APS News

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Mess Around With Liquid Nitrogen. Go Viral. Repeat.

Tatiana Erukhimova, physicist and APS Nicholson Medal winner, reaches millions of people worldwide with her physics demonstrations.

BY SOPHIA CHEN

Tatiana Erukhimova demonstrates a liquid nitrogen explosion — her "favorite enormous cloud" — at an event in February 2024. Credit: Texas A&M University

Two years ago, Texas A&M University professor Tatiana Erukhimova accidentally became famous on TikTok.

The physics department's marketing team had filmed her doing physics demonstrations — marshmallows expanding in an evacuated bell jar; a spinning bike wheel that seems to defy gravity. They posted the videos to the social media platform, where they went viral. "We had more views on TikTok than Texas A&M football," says Erukhimova.

The videos are the latest addition to Erukhimova's storied career in physics education and outreach. She began her career as an atmospheric science researcher before finding she had a knack for engaging students and the public with flashy physics demonstrations. Now, she teaches large introductory physics classes and organizes outreach events with thousands of attendees.

"It has to be the mission of every physics department to make physics accessible and enjoyable," says Erukhimova, who holds an endowed position dedicated to outreach. "Not everyone has to be a physicist, but everyone should have a chance to play with physics. It's also easy to do. You can just take your demonstrations to places where people already are. You can give public talks; you can make videos." (After public universities banned TikTok in 2023, her team built a following on YouTube.)

Erukhimova, the 2023 recipient of APS's Dwight Nicholson Medal for Outreach, spoke to APS News about the importance of engaging the public about physics.

You have a real stage presence. Have you been a performer before?

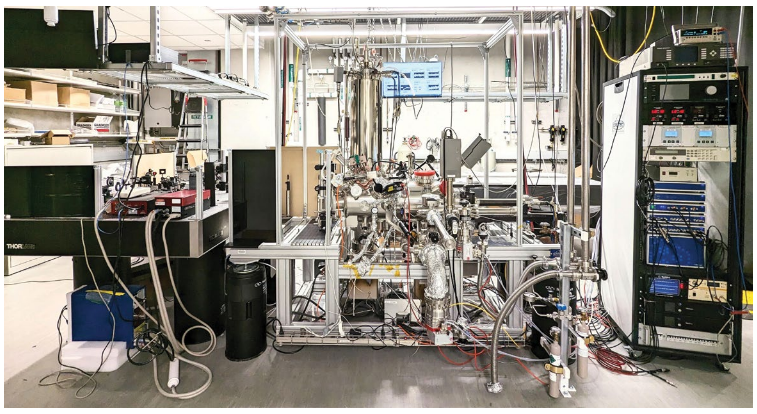
Never, before this. It's not easy for me. Obviously, teaching helps. I've also run physics shows for many

Erukhimova continued on page 5

An Inexpensive, DIY Setup Recycles Precious Liquid Helium in the Lab

At the APS March Meeting, researchers showed off a system for small labs to conserve helium used to cool sensitive equipment.

BY KATHERINE BOURZAC



Parts of the helium recovery system that Shaowei Li's team designed, which cost them about $100,000 — a steep cut from the multiple millions a larger commercial system would cost. Credit: Liya Bi / UCSD

Helium may be the second-most abundant element in the universe, but on Earth it's a finite, nonrenewable resource. Helium is so light that it's not trapped by the lower levels of Earth's atmosphere. And it's extremely challenging to capture, since it's relatively unreactive. Liquid helium is a critical ingredient in systems for cooling equipment used to study quantum systems and image atoms, as well as in the high-performance magnets used in MRI scanners and particle accelerators. But if it is not carefully contained, helium flies to the farthest reaches of the atmosphere or even out into space when it boils.

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This Spring, the Cicadas Are Gathering Like It's 1803

The 13-year and 17-year cicadas will emerge together for the first time in more than 200 years. Scientists are still figuring out how the bugs act in unison.

BY SOPHIA CHEN

Two 17-year periodical cicadas from brood X cling to a leaf. Credit: Gary Riegel / Adobe

Across the American Midwest and Southeast this spring, hordes of insects will emerge from a yearslong stint underground. They'll shed their exoskeletons and adopt their final form, with red eyes, black bodies, and glossy wings. The males will serenade females with song, produced by vibrating membranes on their abdomens, and then — after mating and within a few short weeks — they'll all die.

These strange visitors are periodical cicadas, which mature en masse over 13 or 17-year cycles. And this year is special: One 17-year brood of cicadas, known as Brood XIII, along with a 13-year brood known as Brood XIX, will emerge together in May and June.

"The last time these two broods emerged together, it was 1803," says

Cicadas continued on page 5

Black Hole Portraits Will Become More Frequent

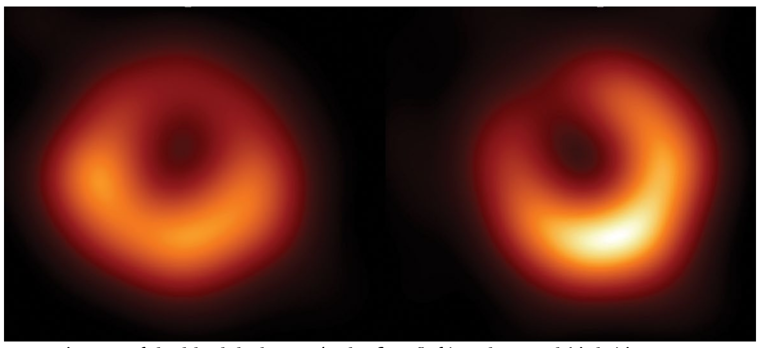
The release of a second, higher-resolution image of the supermassive black hole M87* marks the start of what researchers hope will be an era of many more black hole photos.

BY KATHERINE WRIGHT

This year marks the fifth anniversary of the release of the first-ever image of a black hole, which revealed the glowing doughnut of the supermassive black hole called M87*. The researchers who produced the image — the Event Horizon Telescope (EHT) Collaboration — recently released a second image of that same black hole, which lies 55 million light years from Earth. This image comes from an updated version of the telescope and confirms key features of the black hole, while also revealing changes in the pattern of light emanating from the disk surrounding the object. Starting with this release, the collaboration expects to issue increasingly frequent updates in support of the newly developing field of black hole imaging.

"Producing the first image of M87* was a herculean effort and involved creating, testing, and verifying many different schemes and approaches to analyzing and interpreting the data," says Princeton astrophysicist Andrew Chael, a member of the EHT Collaboration. "Now we are beginning to transition to a point where we understand our instrument and our analysis frameworks really well, so I think we are going to be releasing results a lot more quickly."

Supermassive black holes are extremely distant and compact objects, two properties that make them extraordinarily difficult to image. For example, M87* appears to us as no bigger than an orange on the moon as viewed from Earth. The 2019 image of M87* was pieced together using data collected in April 2017 from eight radio telescopes spread across the globe. All the telescopes in that array collected data simultaneously, allowing scientists to treat them as one giant radio-wave detector. The bigger a radio telescope, the smaller the objects it can image, and an Earth-sized detector opened the possibility of observing sources as small as supermassive black holes. So far, the EHT has imaged M87* and Sagittarius A*, the black hole at the center of the Milky Way.



A new image of the black hole M87. The first (left) and second (right) images are consistent, showing a dark center surrounded by a glowing orb. The brightest part of the orb, however, has shifted counterclockwise by 30°.* Credit: EHT Collaboration

For their second data-collection run, which took place in April 2018, the EHT Collaboration added a ninth telescope to the array — the Greenland Telescope — which allowed the EHT array to make more detailed measurements of M87*. The telescopes work in pairs, and the quality of the final image depends on the pair separations and orientations relative to the object of interest. Making a perfect image would require having pairs of telescopes with all possible values of these two parameters. Earth's rotation provides some additional separations and orientations, but there are still significant gaps in the data. With an extra dish in the array, the team was able to fill in some of these gaps.

Both M87* images show a black disk — the black hole's shadow — surrounded by a glowing orb, which is the light produced by the material orbiting the hole. The diameter of the black hole's shadow and the distribution of light in its glowing orb are roughly the same in both sets of data — an encouraging finding, says Nitika Yurk of NASA's Jet Propulsion Laboratory in California, who is a member of the team that produced the new image.

The diameter of a black hole's shadow is directly linked to its mass. Other measurements of M87* indicate that the black hole is accreting mass at a very slow rate, slow enough that the radius of its orb should stay constant for the foreseeable future. "We didn't expect

Black Holes continued on page 6

Building a Quantum Workforce Doesn't Just Mean Graduating More Ph.D.s

To bring millions of new technology workers into the fold, nations must cast a wide net.

BY MCKENZIE PRILLAMAN

Science stands at the verge of a new quantum revolution. The first one created the field of quantum physics, whose 100-year anniversary will be celebrated in 2025, dubbed the International Year of Quantum Science and Technology. The current, and second, revolution aims to apply quantum principles to new, advanced technologies, like quantum computing, cryptography, and sensing. But that leap requires scaling up the human power needed to bring those advancements to life.

On Feb. 26, experts from around the world gathered in Washington, D.C., to address the gaps in building a quantum workforce at an event called "Narrowing the Quantum Divide," co-sponsored by APS. The speakers emphasized that careers in quantum science and technology can come from a variety of educational backgrounds, and that quantum concepts should be incorporated early in education.

"We need to inspire future generations to be greatly engaged in the quantum revolution," said Jacques Pitteloud, Switzerland's ambassador to the U.S.

The need is dire. For instance, in 2021, the Technology Industries of Finland estimated that the country would need 130,000 new technology experts within the next 10 years, said Jouko Lampinen, professor of computational engineering and dean of the School of Science at Aalto University in Finland. For the U.S. population, that would mean 8 million new experts, he noted.

But being an expert doesn't require a Ph.D. in physics — or a Ph.D. at all. "We need people who are able to implement the ideas developed by all these brilliant scientists," Pitteloud said.

That means knowledge gained from a master's, bachelor's, or vocational program. A study published in 2020 found that coding is the top skill needed in the quantum industry, said Heather Lewandowski, professor of physics and faculty director of CUbit Education and Workforce at the University of Colorado Boulder, who co-authored the work. Hands-on skills, like data analysis and laboratory experience, are also highly valued, she added, and many skills are transferable from other fields.

"We need to think broadly, and really encourage our students to think broadly, about entering the quantum industry with different types of degree preparation," Lewandowski said.

At Front Range Community College's Boulder County Campus, for example, students can learn those hands-on skills and gain real-world experience in two years or less. The Optics & Laser Technology program, which provides career and technical education much like a vocational school, works closely with optics, photonics, and quantum companies to discuss curriculum instruction and program resources, said Amanda Meier, who directs the program.

> "All of our students have had their pick of jobs as they come out," Meier said. "Six months, and they're already getting snatched up by employers."

"We have been trying to keep our pulse alongside our industry partners to know what skills they need in their actual employees," she said. Those taught include a broad range of laboratory skills, like how to work with equipment, cleanup protocols, and safety, as well as soft skills, such as critical thinking, collaboration,

Quantum continued on page 4

Panelists speak at the "Narrowing the Quantum Divide" event in Washington, D.C.
Credit: Elisa Seppänen

THIS MONTH IN PHYSICS HISTORY

April 20, 1972: George Carruthers' Ultraviolet Telescope Lands on the Moon

His invention was the first telescope set up on another planetary body.

BY KENDRA REDMOND

George Carruthers, center, discusses the ultraviolet telescopic device with Apollo 16 Commander John Young, right. Credit: NASA

In the early 1950s, astronomy was an Earth-bound affair. Telescopes on the ground peered up through Earth's atmosphere; the first satellite launch was years away. So when a teenager named George Carruthers approached astronomers at the Adler Planetarium and asked them about conducting astronomy *from space*, they scoffed at the idea.

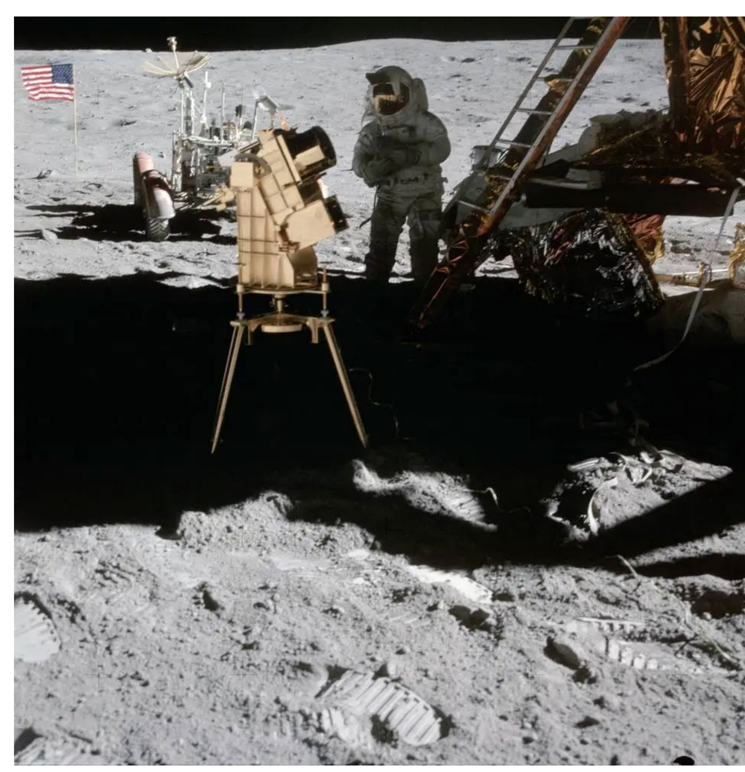
But Carruthers was right: Space-based astronomy was around the corner. Two decades later, a pair of astronauts assembled Carruthers' own invention — a gold-plated telescope for ultraviolet imaging — on the surface of the moon.

As a child, Carruthers first became interested in space flight from a comic book featuring the science-fiction hero Buck Rogers. A love for astronomy soon followed, sparked first by an encyclopedia entry and then a *Collier* magazine series called "Man Will Conquer Space Soon!"

Carruthers' didn't exactly fit in at his rural Ohio elementary school. "A lot of both my teachers and [the] students thought my interest in astronomy was strange," he recalled in a 1992 interview with the American Institute of Physics. He was also one of just a handful of Black students.

But Carruthers' father — a civil engineer — encouraged his son's interest in math and science. He died when Carruthers was 12, and the family moved in with relatives in Chicago. In the city, Carruthers could more easily feed his curiosity; the elevated train took him right to the Adler Planetarium. "The people who were interested in astronomy weren't interested in space flight and vice versa," he recalled. "When I talked about space flight, [the astronomers at Adler] told me that was nonsense, because that was before any space flight mission had ever taken place."

Undeterred, Carruthers immersed himself in the science of rocketry and astronomy during high school and college and headed to the University of Illinois, Urbana-Champaign, for graduate school in aeronautical and astronautical engineering. As part of his thesis, Carruthers studied the spectra of atomic nitrogen recombination in visible light.



Apollo 16 astronaut John Young used Carruthers' ultraviolet telescope to photograph Earth and space from the moon. It was the first telescope used on the surface of another planetary body. Credit: NASA

By the time Carruthers earned his doctorate in 1964, the space race between the United States and the Soviet Union was in full swing, with NASA gearing up for the first American spacewalk. Carruthers clinched a postdoctoral position — and eventually full staff role — in Washington, D.C., in the Naval Research Laboratory's Space Science Division, led by physicist and astronomer Herbert Friedman.

While NASA concentrated on space flight, researchers in Friedman's division were using sounding rockets to probe the structure of the Earth's upper atmosphere, the Sun, and newly discovered ultraviolet and x-ray emitting cosmic sources. It was pioneering work. Getting above Earth's atmosphere was key to seeing the universe in short wavelengths, and it had only become possible with rocket payload experiments in the late 1940s. By the 1960s, the technology for these experiments had improved significantly. With the right resources, Friedman wrote in 1963, "major advances in astrophysics can be achieved in the immediate future through the use of observatories in space."

In his new position, Carruthers applied his experience with spectroscopic techniques to astronomy. Methods for collecting spectroscopic data at the time were prone to quantum efficiency losses and wavelength cutoffs, or they required scanning Geiger counters. In the search for a solution, Carruthers had read about new electronic imaging devices that converted electromagnetic radiation images into electron images. They were efficient, more sensitive than traditional ultraviolet film, maintained the integrity of the image, and captured an entire spectrum in a single exposure. With

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APS Partners with AIP and IOP to Launch New Purpose-Led Publishing Coalition

In February 2024, three nonprofit publishers in physics — AIP Publishing, the American Physical Society, and IOP Publishing — joined forces to create Purpose-Led Publishing, a new coalition that promises to always put purpose above profit.

The three scholarly publishers are united by their nonprofit status, with all the funds made from publishing going back into the research ecosystem. Their collective contributions support the physical science community globally through a range of initiatives, including educational training, mentorship programs, and awards and grants.

PURPOSE-LED PUBLISHING™
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As members of PLP, the publishers have defined a set of industry standards that underpin high-quality, ethical scholarly communications. These form the bedrock of PLP's promise to the scientific community. These standards are as follows:

We will always:

- *Invest 100% of our funds back into science*
- *Publish only the content that genuinely adds to scientific knowledge*
- *Ensure our terms are reasonable*
- *Put research integrity ahead of profit*
- *Admit our errors and set them right*

We will never:

- *Relinquish our not-for-profit status*
- *Have shareholders for whom we put profit above purpose*

PLP members will continue to work closely together to ensure their policies, processes, and standards benefit the scientific community.

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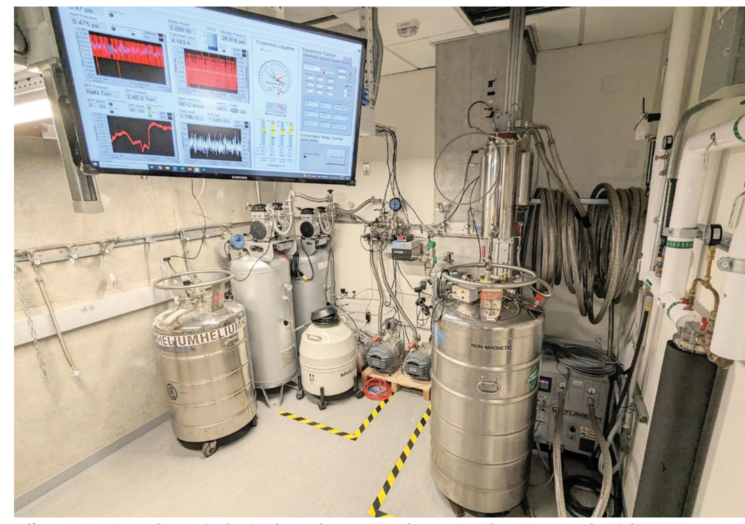


Li's group describes their designs in a preprint submitted to arXiv this January. Credit: Liya Bi / UCSD

Shaowei Li, a chemist at the University of California, San Diego, says the preciousness of helium has become increasingly clear to him in over a decade working with instruments that require supercool conditions. Over that time, he's seen the price of liquid helium rise from about $2 per liter to $20 per liter.

So Li decided to take matters into his own hands and build a system to condense and recycle helium in his lab. At the APS March Meeting in Minneapolis, Liya Bi, a graduate student working with Li, described how they did it. The UCSD team combined an air compressor, brewery equipment, and parts from a hardware store to make a relatively inexpensive system that can recapture 92% of the liquid helium used in their lab — without creating vibrations that would jar sensitive equipment.

Helium is generated by radioactive decay of elements underground, and it's often mined in the same places as natural gas. But humans are using helium at a growing rate, faster than natural processes can replenish it, says Li. Geopolitical and economic turmoil have jeopardized scientists' ability to sustain a steady, affordable supply. Under the terms of a 2013 law, the United States — the world's biggest producer of this critical element — may sell the country's helium reserves, pipelines, and wells to a private company later this year. The impact of this sale on researchers is not clear.

Liquid helium, with its chilly boiling point only a few degrees above absolute zero, is critical for cooling down Li's scanning tunneling microscope (STM), which uses an extremely sharp tip to image and manipulate single atoms on a surface. It requires very cold temperatures to operate, as those atoms must hold still. "Thermal perturbations will mess up the measurements," says Li. His lab uses an STM to study the quantum states of single atoms, which are key to understanding the underlying drivers of chemical reactions. "To study quantum systems, the surrounding has to be as cold as possible," he says.

In the last decade, companies have developed systems for conserving liquid helium. But those systems don't work for labs like Li's. That's because they cost upwards of $10 million and are intended for systems that use large amounts of liquid helium, designed to liquify about 100 liters a day. So they're typically shared between multiple labs or medical imaging bays. Li's lab doesn't have pipes connecting them to one of these systems — the university hospital, he notes, is across the freeway from his lab. Other options vibrate too much to share space with the sensitive STM.

"Helium is getting increasingly expensive and difficult to manage," says Paul Weiss, a chemist at the University of California, Los Angeles. Weiss also uses scanning tunneling microscopy, and he says helium is a major expense for labs operating these microscopes. These setups are extremely sensitive to vibrations, which typically makes helium recovery systems difficult or inefficient to implement, he says.

Li's group made a helium recovery system work by separating the noisy part of the helium conservation system from their STM. Helium that boils off the STM's cryostat is piped into another room, where a noisy air compressor can vibrate without causing problems. The gas is condensed on a cooling coil that Li bought from a brewing supplier — typically used to cool beer — and stored in a metal container called a dewar. The most expensive part is the condenser, which was about $70,000. Li says the entire system cost about $100,000 to build, and he expects to recover the costs in saved helium in two years. Li's group describes their designs in a preprint submitted to arXiv this January.

Though he's a chemist by training, Li says this kind of DIY work isn't too far afield for him. He enjoys building new instruments. A large part of his work is dedicated to building new imaging technologies. At the March Meeting, Li also talked about his work on what he calls hyperdimensional scanning tunneling microscopy, which can provide high-resolution information about the movement of electrons in space and time in response to laser pulses. He said this work is inspired by his Ph.D. advisor, Wilson Ho of the University of California, Irvine, who used to tell him that if something you need doesn't exist, you should try to build it.

Humans are using helium at a growing rate, faster than natural processes can replenish it, says Li. Geopolitical and economic turmoil have jeopardized scientists' ability to sustain a steady, affordable supply.

Weiss calls Li's helium recycler "a clever integrated solution," and notes that the UCSD team is still able to collect high-quality STM data with the system turned on, proving that it can work alongside this sensitive equipment in a small lab.

Li says it should be possible to implement the helium-recovery design in other small labs that house sensitive equipment. The team has applied for funding from the National Science Foundation to further develop the system.

Katherine Bourzac is a science writer based in San Francisco.

Grad Students and Postdocs Don't Earn Fair Wages, so 91 Scientists Brought It Up With the Folks in Charge

For Congressional Visits Day, APS members met directly with congressional leaders and staffers on Capitol Hill.

BY TAWANDA W. JOHNSON

2024 Congressional Visits Day advocates in Washington, D.C. Credit: APS

Grad students and postdocs in physics have long been underpaid — but today, the compensation gap is particularly extreme.

"The salary, or compensation, that students and postdocs receive is about the same as what my husband received 20 years ago when he came to Penn State from Cambridge University as a postdoc," says Amena Khan, an associate professor of instruction at the University of Texas at Dallas. "It is as though one is being penalized for choosing physics as a profession."

To change this, it helps to talk to the folks in charge — so in January, 91 APS members flocked to Capitol Hill in Washington, D.C. for APS's Congressional Visits Day. In 110 meetings with lawmakers and staffers, attendees advocated for science policy priorities, including the RESEARCHER Act, which would start the process of building compensation guidelines for federal science agencies.

For Ari Jain, an attendee and a doctoral student in aerospace engineering at Georgia Institute of Technology, the efforts paid off. After CVD, he spotted an email from the staffer of his congressional representative, Nikema Williams. It felt "a little surreal," he says. "Our team had just sent a thank you-note to her staffer, and he responded the next day saying that she had agreed to co-sponsor the bill."

Physics graduate students earn far less money than those with bachelor's degrees in the field, a deterrent for students considering advanced degrees in STEM. Physics students with bachelor's degrees working in industry earn a median starting salary of $70,000, while grad students make just under $30,000.

"Their salaries are pitifully low, especially against the rising costs of living in our metros and towns," says B.S. Sathyaprakash, a professor who teaches physics, astronomy, and astrophysics at the Pennsylvania State University, who also joined CVD.

The RESEARCHER Act was one of several priorities covered in conversations with members of Congress. To make sure the advocates were prepared, APS staffers spent months organizing for the event, providing advocates with extensive training and background information on APS's policy priorities. These were vital steps for many of the CVD participants, including those who had never advocated on Capitol Hill before, like Khan and Sathyaprakash.

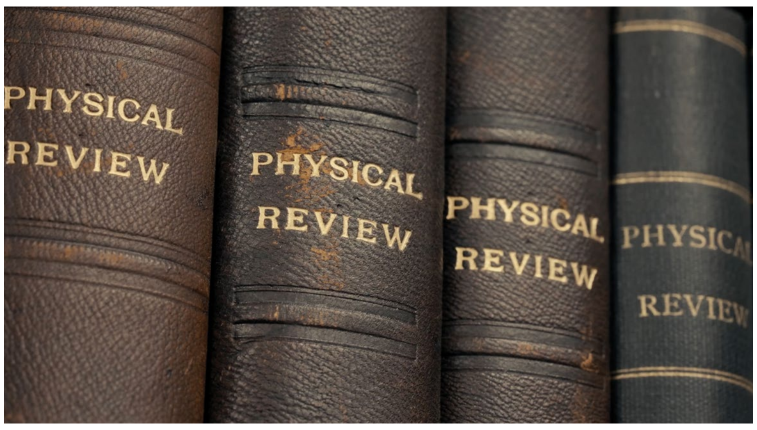
Khan also said she was "lucky to have two experienced colleagues" on her team. "[They] made navigating the day seem almost effortless." Jain, meanwhile, relied on guidance from seasoned CVD advocate David Stilwell, a doctoral student in physics at the University of North Carolina, Chapel Hill.

"Some of it was just little things, like navigating the buildings and making sure our team didn't get too lost," Jain says. "But also, David gave us amazing insight on what to actually expect from the meetings and conversations that we have with staffers."

Tawanda W. Johnson is the APS Senior Public Relations Manager.

APS Introduces The Physics Archive, a Digital Repository of 120 Years of Physics Research

With a one-time purchase, subscribing organizations will have permanent access to all APS journal articles published from 1893 through 2012.



Credit: APS

The American Physical Society has launched The Physics Archive, a product that will grant universities, libraries, and other organizations immediate and permanent access to 120 years of research articles published in the world-renowned Physical Review journals.

The journal articles covered in The Physics Archive span those published from 1893 through 2012. Articles are segmented by journal and copyright year, allowing customers to purchase portions of the scientific literature as it suits their collection strategies and budget needs.

The one-time purchase grants perpetual access to these journal articles on any PDF- or XML-capable device for an unlimited number of affiliated and authorized users, including off-site collaborators. There are no hosting, access, or other ongoing fees of any sort.

A variety of discounts, including volume rates and active subscriber discounts, are available. For more information on titles, pricing, and discounts, visit discover.aps.org/physics-archive.

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and communication. Students earning a two-year associate's degree apply their knowledge through a required internship.

"All of our students have had their pick of jobs as they come out," Meier said. "Six months, and they're already getting snatched up by employers."

Because of the success, she has been working to expand the program and even get high schoolers involved. But many experts say that quantum education should be introduced much earlier than that.

"In the U.S., girls and people of color self-select out of [STEM] around middle school," said Emily Edwards, associate research professor of electrical and computer engineering at Duke University and co-leader of the National Q-12 Education Partnership. "Kids are deciding really early — whether they realize or not — if they have a sense of belonging."

Part of that opting out comes from a lack of representation and role models in STEM fields, particularly quantum science. Organizations like Girls in Quantum aim to build a community of diverse young people interested in the field and provide fun ways to learn.

Another factor is access to information and resources, which the National Q-12 Education Partnership works to tackle. The initiative has figured out where quantum concepts can fit into science and math curricula in American K-12 education and has developed materials for teachers. The goal is to engage 50,000 of them by the end of 2025, Edwards said. "It's all about the teachers."

Tim Smith, head of collaboration and information services at CERN, agreed. "The teachers are the ones that can reach 10,100 times as many students as we can," he said. By getting teachers to bring quantum science into their classrooms, it will become part of the common curriculum and language, he added. "Instead of people saying they've heard [of a quantum concept] in a Marvel movie, they will actually have heard it at school."

Another way to reach students and the general public is World Quantum Day, Smith noted, an international celebration started in 2021 and held annually on April 14. Events across the globe work to raise awareness of the quantum world and its possibilities, he said.

Public engagement events like those held on World Quantum Day and the infusion of quantum concepts early in education will hopefully demystify and democratize the field, the speakers said, which will be needed as quantum science and technology progresses.

Over the "next 10 years, the development will be much, much faster than it was the last 10 years," Lampinen said. There are so many "big, wicked questions" that quantum technology could help to address, like climate change, he noted. A highly skilled and diverse quantum workforce will be poised to "come up with some real, big solutions."

McKenzie Prillaman is a science writer based in Washington, D.C.

Science Policy Highlights

BY THE FYI TEAM

Nominees sought for top federal science and technology awards

The National Science Foundation is seeking nominees for the National Medal of Science, the nation's top scientific honor. The award was established by Congress in 1959 and is presented by the president. Just over 500 scientists and engineers have received the award to date. Nominations for the next round of awards are open until May 5.

A National Medal of Science. Credit: The White House

Other big awards currently open for nominations include the Department of Energy's Ernest Orlando Lawrence Award, which recognizes the contributions of mid-career scientists and engineers supported by DOE, and the U.S. Patent and Trademark Office's National Medal of Technology and Innovation. These nominations are also due in early May.

Competition open for Jefferson Lab management contract

In February, the Department of Energy opened a competition to select a contractor to manage Jefferson Lab in Virginia, citing a desire to improve contractor performance and realize "cost efficiencies." DOE also noted the lab is amid a transition from focusing on nuclear physics to becoming a multi-purpose lab, in part by constructing a major facility that will provide infrastructure for data-intensive science.

The lab employs around 850 people and has an annual budget of about $236 million. The current contractor is a subsidiary of the Southeastern Universities Research Association, which has indicated it will submit a proposal to continue operating the lab. The winner is expected to assume lab operations in June 2025.

DOE anticipates issuing a formal request for proposals this summer. The process DOE is using for the competition mirrors that used for the Fermilab contract competition, which is also underway.

NIST physics labs face urgent infrastructure and safety issues, panel finds

The National Institute of Standards and Technology's Physical Measurement Laboratory (PML) in Boulder, Colorado, needs hundreds of millions of dollars to repair its ailing physical infrastructure, according to a new assessment by a National Academies panel.

The panel's January report notes, for instance, that one of the lab's main research centers, called JILA, is "seriously endangered by a combination of aging and lacking facilities" and that NIST officials have estimated that a $200 million repair effort "would barely bring the facilities up to the standards of international peer institutions."

The panel does not cite repair budget estimates for other divisions of PML, though it does highlight the findings of a related report released by a National Academies panel in 2023 that assessed infrastructure needs across all of NIST. That report concluded NIST would need around $500 million annually for at least 12 years to comprehensively repair and modernize its infrastructure.

Infrastructure aside, the latest Academies panel found that PML "does not adequately ensure the safety of PML staff and visitors," especially concerning laser-safety protocols and the frequency of safety inspections. The panel recommends PML increase the pace of inspections and seek industry advice on safety standards, among other actions.

FYI is a trusted source of science policy news, published by the American Institute of Physics since 1989.

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only journal articles as his guide, Carruthers built and patented a robust image converter of his own. In his first rocket experiment, his device captured far ultraviolet signatures of molecular hydrogen in interstellar space, confirming its existence.

In 1969 — the year that the Apollo 11 mission put people on the moon for the first time — NASA put out a call for experiments that astronauts could conduct on future landings. Independently, Carruthers and the astronomer Thornton Page proposed doing ultraviolet imaging of Earth and space from the surface of the moon. At NASA's suggestion, the two joined forces, Carruthers as principal investigator and chief engineer and Page as science lead, and the project received approval. The planned camera would be "the most advanced light recording system in the world," wrote NASA project scientist Martin W. Molloy in a 1970 memo. Its data could shed light on the structure of our galaxy, the composition of the solar wind, and more.

George Carruthers, right, and William Conway, a project manager at the Naval Research Institute, examine Carruthers' ultraviolet camera for the Apollo 16 mission to the moon. Credit: NASA

In 2012, President Barack Obama awarded Carruthers the 2012 National Medal of Technology and Innovation. Credit: Charles Dharapak / photo retrieved from Naval Research Laboratory

In two short years, Carruthers and Page designed the Far Ultraviolet Camera/Spectrograph. The device was built to survive a launch into space, function on the moon, be controlled by astronauts in full gear, and reveal unknown ultraviolet emissions.

It was packed into a spacecraft, and on April 20, 1972, Apollo 16 and its crew landed with it on the moon. Astronaut John Young set up the 50-pound telescope in the Descartes Highlands. He and Charles Duke spent three days on the lunar surface, collecting rock and soil samples, performing experiments, and manually pointing Carruthers' telescope at Earth and space targets.

The film they brought back contained nearly 200 images, among them the first image of Earth from a distance in ultraviolet light, and images of Earth's polar auroras and tropical airglow belt. A surprising and important finding was that hydrogen extends far above Earth's atmosphere, according to Carruthers. Other images revealed stars and nebulas hidden in visible light and details about the composition and structure of interstellar space.

The project's success solidified Carruthers as a visionary engineer, inventor, and astronomer. He continued working at the Naval Research Lab for nearly forty years before retiring in 2002 as senior astrophysicist, and then went on to teach Earth and space science at Howard University. He became a dedicated mentor for students, including high schoolers, and young Black scientists.

Carruthers died in 2020. In 2022, NASA renamed its GLIDE mission — a space mission to observe Earth's atmosphere in ultraviolet light — the Carruthers Geocorona Observatory, slated to launch in 2025.

And his contribution to Apollo 16 still sits in the lunar highlands. "If an alien life form happens to land on our moon a billion years from now," write Richard Paul and Steven Moss in *We Could Not Fail: The First African Americans in the Space Program*, the visitors would spot Carruthers' invention: "Coated in pure gold, it stands on three legs and stares out blankly at the infinite void: the first telescope ever set up on another planetary body."

Kendra Redmond is a writer based in Minnesota.

Erukhimova continued from page 1

years for dozens and sometimes more than a hundred children. My favorite audience is second graders. You cannot afford to lose their attention.

When did you start doing physics demonstrations?

The first course I ever taught was a small class for juniors on atmospheric thermodynamics at Texas A&M. I loved it. Then I taught 100 freshmen at eight in the morning. That was a completely different experience. Freshmen expect their professor to look like Einstein, and instead, they saw me. They didn't listen. This experience taught me to get their attention and respect from the beginning and to make every class interactive and memorable. I never walk into my first class without a physics demonstration to create that wow factor. Motivated and inspired students learn better.

What demo do you bring on the first day?

Anything counterintuitive makes a long-lasting impression. Sometimes I bring liquid nitrogen to create my favorite enormous cloud, or an electromagnetic bike, where you rotate a crank to turn light bulbs on. I also like demos made from everyday objects. Take a large potato, and place it on the tip of a kitchen knife. If you hit the knife handle with a mallet, everyone expects the potato to fall. Instead, it looks like it goes up because of the potato's inertia.

What outreach programs do you currently put on?

We put on the annual Texas A&M Physics and Engineering Festival, along with physics shows for K-12 students. We run programs for high school physics teachers. We make physics videos for middle and high school students. We bring our demonstrations to places where people already are, from cultural festivals to football games.

I also started the extracurricular program DEEP, which stands for Discover, Explore, and Enjoy Physics and Engineering. This program is probably the closest to my heart. Undergraduate students work under the leadership of graduate students to design, build, and present hands-on demonstrations at outreach events. For example, students, some of them freshmen, built a magnetic train track and 3D-printed a train that levitates over the rails using superconductors. I'm also proud that former graduate student participants started similar programs to DEEP at Rice University and at UT-Austin.

"Anything counterintuitive makes a long-lasting impression," Erukhimova says about her demonstrations. Credit: Texas A&M University

The Texas A&M Physics and Engineering Festival is your university's flagship outreach event. What goes on at the festival?

Our primary goal is to have people enjoy physics. Thousands of people have attended the festival every year since 2003, and hundreds of students and dozens of faculty come together to put it on. No one cares if you're a Nobel laureate or an undergraduate student.

I like our grand finale, where we make a liquid nitrogen-fueled fountain of water. We fill five barrels with water and put two-liter Coke bottles with some liquid nitrogen, along with thousands of plastic balls. Water explodes out with the balls, and the children run to collect the balls. My favorite part is to observe our students sharing their passion for science. They are role models for these children.

We also have top-notch researchers give talks. Stephen Hawking gave a lecture at the first one, so the festival has had national recognition since the beginning.

Why are you passionate about outreach?

We always talk about how the public benefits from outreach, but we often forget that students who do the outreach benefit too. What's the best way to learn something? To explain it! They also improve their communication skills. They gain teamwork and design experience, and they receive recognition from the public and their professors.

We published a study where we interviewed students who ran outreach programs between 2013 and 2019. They reported that through outreach activities, they felt closer to the physics community than through regular classes. Some young students said they were not initially confident that they had a place in the program. By facilitating the outreach programs, they felt like they contributed something, and that made them feel like they belonged. The programs had a special impact on the development of a physics identity for female students, who are underrepresented in physics.

Texas A&M physics's TikTok videos have gotten over 200 million views. Your YouTube Shorts videos have over 600 million views. You were also recently on the Jennifer Hudson Show and CBS News. Do you ever get recognized?

Many times, in different parts of the country. People have stopped me when I was in New York. But the videos are a team effort, requiring not just me but also my colleagues, and I work with three or four people to make them. Social media is just another channel to make physics exciting. You cannot explain much in such a short period of time, but the videos are important because they break the stereotype that physics is inaccessible.

Who inspires you?

The enthusiasm of the students who run these programs with me, and the dedication of my colleagues who understand the importance of informal physics programs. And, of course, children. Tomorrow morning, right after my first class, I will do a physics show for 130 sixth graders. At the end, I will lead them in a chant where we shout, "Physics! Physics! Physics!" The children get so excited, and I love it. It recharges my batteries.

Sophia Chen is a writer based in Columbus, Ohio.

PhysTEC Announces 2023 Inductees to the 5+Club

Eighteen universities graduated five or more highly qualified physics teachers.

Most colleges and universities graduate no more than two trained physics teachers each year, and many graduate none at all, compounding a severe shortage of qualified instructors. To highlight institutions that have made teacher training a priority, the Physics Teacher Education Coalition, or PhysTEC, recognizes schools that have graduated five or more qualified physics teachers — defined as teachers with a degree in physics or physics education — in a given year. These schools are inducted into the 5+ Club, in recognition of their efforts to address the national shortage of physics teachers. Number of students graduated is included in brackets.

5+ Club for 2022-23: Brigham Young University (7); Brigham Young University, Idaho (15); College of New Jersey (6); California State University, Long Beach (11); Illinois State University (8); University of Minnesota (5); New Jersey Center for Teaching and Learning (13); Rutgers University, New Brunswick (5); Stony Brook University (9); Colorado School of Mines (5), University of Texas, Austin (5); Western Governors University (16); University of Wyoming (5).

5+ Club for 2020-23: Bridgewater State University (8); California State Polytechnic University, Pomona (6); California State Polytechnic University, San Luis Obispo (5); Lewis University (5); State University of New York, Geneseo (5).

PhysTEC is a partnership between APS and the American Association of Physics Teachers that aims to improve and promote physics teacher education by transforming physics departments, creating successful models for teacher education programs, and sharing best practices.

To learn more, visit phystec.org.

Cicadas continued from page 1

entomologist Gene Kritsky of Mount St. Joseph University. "Thomas Jefferson was our president."

The cicadas of Brood XIII dwell mainly in Wisconsin, Iowa, and Illinois, while Brood XIX cicadas live in the southeast and Midwest. The two broods may overlap in Illinois. And to physicists' intrigue, when the insects emerge, they will demonstrate another curious talent: Cicadas clearly use math.

For one thing, they emerge in hordes numbering in the billions, to their evolutionary advantage. Their sheer numbers ensure the broods' survival, as "predators get tired of eating them," says Kritsky. Fishing enthusiasts have told Kritsky that the cicadas serve as effective bait only for so long before the fish stop biting. "I've seen people collect five-gallon mayonnaise jars from the restaurant industry, fill them with nymphs, and they'll freeze them and just use a few every so often every year," he says.

Good for cicadas, because they have a lot of predators: dogs, cats, raccoons, squirrels, turtles, and snakes, Kritsky says. "I've even seen owls on the ground during the day picking these things up and eating them." Humans eat them too. "To me, they taste like cold canned asparagus," he says. "That's not surprising because they suck on the watery juices of trees." (Kritsky prefers not to eat cicadas, as he is "very fond of them," but he advises those interested to eat them when their mature exoskeletons have not fully hardened.)

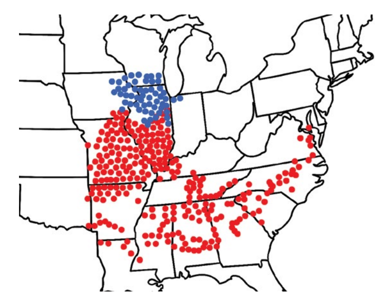
Their life cycles also notably occur in prime number years. This has proven an evolutionary advantage against predators, as applied mathematicians Frank Hoppensteadt and Joseph Keller argued in 1976. If their cycle was a composite number, such as 16, then their emergence would coincide with the maturation of predator species that develop in 2, 4, 8, and 16-year cycles. By emerging every 13 or 17 years, cicadas reduce the likelihood that they mature in synchrony with predator species, lessening their chances of being eaten.

"We have a pretty good idea of how they count the years," says Kritsky. They keep the tally by tracking the seasonal warming of xylem, the nutritious fluid in trees that cicada nymphs feed on. But this tally is imperfect. In the winter between 2006 and 2007, trees in southwestern Ohio began growing leaves and flowers early in an unseasonably warm December and January, before freezing temperatures killed off the budding foliage in February. When the weather warmed again, it was clear that the cicadas miscounted that winter's double warming and freezing cycles as the passage of two years. "The cicadas came out a year early," says Kritsky.

But mysteries about cicada math remain. "What we don't know is how they remember what year it is," says Kritsky. "How do they remember the count?" Clues may lie in the cicada nymphs' early development underground (13-year nymphs molt faster underground than 17-year ones).

It's also unclear how cicadas behave collectively. Previous research had found that the cicadas emerge at a critical ground temperature of 18 degrees Celsius. But in the real world, the ground temperature is far from uniform and depends on factors such as topography, depth, and the presence of shade. Yet the cicadas knew to emerge together even with these large temperature fluctuations. How?

In recent research, published in February in *Physical Review E*, physicists at the University of Cambridge repurposed a simple condensed matter model to answer this question. Originally, physicists devised the model, known as a random-field Ising model, as electron spins arranged in a grid that can flip up or down in a randomly fluctuating magnetic field. To study cicadas, the physicists changed the magnetic field to a map of fluctuating temperatures underground, and the spin direction corresponded to whether the cicadas would emerge.



The 13-year and 17-year cicadas may overlap in some areas. Credit: Gene Kritsky

Using their model, the researchers made a mathematical argument for why the cicadas have to communicate with each other. "Were they not communicating, it would be hard to understand how certain swarms come out," says Raymond Goldstein, one of the researchers.

But the model doesn't say how the cicadas communicate — perhaps by releasing chemicals or making noise, proposes Adriana Pesci, a co-collaborator. Goldstein thinks of their research as "advancing hypotheses," he says. Their model can help researchers determine what types of data to collect. He and Pesci think it would be useful to collect ground temperature data in more detail, for example, or to use drones to capture the patterns of the cicadas emerging.

For Kritsky, who has studied cicadas for five decades, the emergence of each cicada brood marks a timestamp in his memory of the eras of his life. He recalls the last two times he saw Brood XIII — 17 years ago, and then 34 years ago. In 1990, he remembers mapping the brood while staying with his aunt and uncle in Illinois. In 2007, he saw the cicadas crawling up a beehive after a rain, following a lecture he gave in Illinois.

This year, Kritsky recommends going out at night to watch the cicadas emerge from the ground and molt, a process that takes about 90 minutes. "If you've got kids, get them outside," he says. "They'll never forget this."

Sophia Chen is a writer based in Columbus, Ohio.

BACK PAGE

The Steep Price of Free Science Access

Governments and funding agencies have promised the public unfettered open access to research. Scientists could foot the bill.

BY ROBERT ROSNER

Conducting high-quality research is expensive. Salaries and stipends must be paid. Equipment must be purchased and maintained. Reams of data must be collected and analyzed, sometimes by costly supercomputers. Disseminating the results of that investment also isn't cheap, and the cost of scientific publishing has traditionally been shared between publishers and readers. But scientists increasingly find themselves adding new line items to their budgets: publication fees.

Like other producers of print media, scientific publishers have traditionally sold access to their content through subscriptions, primarily to universities and other research institutions, which in turn provide access to their faculty, students, and staff. But over the last two decades, the open access (OA) movement has sought to do away with subscriptions entirely and provide free and unrestricted access to the world's scientific knowledge. On Aug. 25, 2022, the White House's Office of Science and Technology Policy announced that, by 2026, all peer-reviewed journal articles about research funded by the United States government must be freely available immediately upon publication. The announcement follows similar initiatives in Europe, notably Plan S.

> Attaching a monetary value to each paper incentivizes some publishers to publish more, and not necessarily the best, science. All the while, scientists face enormous pressure to publish for career advancement.

The cause is noble in principle. Taxpayers fund a great deal of research through federal grants, and the argument that citizens should have access to the resulting papers is a strong one. Advocates of the OA model also point out that it benefits researchers: Not every scientist works at a university that can afford pricey journal subscriptions, and OA papers are also more widely read and highly cited.

The trouble is this: Publishing high-quality, peer-reviewed journals is expensive, and there is not yet clarity on who, in the OA ecosystem, should bear the cost.

While OA mandates have exacerbated this dilemma, OA itself is not new — especially for physicists, who, after all, created ArXiv, one of the first online repositories of scientific preprints. APS has been a supporter of arXiv since the early 1990s, when journals were only accessible via subscription. Authors who publish in the Physical Review journals are welcome and encouraged to self-archive the peer-reviewed version of their manuscripts on arXiv.

APS launched its first open access journal in 1998, four years before the Budapest Open Access Initiative set the modern OA movement in motion. The journal, *Physical Review Accelerators and Beams*, continues to publish advances in accelerator science, technology, and applications at no cost to authors or institutions thanks to industry sponsors. So-called diamond OA journals, however, are more exception than rule, because relying only on external support is unsustainable.

Instead, publishers have largely moved their journals to the gold OA model, where the revenue that traditionally came from subscriptions is offset by article processing charges, or APCs, paid by authors, whose research is then immediately and freely available to read. Some APCs are reasonable, as in the nonprofit space. Others run upwards of $11,000 per article.

There are consequences to this move. Given the pressure researchers are under to continually publish papers in prestigious journals, these fees can quickly add up and divert funds away from research itself. A recent survey of more than 3,000 physicists conducted by APS and fellow physical societies AIP, IOP, and Optica revealed widespread support for OA, but respondents consistently reported APCs as a barrier to publishing in non-subscription journals. Early career researchers in particular said they struggle to secure funds for publication charges.

Moreover, attaching a monetary value to each paper incentivizes some publishers to publish more, and not necessarily the best, science. All the while, scientists face enormous pressure to publish for career advancement. In a 2020 survey, 12.5% of early career APS members said they have at times considered engaging in unethical behavior to meet the demands placed on them — up from 7.7% in the original 2003 survey. Rates of data falsification also doubled during that period.

A shadow industry of predatory publishers has risen to take advantage of this vulnerability, charging fees but offering little or no review. In one example, an author (read: not a scientist), in response to an invitation from a urology journal, published a fake paper about a fictional disease inspired by an episode of Seinfeld. My own inbox is littered with flattering invitations to submit or review for such-and-such journal, and it's increasingly difficult to distinguish between legitimate publications and scams.

The burden of "pay-to-play" publishing falls especially hard on researchers from less-resourced institutions and lower income countries. As the journalist Shi En Kim wrote recently for *APS News*, "the cost to publish in top-tier journals can be as much as, or more than, the yearly salary or entire research budget of a professor in a developing country." APS — acutely aware of this peril — has made great strides in subsidizing the costs of publishing and accessing research for scientists around the world. But the basic OA equation still needs balancing.

So how do we get back on the road to a sustainable OA future, where publishers like APS can maximize access to research while continuing to invest in the scientific community? Experiments abound — including around how to preserve excellent peer review against the pay-to-play incentives that could undermine it. Some publishers have done away with the acceptance and rejection of papers altogether, releasing only peer-review reports on preprints instead; some scientists have sought to separate the peer review process from scholarly publishing altogether. I am watching these experiments with interest. For now, APS should continue to offer a variety of publishing options to meet the diverse and changing needs of the broader physics communities. Hybrid journals give authors options. APC waivers for researchers from lower income countries help level the playing field. Rigorous journal standards protect the science.

Above all, APS should be guided by its "by scientists, for scientists" creed. The organization, as a nonprofit membership organization, does not have commercial interests. It publishes for the sake of good research — for the people doing, reading, and applying science. "Science is our only shareholder," its recent Purpose-Led Publishing coalition says. As the industry changes, and as the promises and perils of open access become clearer, this mantra will light the path ahead.

Robert Rosner is a theoretical physicist and the William E. Wrather Distinguished Service Professor at the University of Chicago. He served as the 2023 APS President and currently serves as Past President.

Black Holes continued from page 1

any mass change for M87* over the course of one year," Yurk says. "It's really reassuring that the images show that mass consistency." That sentiment is echoed by all the scientists interviewed for this story, including Lia Medeiros, an astrophysicist at Princeton University, and a member of the EHT Collaboration. She notes that replicating previous observations is essential for validating both the observation method and the findings. Seeing this ring-size stability over consecutive years also provides "significant" evidence that scientists correctly understand how black holes behave, she says. "Getting the same result twice may not seem exciting, but for [the collaboration] it was a really big deal."

The two M87* images do, however, have an important difference: The highest-intensity region of the orb sits in different positions, having rotated 30° counterclockwise between the first and second pictures. This shift fits with general expectations from theory, which predicts that the intensity of emission from a black hole's turbulent accretion disk should change over time. But following expectations doesn't make the shift any less interesting, says EHT deputy project scientist Mariafelicia De Laurentis of the University of Naples Federico II, Italy. She notes that there remain many unknowns about exactly what happens in a black hole's immediate environment. The time evolution of the surrounding magnetic fields and the movement of hot spots within the accretion disk have yet to be fully understood, and both likely impact a black hole's appearance. "This difference between the 2017 and 2018 observations highlights the importance of continuous monitoring and analysis to capture the evolving nature of black holes and their accretion disks," De Laurentis says.

> "Black hole astronomy is entering its high-precision era," says Lupsasca.

The EHT Collaboration is actively pursuing such continuous monitoring both with the current EHT and with next-generation black-hole telescopes. In addition to the 2017 and 2018 runs, the collaboration collected data in 2021 and 2022. The array will be collecting data again in April, this time with two additional telescopes. It will also detect higher frequency radio waves than it has in previous years, increasing the maximum frequency from 230 to 345 gigahertz. This change should increase the resolution by about 30%, Chael says. "It's not a dramatic increase, but the images should be sharper."

Two higher-performance telescopes are also in the works, the Next Generation EHT (ngEHT), which, like the EHT, will use only ground-based facilities, and the Black Hole Explorer (BHEX), which will add an Earth-orbiting satellite. As currently envisioned, ngEHT will include an additional eight telescopes, for a total of 20, allowing the collaboration to fill in more data gaps. This improvement should also significantly increase the array's dynamic range — the ratio between the brightest and dimmest signals it can detect. This parameter is expected to reach 1000, Chael says, a 100-fold increase over EHT's dynamic range. That increase could allow the ngEHT to image regions that are further away from M87*'s event horizon, such as the area where a jet of subatomic particles confined in strong magnetic fields is streaming from M87*'s core. This jet has been observed by other telescopes but not the EHT. "With a higher dynamic range, we could be sensitive to the [jet's] much dimmer signals" and investigate it more closely, Chael says.

The resolution of the ngEHT, however, is unlikely to be much higher than that of the EHT. But placing a telescope on a satellite could provide a factor of five increase in resolution, which should be sufficient to observe a predicted black hole phenomenon called a photon ring around both M87* and Sagittarius A*, says Alex Lupsasca, a black hole theorist at Vanderbilt University and a member of the BHEX team. Imaging a photon ring is a major goal for black hole physicists, as it could allow them to unambiguously measure the black-hole's spin, a key parameter and one for which there is currently no robust measurement technique. "If we can get high-resolution measurements and high-dynamic-range measurements, that will open up a whole new window on what we can learn about black holes," Lupsasca says. "Black hole astronomy is entering its high-precision era; it's a once-in-a-lifetime opportunity to be part of that."

Katherine Wright is the Deputy Editor of Physics Magazine, *from which this article was reprinted.*

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