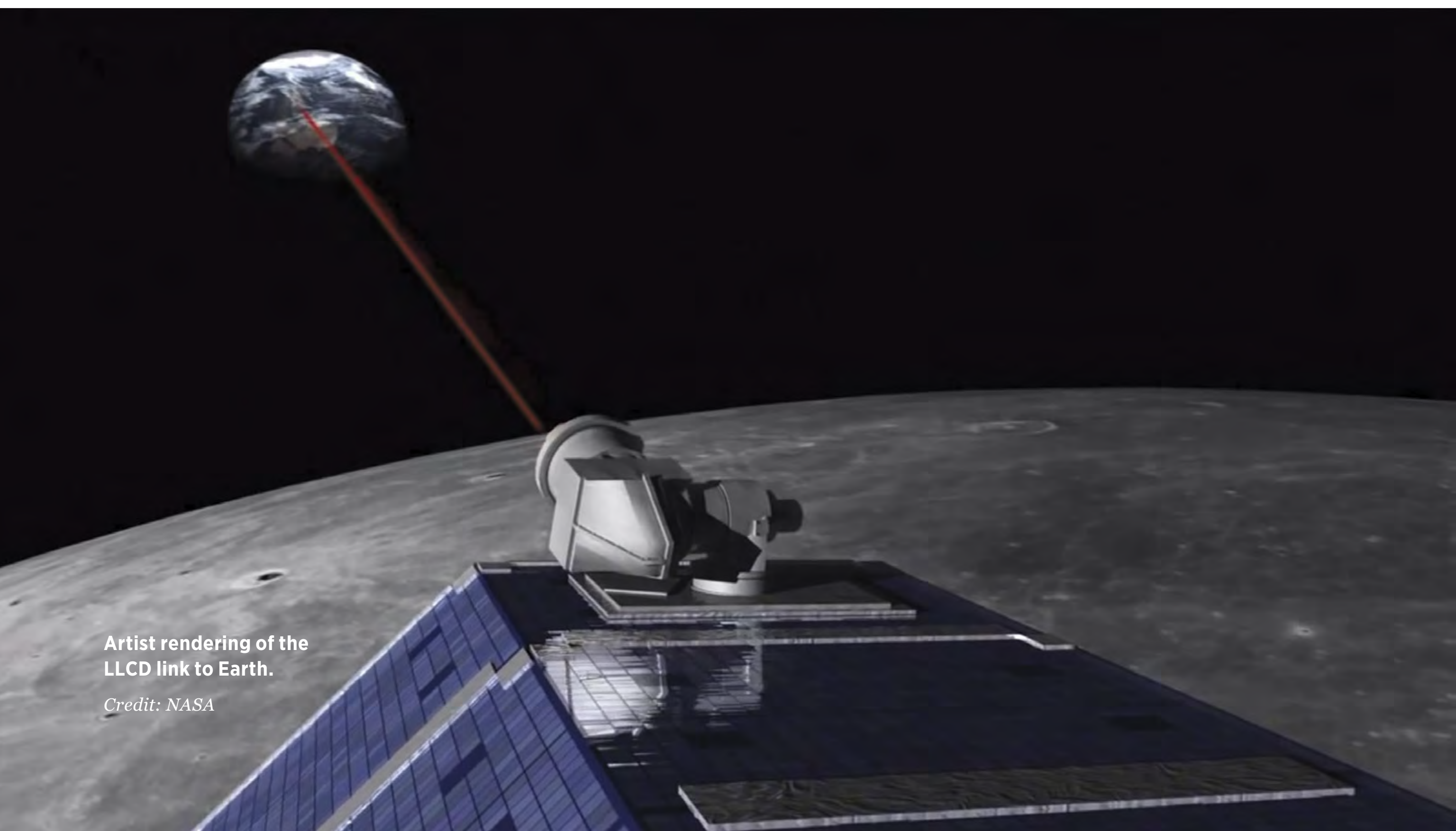
Their team succeeded. In 2013, the LLCD flew as a payload aboard NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE), and the ground-based telescope was able to sustain a laser link with LADEE for up to 30 minutes per orbit, which proved to be more than enough time to transmit large quantities of data at high rates, and in a wide variety of orbital and atmospheric conditions. They achieved error-free uplinks at 20 Mbps, and downlinks at a blazingly fast 622 Mbps.

To put those speeds in perspective, 622 Mbps would allow you to download your average 1 GB "The Earth is smaller than my thumb!" video from lunar orbit to Earth—a distance of more than 380,000 kilometers—in about 13 seconds. This amount of data would take days to transmit via the LADEE radio link.

The LLCD team had to learn how to control for clouds and weather, which could potentially interrupt the laser beam. They handled the inevitability of cloudy skies in two ways: by using a fast reacquiring system that uses a repeat-request protocol—useful for delivering data despite intermittent clouds—and by preparing alternate ground terminals should the atmosphere in one location prove obstructed. "Each lunar orbit we had the opportunity to choose, at the last minute, the terminal with better cloud conditions," says Boroson.

This successful demonstration of lunar lasercom convinced NASA that this technology was what they were looking for, and NASA subsequently developed the Laser Communication Relay Demonstration satellite, which will launch to geosynchronous orbit on a two-year test mission sometime in 2019. MIT Lincoln Laboratory is now helping NASA develop a variety of other laser communication systems, including laser terminals for the International Space Station and the Orion manned space capsules.

While work continues on laser communications for new and exciting applications in space, the same group at Lincoln Lab is looking down—deep down—to adapt their laser communication system to water.



Artist rendering of the LLCD link to Earth.

Credit: NASA

DIVING DEEP

Underwater optical communication is not a new idea, but it has recently reached a significant commercial milestone: in March of this year, the world's first live video was optically transmitted from an untethered submersed vehicle off the coast of Seychelles in the Indian Ocean and broadcast to audiences around the world using UK-based Sonardyne's LED optical communication system, BlueComm.

The real-time video broadcast was part of the Nekton Deep Ocean Research Institute's First Descent Expedition, which intends to increase understanding about one of the world's least-explored oceans. Very little research has been conducted beneath scuba-diving depth—about 30 meters—in the waters around Seychelles. This new expedition intends to explore the Bathyal Zone, which is at a depth of 200-3000 meters, and is home to the greatest marine diversity.

Credit: Sonardyne

Ultraviolet and green BlueComm lights as used in the Nekton mission.

In an article for Sky Ocean Rescue about the expedition, Nekton mission director Oliver Steeds noted, "I think we have been looking up when we should have been looking down. We have had this great era of space exploration and that has pushed back the frontiers of our knowledge. But the deep ocean is the last great frontier, the last great piece of our planet that we still don't know about."

Two more hour-long live broadcasts from the Indian Ocean followed the first, allowing viewers to share the same excitement as the scientists as they explored underwater habitats, all using BlueComm's light-based communication platform.

Traditional underwater communication relies on acoustic waves, which transmit at very low data rates, especially at long ranges. But only light waves can support the bandwidth needed to transmit high-res video like the one broadcast from the waters of Seychelles.

Underwater optical communication resembles space-based systems in many ways—there's a transmitting terminal, a receiving terminal, and a light beam—but the water environment introduces unique challenges to a communication system.

For one thing, water absorbs and scatters light a lot more than atmosphere, which is a nearly lossless medium. And, whereas infrared wavelengths transmit well in the atmosphere, the long wavelengths of infrared light do not transmit at all in water. Only blue and green wavelengths, from approximately 430 nm (in clear water) to 570 nm (in turbid water) can transmit, so telecom technology that has been developed for infrared wavelengths can't be repurposed.

Adding to these complications is the matter of location. Star trackers and GPS technology allow easy coordination between ground telescopes and satellites—one of which is firmly anchored to the ground, and the other of which is in motion in a predictable pattern, like orbit. But GPS doesn't work underwater, so getting the transmitter to locate the receiver can be a challenge—especially if both of them are independently in motion.

BlueComm has approached these challenges by utilizing blue LEDs in the 450 nm region of the spectrum. The light is transmitted in a broad array, so the receiving terminal only needs to be in the general area to pick up the spreading signal. The downside to the LED array is that the beam's divergence drastically reduces the data rate that can be supported by the beam. BlueComm can transmit a maximum of 10 Mbps up to 150 meters—a little less than a tenth of a mile.

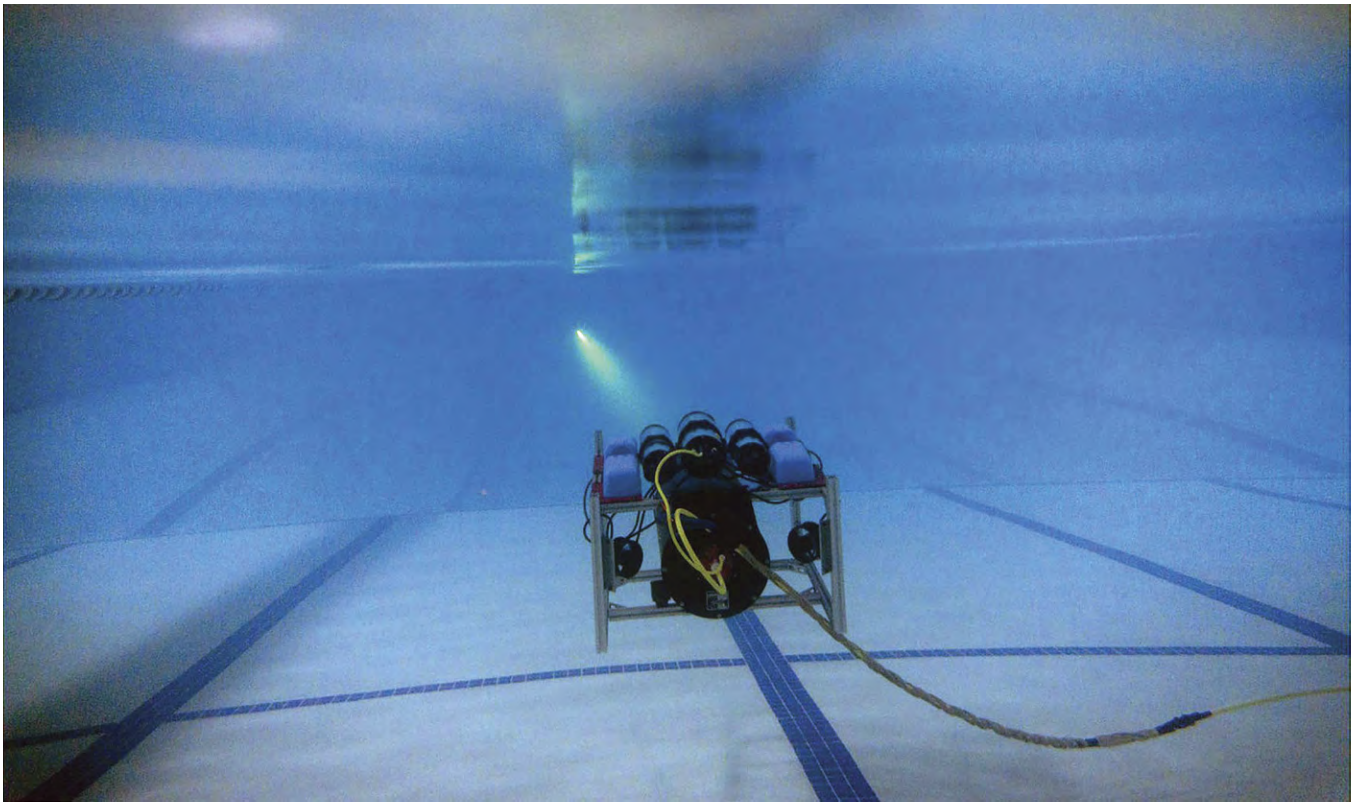
NEXT-GEN UNDERWATER OPTICAL COMMUNICATION

Although Sonardyne's LED-based BlueComm system has already proven a commercial success, the MIT Lincoln Laboratory group who worked on the LLCD for NASA envisions a next generation of underwater optical communication. Specifically, they think it's possible to transmit gigabyte data rates over several hundred meters in open ocean. Instead of using LEDs, they're going to do it using narrow-beam blue/green lasers and highly sensitive receivers.

Nicholas Hardy, who is on technical staff with the Undersea Optical Communications Group at Lincoln Lab, spent the last two years developing an underwater lasercom system that could pull this off, and he presented the results of their underwater lasercom demonstrator project at Photonics West 2019. [**spie.org/lasercom**]

The Lincoln Lab Undersea Optical Communications Group considered the pain points of existing underwater optical communication technology—difficulty of signal acquisition between independently moving terminals, the necessity of acoustic backup, low data rates, interference of surface light—and designed a system that solved those problems. "We realized that a robust pointing, acquisition, and tracking system could be a key differentiator in next-gen underwater optical communication," says Hardy.

Knowing a vehicle's precise location underwater to establish the link is the first challenge of any optical system, and



Credit: doi.org/10.1117/12.2511178

Two ROVs tracking each other and communicating with the laser link.

it's particularly challenging when the light source is a highly focused laser beam, which needs to find and focus on a small target. Anyone who has tried to hold a laser pointer still on a slide can sympathize with the problem. To optically create a link without help from an acoustic signal, the Lincoln Lab team found that it's best to precoordinate the vehicles to rendezvous at a certain depth. Then, it's easy to scan out a line at that depth to look for the other vehicle—much easier than conducting a three-dimensional search when neither depth nor positional information is known.

Once that communication link is established between the laser transmitter and the receiver, data transfer can begin immediately. Of course, the ocean isn't a vast prairie of watery space; features like terrain and even marine life can interfere. Hardy recalls that during one of their very first harbor tests, a swarm of small jellyfish swam right through the beam, but they were still able to communicate through it. "But bigger things like a fish will probably break the beam," he conceded. In that scenario, the vehicles would automatically begin a reacquisition sequence, first trying to find each other's last known location, then engaging search-and-scan mode to re-establish the link.

In addition to the occasional parrotfish, one of the real killers in underwater optical communication is solar background light. Light in the visible spectrum scatters a lot in water, making it difficult for LED systems to do any communications near the surface in the daytime. The Lincoln Lab underwater lasercom system solved this problem by filtering out nearly all background light so that it doesn't reach the photon detector. By only receiving photons from within a very narrow range (a few milliradians), the system can be operated near the surface during the day—a flexibility that will be key for many operations.

FROM OUTER SPACE TO UNDERSEA

The team at Lincoln Lab was able to develop the underwater lasercom system in just two short years by utilizing commercially available parts and building on their earlier expertise from the LLCD platform for space communication.

According to Boroson, "We just saw an opportunity. We thought that some of the pointing capabilities and our knowledge of very efficiently digging data signals out of weak optical signals would be relevant, so we turned our attention underwater."

That's a transition that's not uncommon to astronomical engineers, since a water environment is frequently used for testing processes and equipment prior to space missions. NASA even has a replica of the International Space Station immersed in a large swimming pool in Houston, Texas, where astronauts like Scott Kelly suit up in space suits to execute training exercises.

As for the transition from space lasercom to underwater lasercom, Hardy says, "A lot of the general analysis of how you do the systems and systems architecture is the same. Which is why when we went from space to undersea, we could do it very quickly."

The advent of underwater lasercom is exciting news, worthy of being broadcast on every wavelength. ■

*–**Gwen Weerts** is the managing editor of* SPIE Professional.

SPIE and OSA
jointly commissioned a professional conduct survey

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> – **Kent Rochford,** SPIE CEO

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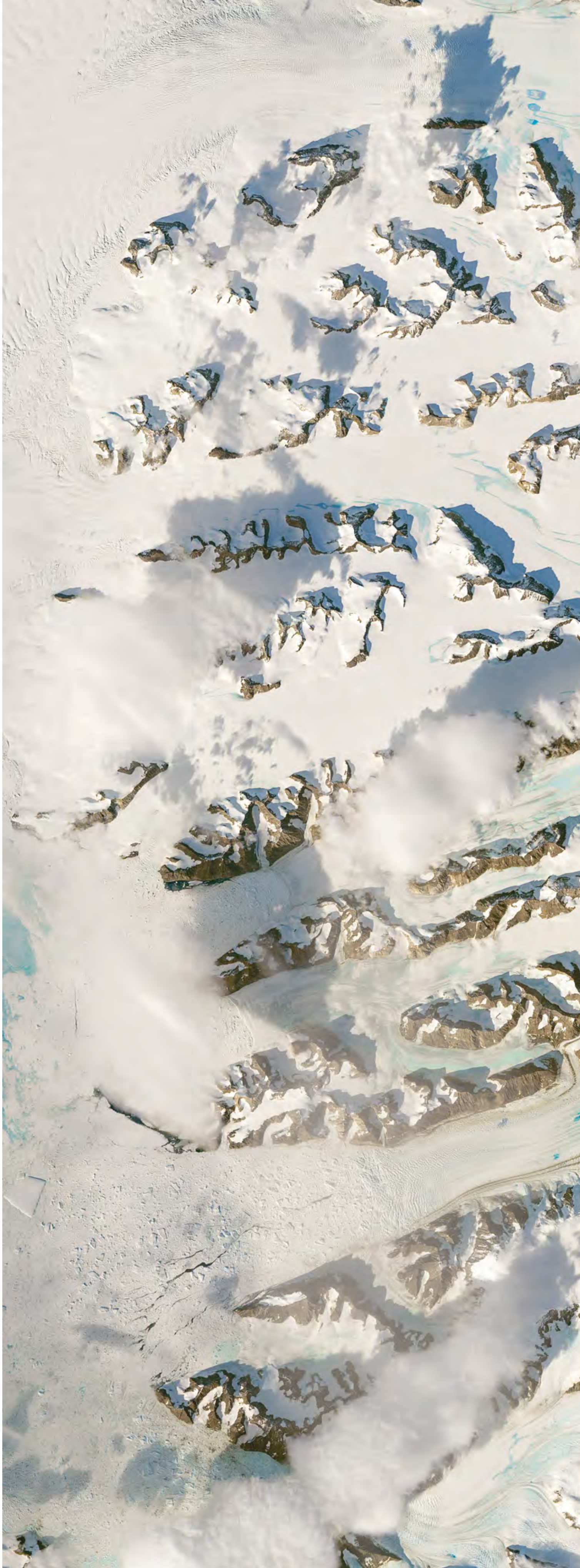
WHAT HAPPENS IN THE ARCTIC DOESN'T STAY IN THE ARCTIC

New satellite data helps scientists understand how melting ice affects global climate

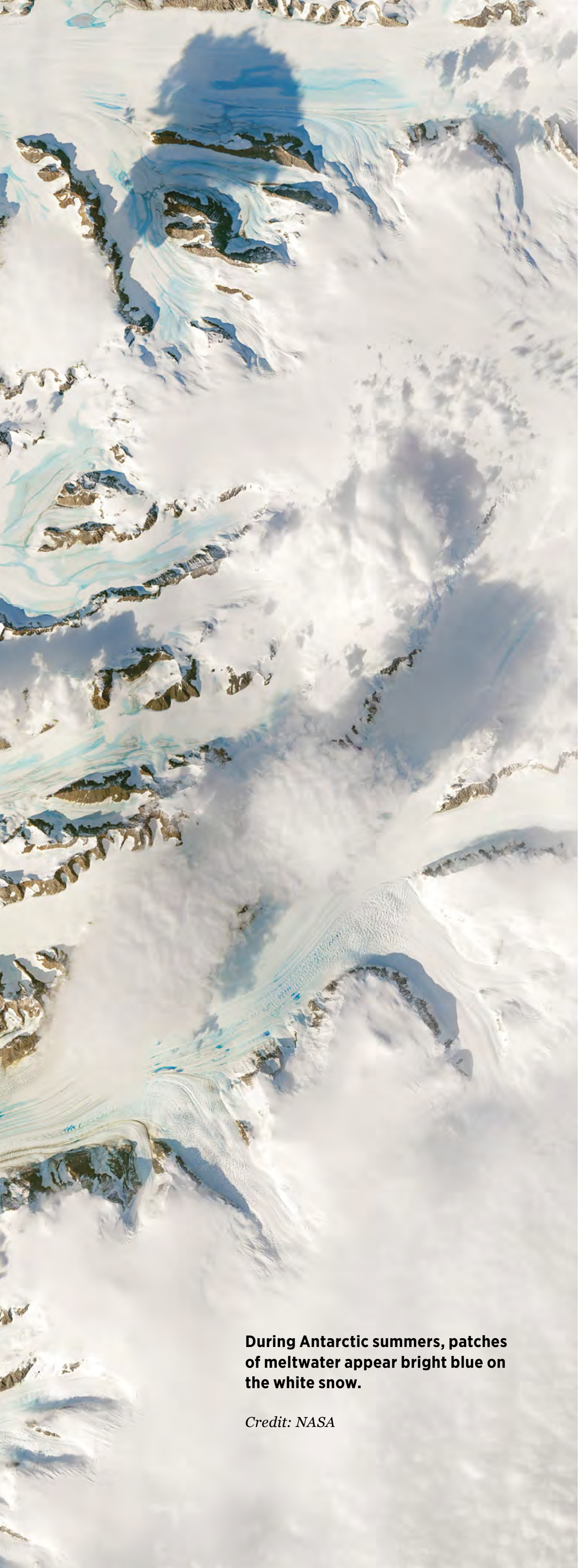
By **Nick Stockton**



Of the more than 4,000 exoplanets astronomers have identified since the mid-1990s, only about a dozen are the right size, composition, and of a sufficient distance from their home star to earn the label "Earth-like." Extrapolated across all the stars in all the galaxies, as many as 40 billion habitable worlds may exist in the known universe.

As of press time, however, only one world is confirmed to harbor life: ours. Which is why NASA has launched hundreds of Earth-facing satellites over the past 60 years, each employed at cataloging some facet of the unique biosphere. And with Earth's rising temperature threatening organisms great and small, scientists need satellite data of things like rainfall, ozone, and ocean circulation to figure out what life on this planet will look like in the near future. NASA's newest probe—launched last September—looks at ice.

The appropriately named ICESat-2 measures the thickness of terrestrial glaciers and floating sea ice using an innovative,



During Antarctic summers, patches of meltwater appear bright blue on the white snow.

Credit: NASA

super-precise instrument called ATLAS. ICESat-2's ground team has been furiously processing its returns, and expect to publish the first publicly available dataset in early summer. Scientists will use this data to understand how glaciers behave as they melt, where sea ice is thinnest, and what the progressive loss of both means for sea levels and temperatures around the world.

The gigantic glaciers covering Greenland, Antarctica, and to a lesser extent, parts of Canada and Russia hold the bulk of Earth's fresh water. Even more critically, they determine the shape of coastlines on every continent. Floating sea ice fluctuates in size from season to season. As the Northern Hemisphere tilts towards the sun each summer, the frozen cap covering the Arctic Ocean thins and thaws. But, in the Arctic, a sizeable fraction of sea ice persists from year to year. This so-called multi-year ice drives weather patterns across the Northern Hemisphere, and longer-term climate around the world. "What happens in the Arctic doesn't stay in the Arctic," says Tom Neumann, a cryospheric researcher who leads NASA's ICESat-2 science mission.

Ice has a high albedo, reflecting up to 70 percent of incoming sunlight back out to space. Conversely, open ocean water only reflects about 6 percent of sunlight, absorbing the rest. So, the size of the Arctic ice cap determines the total amount of solar energy Earth absorbs each day. Over the season, the Arctic's day-to-day temperature creates wind patterns that influence weather many thousands of miles to the south. Compounded over the years, the extra heat absorbed by the ocean contributes to general warming patterns all over the world.

PEERING INTO THE POLES

Scientists owe much of what they know about polar ice to satellites. Probes equipped with optical, infrared, even gravity sensors have helped them understand the rate and total extent of loss over the years. Additionally, weather satellites give them the ability to connect the dots between ice and phenomena like polar vortexes and jet stream fluctuations.

However, one of the big holes in these data concerns the variable thickness of ice on both land and sea. For glacier ice, it's challenging to get a grasp on how fast (or slow) glaciers are melting without frequent updates to their elevation maps. For oceanic ice, scientists need thickness data of the ratio between first-year ice and multi-year ice to predict how much sea ice will survive each summer.

Collecting thickness data is tough, though. NASA and other agencies have flown countless airborne lidar missions—with the laser apparatus attached to an airplane—but these have high fuel costs and require lots of flights to collect even a fraction of these gigantic land masses.

Space-based lidar missions can collect more data more efficiently, but come with their own challenges. For one, they have to be virtually fail-proof in an environment that is exponentially more hostile than anyplace an airplane might fly on Earth. For instance, this means engineers must design sensors that can accurately track returning photons down to the trillionth of a second when daily temperatures swing between –148°F and 248 °F. If a laser blows a fuse or the GPS tracker goes out on an airborne mission, that might ruin a day's worth of data. If a space mission starts flying blind, you can say goodbye to years' worth of work and millions of dollars of equipment.

THE LIDAR LEARNING CURVE

ICESat-2 is, as the name suggests, a sequel mission. The first ICESat launched in 2003 and came (carefully) crashing down into the Barents Sea in 2010. From the start, it had a troubled run. Just a few months after launching, corrosion in the pump diodes caused one of the three lasers in the lidar apparatus—called GLAS, short for Geoscience Laser Altimetry System—to fail. Even with two backup lasers, the ICESat team wasn't taking chances. They modified the mission, turning on GLAS for one month at a time every three or six months rather than operating continuously as planned.

Despite its operational limitations, GLAS revealed some vital science to the team. "It showed that the outlet glaciers near the edge of the ice sheets were much more dynamic than we originally thought," says Neumann. These revelations helped cryo-scientists make better estimates of how the melting happens—as outlet glaciers change shape, they cause interior ice to shift.

But the data-gathering potential of ICESat was limited by its design. It fired in a single beam with a footprint roughly 70 meters in diameter at roughly 150 meter intervals along its track. If ICESat had flown over an American football field, it could take just one measurement at each end zone.

In addition to the large gaps between measurements, ICESat had limited ability to show changes in ice over time. To measure ice loss in glaciers, scientists have to compare two passes, taken months or years apart. However, ICESat only had that single beam, and couldn't perfectly retrace its steps each orbit. "So if the second pass showed a decline in elevation, but was a few meters to the left or right of the original track, you would have no way of knowing whether you had measured real ice loss or just the angle of a slope," says Neumann.

The instrument had trouble at sea as well. Over a season, ocean currents, surface wind, and solar warming create open spots—called leads—amid the sea ice. If you remember anything from your repeated viewings of *Titanic* back in the 90s, only about 10 percent of sea ice mass floats above the surface. Multi-year ice (which is far less likely to melt away each summer) will be thicker and float higher above the ocean. Leads provide scientists a window into how far above sea level ice is floating amid otherwise unbroken floating sheets—thereby allowing them to estimate the ratio of first-year to multi-year ice covering the Arctic.

Although the 70-meter footprint of ICESat was small for its time, it wasn't tight enough to capture all the detail the team wanted for floating sea ice. Lidar units that spread their pulse energy over a wider area tend to have more beam divergence. This leads to a lower signal-to-noise ratio. "Lots of leads are in the ~25-meter wide range, so to get a measurement of the sea surface height in that lead, you have to have a smaller footprint," says Neumann.

ENGINEERING FOR MORE DATA, MORE DETAIL

Despite the setbacks and limitations, the original ICESat yielded a bonanza of polar data. In 2007, when the National Science Foundation was making its recommendations to NASA for the next 10 years, it prioritized orbital, Earth-facing lidar.

"We started off with a requirement for smaller beams in parallel pairs," says Neumann. The tighter focus would allow the sensor to pick up small leads, and the paired beams would eliminate any ambiguity over whether the satellite was looking at sloping glacier or one that was melting. Originally, the design specs called for 16 beams—quite a big jump from one single shot! However, each additional beam complicates the design of every other subsystem on the unit. "Now you've got more data streams to process. You have to align all these beams so they can be collected by the telescope," says Neumann. The estimated cost of calibrating all this complexity caused the team to recalibrate their ambitions. They scaled down to six paired beams and called it ATLAS—short for Advanced Topographic Laser Altimeter System.

A technician checks the flight door for the ATLAS on NASA's ICESat-2 on 21 June 2018.

In the time since the original ICESat launched, technologies for lidar, computing, and satellites had all advanced significantly. The first ICESat's GLAS sent out just 40 pulses each second. When you calculate the photon bounce-back rate—between one and ten for each pulse—that's actually not a lot of detail.

On the other hand, ICESat-2 fires 10,000 pulses each second in each of its six beams. The footprint of each beam is around 15 meters in diameter, and it gets a return every 70 centimeters, which is about 130 measurements between the two end zones of a football field.

This dramatic jump is thanks to the way the newer satellite counts the returning photons. The original ICESat used a full-waveform lidar. Each pulse was about six nanoseconds long, and the satellite's onboard detector would measure the intensity of the returning waveform. This approach limits the number of pulses you can send per second.

The improved computers aboard ICESat-2 allow it to count individual photons as they come crashing in. Neumann compares it to tagging salmon. “The system catches one, tags the time it picked it up, then files away that data for processing later,” he says. The only other data needed is the location and elevation of the satellite relative to Earth at the time the photon’s pulse was fired and when it was recaptured.

Extending the salmon analogy, ICESat-2 uses a fine-mesh net. Its lasers pulse at 532 nanometers, and the satellite’s 76-centimeter telescope only allows for the tiniest deviation from that wavelength in photons it picks up. That’s good gatekeeping from riff-raff across the rest of the electromagnetic spectrum, but it doesn’t catch all the 532-nanometer photons emitted by other light sources. Namely, the sun. “When the sun is high in the sky, and you have fresh snow, you’ll pick up around 5 million photons at 532 nanometers coming from it per second,” says Neumann. That might sound like a lot, but it’s only one photon every 10 meters. Solar photons are pretty easy to filter out by graphing their time of collection alongside that of photons fired by ICESat-2. The satellite’s points will look like a thickly etched line (a profile of the ground below), while the solar photons are noise surrounding it.

ICESat-2 also realized a massive jump in accuracy. Its designers outfitted it with what they call the Laser Reference System. It tracks the satellite’s roll, pitch, and yaw. However, rather than using accelerometers for the job, like an inertial measurement unit (IMU), it uses backward-facing cameras to compare the stars behind ICESat-2 to the exact point on Earth its laser is firing (as determined by GPS). In fact, for redundancy’s sake, ICESat-2 also has IMUs and two backup star cameras. ICESat-2’s original specs called for pointing control within 45 meters of its previous track. Performance so far is within 10 meters.

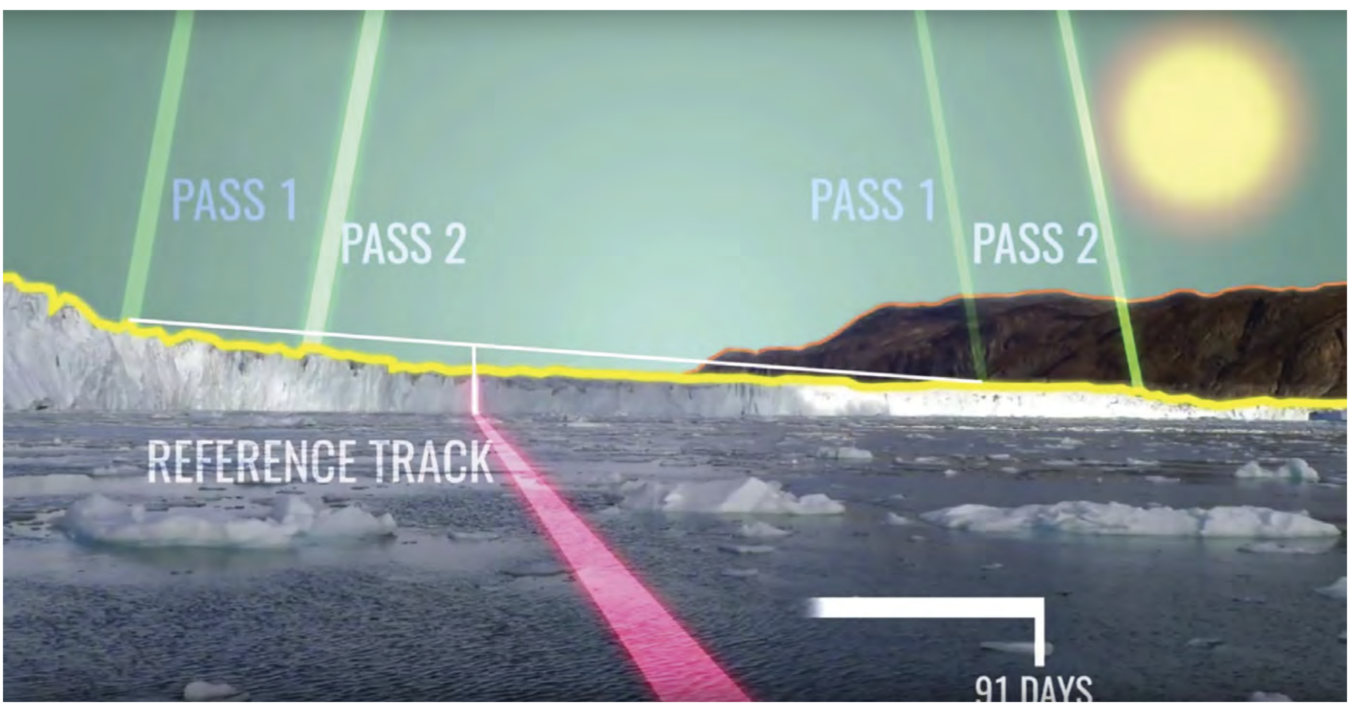
“It’s insane to me that any of this works at all,” says Neumann. “When we first turned it on last October, a couple of folks stayed up all night processing the return data. I tried to sleep, but woke up at 4 a.m. to check my email.” His reaction to the successful readouts in his inbox isn’t printable, but suffice to say he was elated. A few months later, in December, he presented the satellite’s preliminary processed data to the American Geophysical Union Meeting in Washington, DC. It showed previously unmapped Arctic valleys, remote ice sheets, forest canopies, even shallow coastal waters in the tropics—data the green laser picked up while transiting between the two poles.

You can find more than 200 papers about the optics and instrumentation aboard ICESat-2 in the SPIE Digital Library: **spie.org/ICESat-2**

Neumann expects even more significant results when his team publishes its first publicly available data, which should be available by the time this issue is published. Cryospheric scientists around the globe will be able to make unprecedented measurements of polar ice sheets. And that’s not counting what applications ice-centric disciplines will find for the data. Because, unlike its predecessor, ICESat-2 will remain operational all the time, capturing photons from forests, cities, and other landscapes.

“Stay tuned,” says Neumann. “Creative people are going to take these little points of latitude and longitude and turn them into knowledge you’ve never even thought of.” ■

*–**Nick Stockton** is a freelance writer based in Pittsburgh, Pennsylvania. He contributes to* WIRED *and* Popular Science.



Credit: NASA

Atlas uses three pairs of beams, 90 meters apart, with a reference track between the beams. On following passes, even if the two beams are slightly upslope or downslope from where they were on the first pass, scientists can still calculate the elevation change of that track.

It's Up to All of Us to Promote Photonics

on the International Day of Light and Every Day

By **John M. Dudley**

Continued support for research and investment in photonics requires that the public and policy makers are made aware of its significance for societal development.

As workers in photonics, we are intimately aware of the centrality of light to both life and society. We understand how sunlight drives photosynthesis, and we are directly involved in the study and applications of light-based technologies in communications, manufacturing, and medicine.

But while we scientists need no convincing of the importance of our field, it is a mistake to take for granted that others share our enthusiasm and understanding. Outside the scientific community—among members of the public, as well as within funding bodies and governments—the key role played by photonics in the infrastructure of modern society is greatly underappreciated.

I have witnessed this first hand for nearly ten years. In order to eventually obtain the United Nations proclamation of the year 2015 as the International Year of Light and Light-Based Technologies, we had to work tirelessly to explain to science diplomats and policy advisors what exactly photonics is and how it benefits society. I was constantly surprised how even the most senior officials were nearly always completely unaware of the way light formed the backbone of the internet, and were only vaguely familiar with the way that photonics is used in fields such as energy, agriculture, and health. To get the attention of the United Nations, it was necessary to educate first, and then to lobby. It was also necessary to be patient and to persevere!

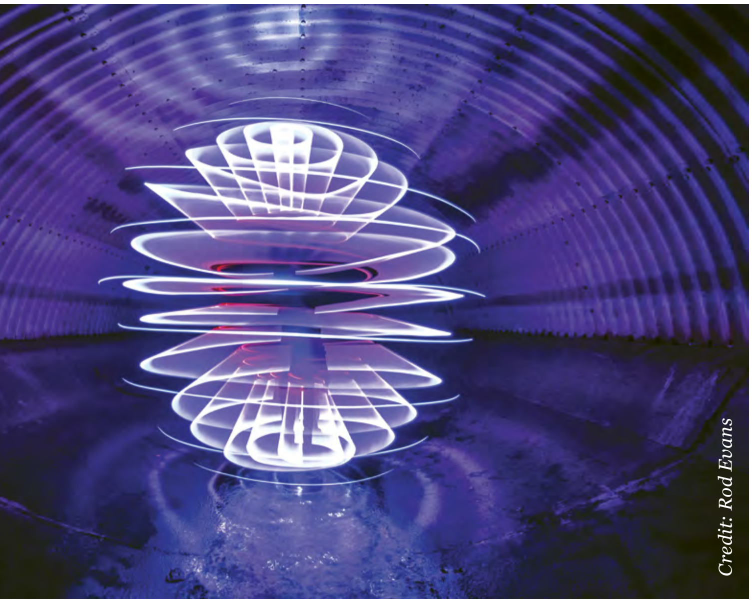
The International Year of Light was viewed as a great success by UNESCO, and at the end of 2015, it became clear that the international photonics community had an opportunity to build on this momentum. Strongly supported by SPIE and other scientific societies, a consortium of partners worked with UNESCO to create an enduring legacy in the form of a permanent International Day of Light. This was proclaimed by UNESCO in 2017 and is now on the permanent calendar of UNESCO observances. Although the themes of the International Day of Light are broad, science and technology were certainly at the center of the arguments advanced to UNESCO. In fact, the day selected for the celebration was 16 May, the anniversary of the first operation of the laser by Ted Maiman in 1960.

There are relatively few science observances within the United Nations system, and an International Day of Light is a remarkable recognition of how light-based technologies are perceived as important to the concerns of the United Nations

SPIE IDL PHOTO CONTEST

This annual photo contest raises awareness about the International Day of Light and how light impacts cultural, economic, and political aspects of our global society. Amateur and professional photographers alike should submit photos demonstrating the vital role that light plays in our lives for a chance to win US$2,500.

See more contest details at: **spie.org/contest**



Credit: Rod Evans

Light painting is a new medium for public outreach about the exciting visual aspects of light and color.

and its agencies. Indeed, the International Day of Light has the specific objective to improve the public understanding of how light and light-based technologies touch the daily lives of everybody, and are central to the future development of the global society. All of us in photonics must surely agree that this is a tremendously worthwhile goal.

A question I am often asked, however, is what exactly should we do on the International Day of Light? There is no one answer, of course. There are many possibilities, and essentially every kind of activity that promotes light to any audience is to be encouraged. For example, light and optics are tremendous themes for public outreach, and can be used to stimulate wider interest in science in general. Children are attracted to the many exciting visual aspects of light and color, and adults are interested in the underlying technologies and discussions of the many related career opportunities for their children. Discussing everyday optical effects, such as the color of the sky, clouds, and rainbows, never fails to interest people, and opens up opportunities to talk about the latest developments in optics and photonics research.

It is also possible to combine science outreach with a cultural performance. Indeed, there are many advances in how photonics is being applied in this way, such as in dynamic mapping and light painting. There are also opportunities to explain the use of advanced optical technologies in fields such as art history, archaeology, and in the preservation of cultural heritage. Moreover, the theme of light allows us to raise awareness of what we can see when the lights are turned off, and the need to reduce unwanted light pollution—to appreciate the cosmos, as well as to save energy and improve our health.

We have the opportunity with an International Day of Light to touch on even wider issues. The association with UNESCO readily allows consideration of how to build educational capacity, how to implement technological solutions in poorer regions of the world, and how to effectively address gender issues. These are themes that are sometimes difficult to include in a regular scientific conference, but they are ideal for an event held in the context of the International Day of Light.

SCIENTISTS HEAD TO CAPITOL HILL

In addition, we should not hesitate to engage on the political level. In fact, even after a year of effort at the end of 2015, we were really only beginning to connect the different sectors that need to work together to solve the global problems where photonics has the solution. And we were also just beginning to learn how to effectively communicate with policymakers.

Scientists are very often puzzled by the failure of scientific evidence to influence policy, but it is important to appreciate that the policy environment involves input from many different areas. There is also often high turnover in government positions, so the same arguments have to be repeated frequently to new faces. But it is possible to make real progress, and in 2015 there were some remarkable political achievements with photonics being discussed in diverse forums—from the Parliament of Andorra to the Senate of the United States.

An annual International Day of Light gives us the mandate and visibility to continue this effort. Although it may seem daunting to enter the political ecosystem of science, it is vital that policy decisions receive informed input from active and committed scientists. If we in the field of photonics do not get involved to defend our own sector, then our place will be taken by others. The policy environment is one that continually receives input from many different sectors, and this is something we must always bear in mind.

That said, we are very fortunate in that there is no shortage of concrete and accessible illustrations of how photonics has changed the world, and we just need to learn how to use these examples to press home our point. For example, with smartphones in the hands of more than a third of the world's population, it is easy to explain how technology changes lives, but we have to go a little further in discussing the long timeline needed from research to societal application.

We also have to explain how applications that eventually become widespread sometimes have no relation with the initial research objectives. As Charles Townes said, "what doctor, wanting a new surgical tool as the laser has turned out to be, would have urged the study of microwave spectroscopy?"

Now is the time to communicate this important message. If we can encourage more appreciation of the strategic importance of basic research, this will be beneficial to us all for many years to come.

Of course, making changes of any kind on a societal level requires patience and perseverance. Since an International Day of Light comes around every year, we will have many opportunities. Although as individuals our actions may be limited, we are supported by an international network of scientific bodies such as SPIE who can help us in our efforts. We all have a role to play! ■

*–SPIE Fellow **John Dudley** is professor of physics at the Université Bourgogne-Franche-Comté and the CNRS Institute FEMTO-ST in Besancon, France. His research covers broad areas of optical science.*

A version of this article was originally published as a commentary in *Advanced Photonics*. **doi.org/10.1117/1.AP.1.2.020501**

SPIE Awards

Since 1959, SPIE has honored the best in optics and photonics for their significant achievements and contributions in advancing the science of light

A. E. CONRADY AWARD IN OPTICAL ENGINEERING

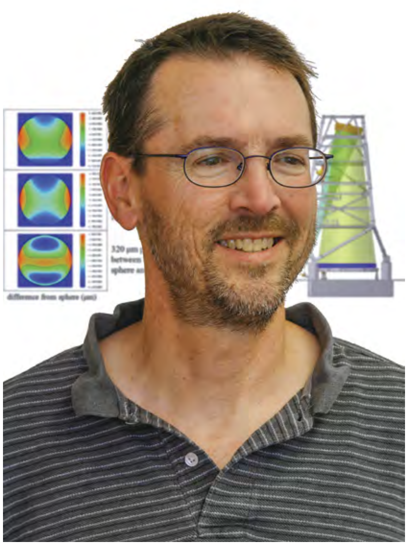
Great discoveries in astronomy are often associated with scientists who spend nights at the telescope and write scholarly articles presenting their observations. Behind many of these discoveries are scientists and engineers who build the tools that enable those observations. The creative contributions they make—the result of long days, many blind alleys, and flashes of brilliance—are sometimes overlooked.

Hubert M. "Buddy" Martin, a project scientist at the Steward Observatory and associate research professor of optical sciences at the University of Arizona (UA) is considered by many of his colleagues to be one of those scientists whose lifelong work has enabled others to pursue their scientific goals and make breakthrough discoveries in astronomy.

In recognition of his work, Martin is the 2019 recipient of the SPIE A. E. Conrady Award in Optical Engineering. The award recognizes Martin's exceptional contributions in design, construction, and testing of optical systems and instrumentation.

"Optical and telescope designers tend to receive more of the limelight than makers, but without Buddy's proven ability to complete very large aspheric mirrors to exacting tolerances, some of the most powerful new telescope designs would have been impossible and not seriously considered," says Roger Angel, Regents' Professor of Astronomy and Optical Sciences at UA.

"He has been central to the string of advances in design, fabrication methods, metrology, and analysis that have allowed the lab to constantly improve its ability to make the largest and most aspheric optics ever. As I understand, these are exactly the kind of contributions the Conrady award is set up to recognize."



Credit: Ray Bertram/Steward Observatory

Hubert M. "Buddy" Martin

The SPIE A. E. Conrady Award is presented annually in recognition of exceptional contributions in design, construction, testing, and theory of optical and illumination systems and instrumentation. Martin will receive the award at SPIE Optics + Photonics in August, where he will also give a plenary talk on advances in telescope mirror technology.

DENNIS GABOR AWARD IN DIFFRACTIVE OPTICS

Min Gu

"Optics is a tremendously exciting field, and nanophonotics is at the frontier of research in so many ways," says SPIE Fellow Min Gu, Distinguished Professor and Associate Deputy Vice-Chancellor for Research Innovation and Entrepreneurship at the Royal Melbourne Institute of Technology in Australia. "Our work is driven by a desire to deliver real solutions to the real issues faced by industry and the community in conjunction with artificial intelligence."

This work has earned Gu the SPIE Dennis Gabor Award in Diffractive Optics, which he accepts "on behalf of the entire research team." The award recognizes his pioneering work in nanoscale information optics, including optically digitized holography and optical data storage using advanced nanomaterials.

Known internationally for his expertise in 3D optical imaging theory, Gu's discoveries are helping drive the development of solutions to some of the biggest challenges in renewable energy, information technology, and big data storage.

"Professor Gu has played a major role in the development of 3D optical imaging theory and its instrumentation for modern optical microscopy, says SPIE Fellow Mitsuo Takeda of Utsunomiya University in Japan, who received the award in 2010. "Specifically, he made great contributions to the progress of information optics through his seminal work on the unification of 3D Fourier optics and nonlinear optical microscopy (based on two-photon and/or multi-photon absorption processes), which has enabled 3D imaging and data writing with the resolution beyond the traditional limit set by Abbe theory."

Named after the Nobel-winning inventor of holography, the SPIE Dennis Gabor Award in Diffractive Optics is presented in recognition of outstanding accomplishments in diffractive wavefront technologies, especially those that further the development of holography and metrology applications. Gu will receive the award at SPIE Optics + Photonics in August.

GEORGE W. GODDARD AWARD IN SPACE AND AIRBORNE OPTICS

"Dr. Giovanni Fazio is a giant in the field of infrared astronomical instrumentation," says Lisa Storrie-Lombardi, Spitzer and NuSTAR project manager at the Jet Propulsion Laboratory. "As the principal investigator of the Infrared Array Camera (IRAC) on the Spitzer Space Telescope, his work made possible one of the most exciting scientific discoveries of 2017—seven Earth-sized planets orbiting the dwarf star TRAPPIST-1. This is one of NASA's highest impact science results ever."

Credit: NASA

Giovanni Fazio

Fazio, a senior physicist at the Harvard-Smithsonian Center for Astrophysics, is being recognized for his exceptional achievements in the area of infrared instruments with the 2019 SPIE George W. Goddard Award in Space and Airborne Optics.

In the 1960s, Fazio pioneered the development of gamma-ray astronomy using balloon-borne telescopes and initiated construction of a 10-meter optical telescope at the Whipple Observatory in Arizona to search for ultra-high energy gamma rays. Throughout his career, Fazio has led work on ground-based infrared instruments including infrared bolometers, infrared cameras using many kinds of detector arrays, and the solid-state photomultiplier. These instruments have been used for observations of everything from the solar corona to the distant universe.

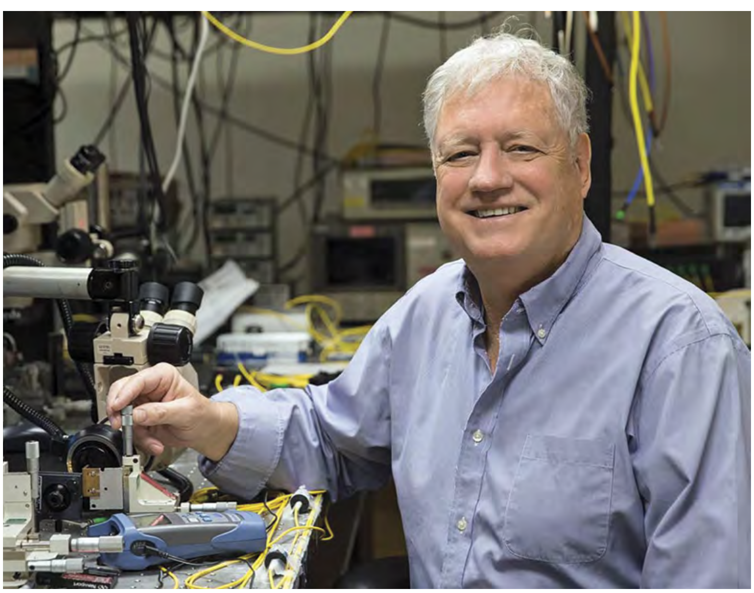
Credit: RMIT

"Dr. Fazio's work has had a profound impact on the entire field of infrared astrophysics and all of the scientific disciplines that now thrive on infrared data," says Storrie-Lombardi. "Besides being a brilliant instrument builder, he is a role model as a scientist and human being. Whenever I see Giovanni he is always interested in looking to the future, new scientific questions, and what we can learn."

The SPIE George W. Goddard Award in Space and Airborne Optics is presented in recognition of exceptional achievement in optical or photonic technology or instrumentation for earth or planetary or astronomical science, reconnaissance, or surveillance from airborne or space platforms. Fazio will receive the award at SPIE Optics + Photonics in August.

ADEN AND MARJORIE MEINEL TECHNOLOGY ACHIEVEMENT AWARD

Avalanche photodiodes (APDs) are the basis of high-sensitivity receivers and are used throughout the world by a wide variety of companies. Joe C. Campbell, the Lucien Carr III Professor of Electrical and Computer Engineering at University of Virginia, has been a leader in APD research for the past 30 years.



Credit: Dan Addison, University Communications

Joe C. Campbell

In recent years, Campbell's group has continued to refine and improve the performance of APDs and advance fundamental knowledge of the physical principles that contribute to low-noise and high-gain bandwidth products in APDs. Modeling by Campbell's students has shown that the very low multiplication noise that has been achieved is a result of the nonlocal nature of impact ionization and its importance in APDs with thin multiplication regions. Using new materials and structures, Campbell's group has demonstrated record low-noise and gain-bandwidth products for communications APDs.

For these pioneering contributions to high-speed, low-noise APDs used in optical communication systems, Campbell is the 2019 recipient of the SPIE Aden and Marjorie Meinel Technology Achievement Award.

"There can be no question that Joe was the major contributor worldwide in developing useful long wavelength (1300–1600 nm) APDs," says Larry Coldren, Fred Kavli Professor of Optoelectronics and Sensors at

University of California, Santa Barbara. “His original invention of the separate absorption and multiplication structure, as well as his many contributions to novel structures since, has had a major impact in the optical communications arena. He continues to make significant contributions to detectors and receivers in the UV and visible as well as in the IR spectral regions.”

The SPIE Aden and Marjorie Meinel Technology Achievement Award is presented in recognition of outstanding technical accomplishment in optics, electro-optics, photonic engineering, or imaging. Campbell will receive the award at SPIE Optics + Photonics in August.

G. G. STOKES AWARD IN OPTICAL POLARIZATION

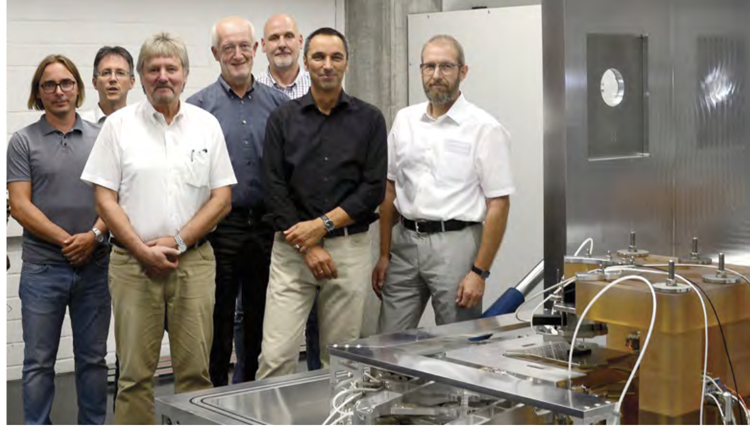
SPIE Fellow Joseph Shaw, professor of electrical and computer engineering at Montana State University (MSU), and director of the Optical Technology Center at MSU, is a pioneer and leader in the quantitative understanding of polarization in nature. Shaw’s work has led to important “firsts,” such as the first observation of the effect of sky state on polarized emission, the first observation and explanation for the role of the earth in polarized observations in the sky, and the first observation of the effects of sub-visible clouds on the distribution of sky polarization.

These works have contributed to atmospheric science and remote sensing, as well as a range of applications where understanding the polarization state leads to more accurate results. Also an avid photographer, Shaw published the SPIE Press book, *Optics in the Air: Observing Optical Phenomena through Airplane Windows*, in 2017.

Shaw is the 2019 recipient of the SPIE G. G. Stokes Award in Optical Polarization in recognition of contributions made to the understanding of the distribution of optical polarization in the natural environment through the development of instruments, measurement methods, and analysis techniques.

“In addition to his impressive research contributions, what sets Joe apart is his exemplary behavior as a collaborator, mentor, and teacher in the optics and photonics community, says SPIE Senior Member Julia Craven of Sandia National Laboratories. “SPIE awards should call attention to and reward those who are not just outstanding researchers, but also exceptional members of the community. By being a welcoming collaborative conference

Joseph Shaw



Osten, third from left, in his new Nano-Measurement and Nano-Fabrication Lab.

organizer, and an approachable, caring mentor and professor, Joe Shaw is certainly well deserving of the Stokes Award,” says Craven.

The SPIE G. G. Stokes Award in Optical Polarization is presented for exceptional contribution to the field of optical polarization. Shaw will receive the award at SPIE Optics + Photonics in August.

CHANDRA S. VIKRAM AWARD IN OPTICAL METROLOGY

During his 40+ year career, SPIE Fellow Wolfgang Osten, professor at Universität Stuttgart, has made significant contributions to optical metrology. His research focuses on new concepts for industrial inspection and metrology by combining modern principles of optical metrology, sensor technology, and image processing.

Osten and his research team developed the first automated system for the quantitative and qualitative evaluation of interferograms, and tilted-wave interferometry for aspherical and free-form surface measurement. Both techniques have since been commercialized.

“Metrology is a key component of industrial value creation,” said Osten in a 2017 interview with Laser World of Photonics. “Only what can be measured can be produced and optimized. Today, industry simply cannot do without optical sensors and especially not in a digital transformation.”

In recognition of his significant contributions to the development of wide-scale optical imaging and metrology, which have stimulated new approaches and technologies for the inspection of nano, micro, and macro objects, Osten is the is the 2019 recipient of the SPIE Chandra S. Vikram Award in Optical Metrology.

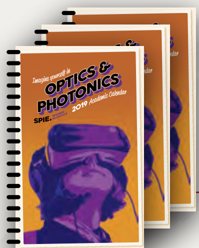
“Professor Osten is one of the most recognized ‘gurus’ for the international community of experienced and young researchers working in optical metrology and optical imaging as well as in the disciplines where optics is crucial for better product quality, archiving, and exploring biological structures,” says SPIE Fellow and 2005 SPIE Past President Malgorzata Kujawinska of Warsaw University of Technology. “The conferences which he initiated, such as Fringe, Holomet, Interferometry (San Diego), Optical Metrology (Munich), and recently Digital Optical Technologies (Munich), have been the international forums which inspire the entire optical community.”

The SPIE Chandra S. Vikram Award in Optical Metrology is presented for exceptional contribution to the field of optical metrology. Osten will receive the award at SPIE Optics + Photonics in August. ■

Visit these and other companies at the Job Fair at Optics + Photonics, 13–14 August. Come prepared to discuss your skills!

SPIE IN THE COMMUNITY

In 2018 SPIE provided over $4 million in community support, including scholarships and awards, outreach and advocacy programs, travel grants, public policy, and educational resources. These are just a few of the outreach programs supported by SPIE, which raise awareness and interest in optics and photonics around the globe.



6,000 WOMEN IN OPTICS PLANNERS

Profiling 26 women in science and engineering, distributed around the globe and at 7 networking events

19 STUDENT CHAPTERS

Participated in the Outreach Games at Optics + Photonics

14 INTERNATIONAL DAY OF LIGHT MICRO GRANTS AWARDED

Supporting events that touched 23,000 people in 12 countries

2019 SPIE Election Opens July 1

SPIE exists to serve people working in optics and photonics research, education, industry, and policy. The infographic above shows just a few of the numerous ways that SPIE supports the community.

SPIE is able to make this impact because of the dedicated volunteers who serve on SPIE committees and the Board of Directors. These people steer our decisions and activities, and ultimately determine how those $4 million dollars of community support are spent.

Every year, SPIE Members have the opportunity to elect the leadership who will guide the direction of SPIE. In the 2019 election, four new directors and a secretary/treasurer will be elected, in addition to a new vice president.

The candidates for vice president are SPIE Fellows Anita Mahadevan-Jansen, professor of biomedical engineering at Vanderbilt University, and Kyle Myers, director of the Division of Imaging, Diagnostics, and Software Reliability for the US Food and Drug Administration.

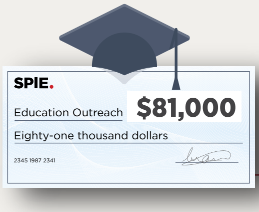

Mahadevan-Jansen


Myers

Mahadevan-Jansen is the founding director of the Biophotonics Center at Vanderbilt University. Her research group focuses on applications of optical techniques for diagnosis of pathology and neuromodulation, including clinical translation of optical spectroscopies and imaging for disease diagnosis and guidance of therapy. She has previously served on the SPIE Board of Directors and the following SPIE committees: Diversity and Inclusion Ad Hoc, Awards, Membership and Communities, and Fellows.

Myers received her PhD in optical sciences from the University of Arizona in 1985. She coauthored the book *Foundations of Image Science* with Dr. Harrison H. Barrett in 2004, which won the First Biennial Goodman Book Writing Award from OSA and SPIE. In addition to serving on the SPIE Board of Directors, she has also been a member of the SPIE Awards Committee and Membership and Communities Committee. She is a member of the editorial board of the *Journal of Medical Imaging*.

The person elected vice president for 2020 will join the SPIE presidential

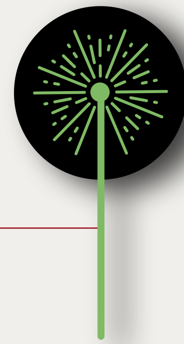


22 EDUCATION OUTREACH GRANTS AWARDED

Totaling $81,000; 50% of the winners were from outside the US

40 PRISMATIC MAGIC LASER SHOWS

Performed at the USA Science & Engineering Festival in Washington, DC, which has approximately 16,000 attendees



25,000 FREE OUTREACH MATERIALS

Distributed around the world, including:

194 Educational DVDs
8,000 Bookmarks
8,000 Science Posters
9,500 Diffraction glasses

170 OUTREACH KITS

Distributed to SPIE Student Chapters, teachers, and volunteers for use in their outreach efforts

4 WOMEN IN OPTICS GRANTS AWARDED

Supporting groups that increase opportunities for women in optics and photonics

chain, becoming SPIE president-elect in 2021 and president of the Society in 2022. The officers currently in the presidential chain are SPIE President Jim Oschmann, retired from Ball Aerospace, SPIE President-Elect John Grievenkamp of the University of Arizona, and SPIE Vice President David Andrews of the University of East Anglia.

Jason Mulliner, CFO at Alluxa (USA), is the candidate for secretary/treasurer. Mulliner previously served as secretary/treasurer in 2019. He has also served as a judge for the SPIE Startup Challenge, and currently serves on the SPIE Committee for Compensation and the Financial Advisory Committee.

Mulliner

Four positions are open for SPIE directors, who will serve three-year terms. The candidates are:

- Dan Curticapean, Offenburg University (Germany)
- Anderson Gomes, Universidade Federal de Pernambuco (Brazil)
- Babak Parviz, Amazon Web Services (USA)
- Halina Rubinsztein-Dunlop, The University of Queensland (Australia)
- Cristina Solano, Centro de Investigaciones en Óptica (Mexico)
- Sarun Sumriddetchkajorn, National Electronics and Computer Technology Center (Thailand)
- J. Scott Tyo, University of New South Wales Canberra (Australia)
- Katie Schwertz, Edmund Optics, Inc. (USA)

SPIE President Jim Oschmann will become immediate past president. He will announce the election results at the SPIE Annual General Meeting at Optics + Photonics in San Diego, California, on 13 August.

Curticapean

Gomes

Parviz

Solano

Schwertz

Tyo

Rubinsztein-Dunlop

Sumriddetchkajorn

Optics + Photonics

11–15 August 2019 in San Diego, California

At SPIE Optics + Photonics, researchers will gather to hear advances in optical engineering and applications, nanotechnology, quantum science, organic photonics, and astronomical instrumentation. This event offers innovative technologies to help industry, academia, and government find better ways to preserve our environment, understand and develop new photonics technologies, and discuss emerging applications for optics and photonics.

Plenaries focus on Astro, Nano, Opto

In odd-numbered years, SPIE Optics + Photonics includes a technical program focused on astronomical instrumentation, in addition to the annual conference tracks in nanoscience, organic photonics and electronics, and optical engineering. Several plenary talks will give updates on completed and upcoming space missions.

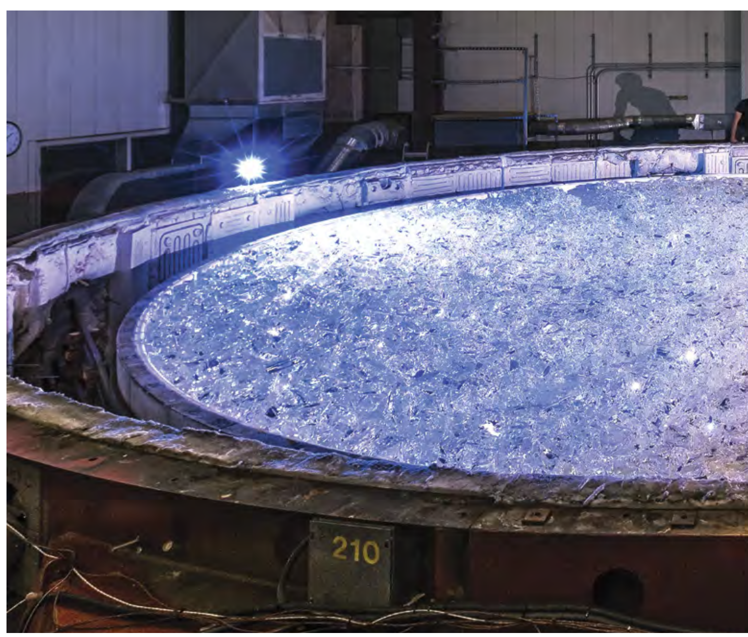
John Callas from NASA's Jet Propulsion Lab will discuss the exploration and discovery of Mars made possible by the Mars Exploration Rover Opportunity. The rover was originally designed for a 90-day mission, but successfully explored Mars for 14.5 years, traveling over 45 kilometers. Its objective was to assess the past habitability at different locations on the surface of the red planet, and was our first overland exploration of another world.

Martin Gehler will discuss the European Space Agency's LISA mission, which will be the first space-based gravitational wave observatory, consisting of three spacecraft separated by 2.5 million kilometers in a triangular formation following Earth in its orbit around the Sun. Gehler will present the mission concept and discuss its current state of development, as well as the technological challenges, especially with the optical metrology.

Massimo Mascaro, part of the Applied AI team for Google Cloud, will discuss the potential of AI and cloud computing to profoundly augment the toolset that scientists have at their disposal. He will discuss some of the recent work done in collaboration with NASA to help process exoplanet data and characterize life signatures identified by TESS and Kepler.

Hubert M. "Buddy" Martin, project scientist at University of Arizona's Mirror Lab, will describe the advances in mirror technology that enabled the current generation of 8- to 12-meter telescopes. These technologies are now being used to plan and build giant telescopes of 25 to 39 meters.

In addition to these astronomy-themed talks, plenary speakers will present on other topics related to the conference, including plasmonics-enhanced terahertz spectroscopy, 3D super-resolution imaging in cells, and stretchable optoelectronic devices. More plenaries, in addition to hundreds of talks, will round out the four-day technical program.



Giant Magellan Telescope mirror mold filled with low-expansion glass, ready Hubert Martin will discuss advances in mirror technology for giant telescopes

Learn something new

Optics + Photonics will offer numerous course options (**spie.org/opcourses**) for continuing education needs, all taught by leading experts. Two courses on design are perennial favorites: Practical Optical System Design (SC003) and Introduction to Optomechanical Design (SC014). Optomechanics and Optical Manufacturing (SC1085) and Deep Learning and Its Applications in Image Processing (SC1222) are also guaranteed to be popular.

Several new courses have been added to the course catalogue to engage people interested in these growing topics of research:

- Optical Measurement of Surface Topography (SC1271)
- Mirror System Design with Freeform Surfaces (SC1272)
- Introduction to Magnetic Random Access Memory (MRAM): Fundamentals, Current Status, and Emerging Device Concepts (SC1273)
- Introduction to Fundamental Performance Limits of CCD and CMOS Imagers (SC1274)
- Photodetectors—A Practical Selection Guide (SC1277)

Job fair

Over the years, SPIE has worked with more than 4,000 companies, recruiters, and research institutions to help them find technicians, technical sales people, scientists, and engineers. At Optics + Photonics, the job fair will be held in conjunction with the exhibition, where recruiting companies will be ready to talk to prospective employees. Job seekers should bring resumes and be prepared to tell the recruiter about themselves in two minutes or less. The job fair is free to attend, but registration is required. [**bit.ly/OP19-jobfair**]

Student program

Students enjoy attending Optics + Photonics for the numerous student and career development activities. Following Saturday's perennially popular student chapter leadership workshop, student chapters will present their optics demonstrations at the lively Optics Outreach Games on Sunday night. Students will also present posters at the Student Chapter Poster Exhibit, explaining how their chapters have helped increase optics awareness and literacy in their regions.

Credit: University of Arizona

for the lid of the furnace to be placed at University of Arizona's Mirror Lab.
during his plenary talk.

Professional development

Attendees will have the opportunity to focus on career development through numerous workshops and presentations that will help hone valuable job skills. Listed below are just a few of the activities related to professional development that come with registration. No advance registration is required, but seating is limited and will be granted on a first-come, first-served basis.

- Networking for Researchers
- Grant Writing
- Making the Most of your Presentation
- Women Communicating with Confidence
- Conveying Messages with Graphs
- Effective Resumes and Successful Interviewing
- Careers in Industry
- Salary Negotiation

Register to Attend: spie.org/OP

Action Item: Earth!

How remote sensing technology will map our planet's dynamic changes

SPIE Remote Sensing

9–12 September 2019 in Strasbourg, France

"What we need today is high-resolution timely geospatial information on a global scale," says Alberto Moreira, director of the Microwaves and Radar Institute at the German Aerospace Center (DLR). "Every minute, something is happening on Earth: it can be deforestation, an earthquake, a tsunami, a calving glacier. It commonly takes hours, even days, until you know the full extent of the damage and where you need to help people."

For Moreira, who will be giving a plenary, "The Future of Spaceborne Radar Remote Sensing," at the 2019 SPIE Remote Sensing symposium in September, the answer lies in observing and mapping our landmasses and oceans as efficiently, effectively, and accurately as possible, using a combination of full-fledged as well as smaller, lightweight radar satellites, interferometry, tomography, data-processing algorithms, and AI.

Radar in space, he notes, is the only technology that can provide geospatial information in a timely manner. "This is the only sensor technology that can map Earth independent of the weather, independent of day and night illumination, and with high resolution," he says.

The goal of generating a highly accurate digital elevation model (DEM) of Earth's topography led to TanDEM-X, a dual-satellite project utilizing formation flying and interferometric synthetic-aperture radar (SAR). This resolution-improving technology and satellite mission was initiated and led by Moreira.

Launched in 2010, TanDEM-X generated its DEM with pioneering accuracy, mapping Earth in three dimensions using interferometric processing. "Interferometry is the most accurate measurement that exists; it's the same concept that was used to image that black hole in space for the first time just a few months ago," explains Moreira. Today, TanDEM-X continues to capture three-dimensional images of our landscapes 30 times better than any other dataset available on a global scale. This project also paved the way for Moreira's newest satellite mission, Tandem-L.

TanDEM-X takes a year to map Earth, capturing about a few hundred gigabytes of data per day. That's too slow for our contemporary challenges: climate change, food security, disaster monitoring, megacities, and water shortages. "You cannot catch the dynamic processes that are happening across Earth in a timely fashion now," Moreira explains. "But Tandem-L will be able to map the whole Earth twice a week—we'll be able to see all the changes, as they are happening, every few days. There will be a huge amount of data—10 terabytes a day!"

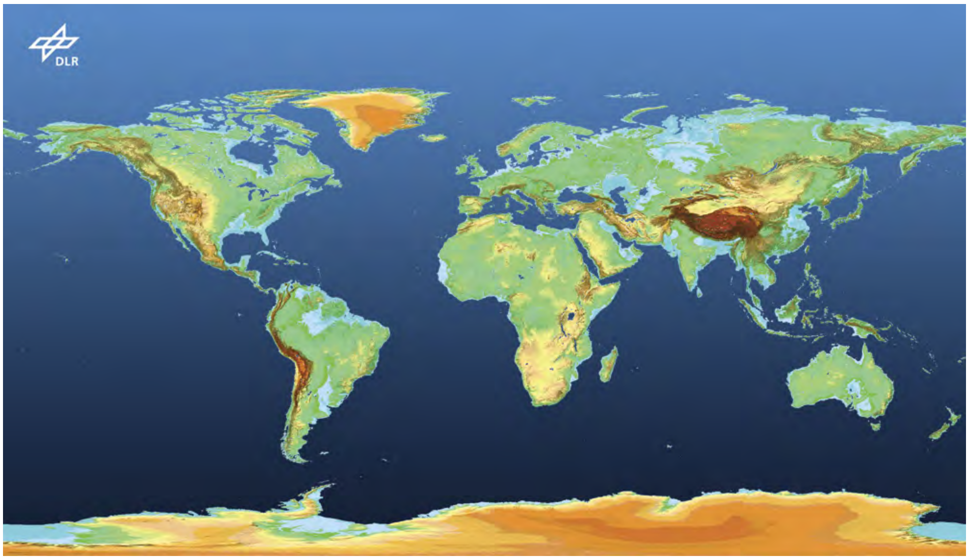
Moreira explains that he is developing airborne systems to simulate that kind of high-volume data, so that when TanDEM-L is flying five years from now, a cloud-based computer environment will be able to efficiently process data and retrieve information. He says, "We'll be able to capture, for example, forest height and biomass, soil moisture, ground deformation, glacier velocity and volume, and their changes on a global scale."

Making that leap from X to L entails smartening the entire remote-sensing system, using disruptive technologies like a small digital feed array and a large lightweight deployable reflector with 15-meter diameter to boost the performance of the radar satellite, as well as enhanced information-processing techniques, like tomography and machine-learning algorithms. "Today, artificial intelligence is only used for the data evaluation, and that area is rapidly improving," says Moreira. "But our goal is to make the whole system intelligent, starting with the sensor and including the entire data flow and satellite operation."

Moreira started his own observational experiences by piloting glider planes in his 20s. "I could discover new areas that I had not seen before, and that's the same thing that we do with remote sensing," he says. "We try to discover our Earth, to understand how our system, Earth, is changing. If we understand that, then we can also better predict Earth's system development. Then," he says, "we can make decisions that actually are very important—for our future and for Earth."

–***Daneet Steffens*** *is the PR manager for SPIE.*

To see Moreira's plenary talk on the state of the art and applications of spaceborne synthetic aperture radar, register to attend SPIE Remote Sensing: **spie.org/remote-sensing**



Credit: DLR

TanDEM-X Global Digital Elevation Model.

SPIE.

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For information about advertising in *SPIE Professional*, contact Melissa Farlow at melissaf@spie.org.

Upcoming events and deadlines

JULY

- **1:** Voting opens for the SPIE 2019 election
- **7-9:** Applied Optics and Photonics China in Beijing, China
- **24:** Abstracts due for SPIE Photonics West
- **24:** Abstracts due for SPIE AR, VR, MR

AUGUST

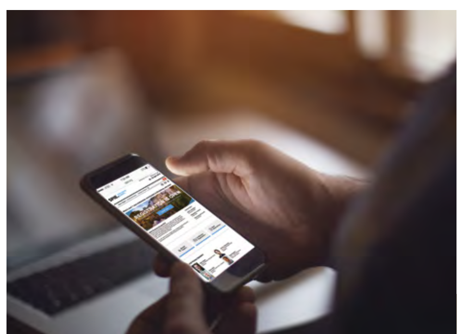
- **6:** Voting closes for the SPIE 2019 election
- **7:** Abstracts due for SPIE Medical Imaging
- **11-15:** SPIE Optics + Photonics, San Diego, California, USA
- **13:** SPIE Annual General Meeting in San Diego, California, USA
- **21:** Abstracts due for SPIE Advanced Lithography

SEPTEMBER

- **6:** Deadline to apply for SPIE-Franz Hillenkamp Postdoctoral Fellowship
- **9-12:** SPIE Remote Sensing, Strasbourg, France
- **9-12:** SPIE Security + Defence, Strasbourg, France
- **15:** Nominations due for SPIE Fellows
- **15-19:** SPIE Photomask Technology + EUV Lithography, Monterey, California, USA
- **16:** Submission deadline for SPIE International Day of Light Photo Contest
- **22-25:** SPIE Laser Damage, Broomfield, Colorado, USA
- **25:** Abstracts due for SPIE Photonics Europe

OCTOBER

- **1-4:** Seventh European Workshop on Optical Fibre Sensors, Limassol, Cyprus
- **14-17:** SPIE Optifab, Rochester, New York, USA
- **16:** Abstracts due for SPIE Smart Structures + Nondestructive Evaluation
- **16:** Abstracts due for SPIE Defense + Commercial Sensing
- **20-23:** SPIE Photonics Asia, Hangzhou, China
- **23:** Applications due for Rising Researchers
- **26-28:** 2019 International Conference on Optical Instruments and Technology



SPIE EVENTS

Find detailed information about SPIE conferences at **spie.org/conferences**

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