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APS News

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To Become Brighter, Synchrotron Light Sources Must First Go Dark

Around the world, specialized accelerator facilities are going offline in preparation for major upgrades to storage ring technologies.

BY LIZ BOATMAN

A time-lapse view of Berkeley Lab's Advanced Light Source building. The ALS, like many light sources around the world, are being upgraded to fourth-generation technologies. Credit: Haris Mahic/Berkeley Lab

Each year, scientists from around the world apply for coveted "beam time" at specialized particle accelerator facilities known as light sources. But while they share facilities, they don't often share fields: One team might be studying proteins implicated in disease, one might be tinkering with materials that remove toxins from emissions, and still another might be studying biodiesel-producing algae.

What unites their research is the need for very bright light — high fluxes of photons, usually x-rays — that can be controlled and recorded with precision optics and imaging systems. In a synchrotron light source, strong magnets herd a beam of electrons at nearly the speed of light through a curved storage ring. As the beam speeds along, specialized magnets wobble it, shaking out photons that are useful for scientific studies.

Now, the power is being turned off at many light sources, which often operate 24 hours a day. But it's all part of the plan: These light-emitting storage rings are "going dark" so they can be upgraded, a leap toward fourth-generation light sources.

At the APS April Meeting in Minneapolis, several physicists presented their work tackling critical challenges associated with these upgrades.

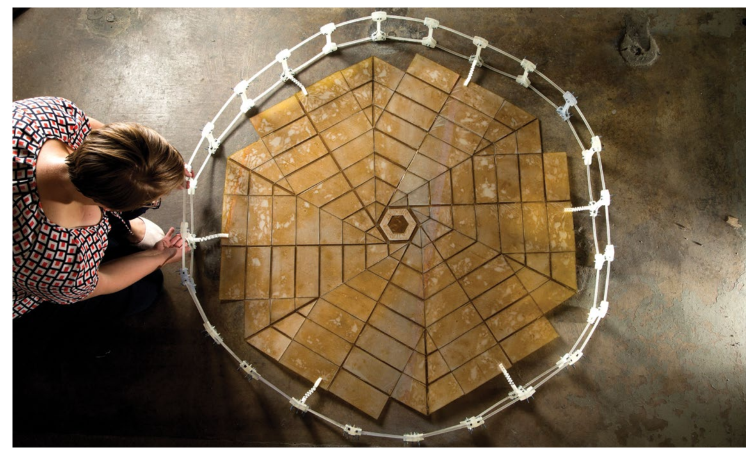
Joe Calvey, a physicist at Argonne National Laboratory's Advanced Photon Source in Illinois, has spent the past eight years studying how tiny amounts of gas in the accelerator chamber, like carbon dioxide or

Light Source continued on page 3

The Dawn of Bendy, Squishy Robots

At the March Meeting, the metal contraptions of the popular imagination made way for soft robotics powered by fluids and formed using origami folds.

BY SOPHIA CHEN



A researcher studies a prototype of a solar panel array that folds up origami-style, designed by NASA and Brigham Young University researchers. Credit: BYU

The robot, according to emojis and The Jetsons, is a shiny, angular-jointed, metal machine. It contains a computer chip that runs software to control its motion, and you can probably destroy it by pouring water on it.

But researchers are moving toward new paradigms for autonomous machines. Instead of making robots out of metal, they want to make robots out of soft, bendy materials like silicone, vinyl, and nylon fabric, to work more safely alongside humans. Some prototype machines can execute logic without any electronics, and they can still work after being submerged in water or run over by a truck.

Soft Robotics continued on page 5

High School Students "Go Quantum" with Virtual Visit From Physicist

To celebrate World Quantum Day, physicist Brian La Cour — a volunteer with APS's Quantum To-Go program — dropped into a physics classroom in Arkansas to demystify qubits.

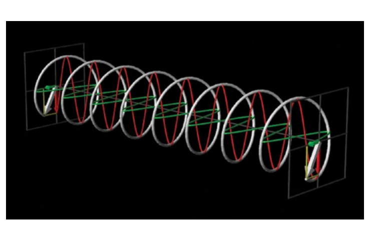
BY LIZ BOATMAN

There's a lot of quantum talk these days, from quantum computing to *Ant-Man and the Wasp: Quantumania.* And while "quantum" conjures a particular set of concepts in a physicist's mind — discrete states, particle-wave duality — it can mean something different to a member of the general public, including your average Marvel movie-watching high schooler.

On April 6, Brian La Cour, a quantum physicist at the Applied Research Laboratories at the University of Texas at Austin, logged in virtually to Patrick Foley's AP Physics 2 class in Little Rock, Arkansas, to talk with high school juniors and seniors about all things quantum.

"I love interacting with young people and sharing my love of quantum physics with them," said La Cour.

The visit was organized by Quantum To-Go, a collaborative initiative developed by APS's Physicists To-Go program and the National Q-12 Education Partnership to celebrate



A superposition simulation through EMANIM, an online virtual wave simulator — one of several tools for educators trying to teach tough quantum concepts. Credit: András Szilágyi (2019) "EMANIM: Interactive visualization of electromagnetic waves" (https://emanim.szialab.org)

World Quantum Day, which occurs annually on April 14. Launched in 2020, Physicists To-Go brings physicists from across the country and around the world directly into the K-12 or undergraduate classroom (usually virtually). APS expects this spring's Quantum To-Go initiative to impact 140 classrooms, including a handful in Japan, Georgia, India, and South Africa.

Quantum continued on page 6

Muon Telescope Developed at Fermilab Could Unlock Mysteries of the Great Pyramid of Giza

At the APS April Meeting, researchers discussed their plans to use fundamental particles to peer inside a wonder of the ancient world.

BY LIZ BOATMAN

In 1968, American physicist Luis Walter Alvarez traveled to the sun-scorched desert of Egypt on a quest to discover hidden chambers inside one of the greatest structures ever built, the pyramid of Khafre. But Alvarez wasn't excavating with shovels or picks. Instead, his tool of choice was a fundamental particle — the muon.

Produced by the interaction of cosmic rays with Earth's atmosphere, muons — similar to electrons, but about 200 times heavier — rain from the sky at nearly the speed of light, with enough energy to penetrate even the densest, largest structures.

Alvarez reasoned that muons traveling through the pyramid would be affected by what they encountered on the way. Muons that transited the pyramid's limestone walls would be stopped or deflected, or strike the detector with only a fraction of their energy left — but muons passing through empty spaces, like the pharaoh's burial chamber, would whiz straight through. So Alvarez set up a special muon detector in the pyramid's base and began collecting data.

Unfortunately, he didn't find much. But his work inspired new efforts to use muons to "see" inside volcanoes, nuclear reactors, and, of course, other pyramids.

At the APS April Meeting in Minneapolis, Ralf Ehrlich, a researcher at the University of Virginia, discussed plans to use a "muon telescope" to map the entire 454-foot-tall Great Pyramid of Giza, built by the pharaoh Khufu. Sitting next to Khafre's pyramid, the Great Pyramid is the tallest pyramid on Earth. Muons detected from different locations and directions will be combined to generate a single 3D reconstruction — similar to tomographic imaging, used in medical CT scanners.

The Giza pyramid complex of Egypt, including the pyramid of Khafre (middle) and the Great Pyramid (background) — the tallest pyramid ever built.

"The idea first came to me when I visited Egypt in 2010 and I spent a day on the Giza plateau," says Alan Bross, a senior scientist at Fermilab in Illinois and project lead on the work that Ehrlich presented. He knew the Great Pyramid was big, but in person, "it was just amazing." At that time, Bross was studying cosmic-ray muon imaging for cargo container inspection.

Back home, Bross couldn't shake the pyramid from his mind. He reached out to an expert on the Giza pyramids, Mark Lehner of the Institute for the Study of Ancient Cultures (formerly, the Oriental Institute) at the University of Chicago. The duo slowly explored the idea. In 2017, when another team reported the discovery of a massive chamber close to the center of the Great Pyramid, Lehner asked Bross whether Fermilab could do a follow-up study to verify the finding.

Bross assembled a team and, in early 2018, received approval from the Egyptian Ministry of Antiquities to carry out the "Exploring the Great Pyramid" project. In 2019, the University of Chicago's Big Ideas Generator awarded Bross $150,000 to develop the muon telescope, and Fermilab matched the funds.

Muon Telescope continued on page 4

The Path to a Clean-Energy Electric Grid Has Roadblocks, but Physicists Can Help

At the April Meeting, experts discussed the challenges to achieving a 100% clean-energy electricity sector.

BY KENDRA REDMOND

Solar panels at the National Renewable Energy Laboratory in Golden, Colorado.
Credit: Werner Slocum / NREL

The Biden administration's plan to mitigate climate change calls for a 100% carbon-free US electricity sector by 2035 — just twelve years from now. The installed capacity of wind, solar, and battery storage power plants is rapidly rising, but there's still a long way to go — and the barriers to success may not be what you think, says Joseph Rand, a researcher in the electricity markets and policy department at Lawrence Berkeley National Laboratory.

In an invited talk at the APS April Meeting 2023, sponsored by the APS Forum on Physics and Society, Rand first gave attendees the good news: Efforts to generate alternative energy efficiently and inexpensively have paid off.

Before they can be built, proposed power plants undergo an interconnection study that determines the cost of connecting them to the US electrical grid. Rand and his colleagues recently looked at 10,200 requests in the queue and found that nearly all were for zero-carbon projects. Requests for gas power plants have decreased since 2014, and requests for nuclear and coal are practically zero. That's because wind and solar make sense "from a simple economic standpoint," Rand said.

The US's existing power plant fleet produces about 227 gigawatts of power from wind, solar, and storage, roughly 10-15% of the projected need. Studies show that to be 100% clean, the electricity sector needs that number to be 1,500 to 2,000 gigawatts. It's a big jump, but Rand noted that of the 2,000 gigawatts in the interconnection queue, the vast majority are from wind, solar, and storage projects.

So what's the problem? The main barriers "are social, institutional, and regulatory in nature," he said. For example, his team found that only 21% of the proposed projects that requested an interconnection study between 2000 and 2017 were built by the end of 2022, and 72% had withdrawn. Studies suggest that's probably because developers shoulder the entire cost of updating the grid to accommodate their plants — a cost that's often prohibitively expensive — and because, for procedural reasons, it can take more than three years to get a request approved in some areas.

Another challenge: acquiring local building permits for new plants.

Clean Energy continued on page 3

THIS MONTH IN PHYSICS HISTORY

June 1980: Vera Rubin Publishes Paper Hinting at Dark Matter

Work by Rubin, a champion of women in science, suggested that galaxies contain hidden mass.

BY TESS JOOSSE

In 1933, the Swiss astronomer Fritz Zwicky was perplexed by the behavior of the Coma cluster of galaxies, some one thousand-strong. The cluster spun so fast that it ought to burst apart — but didn't. Zwicky postulated it was hundreds of times more dense than it seemed to be based on visible, glowing matter alone, meaning some kind of invisible "*dunkle Materie*," or dark matter, must bind it together.

The concept did not catch on. "It was too outrageous to believe for almost four decades," says Neta Bahcall, an astrophysicist at Princeton University. But by 1980, an astronomer named Vera Rubin had accumulated a convincing body of evidence that something unseen in the universe was causing galaxies to behave in unexpected ways.

Vera Rubin measuring spectra at the Carnegie Institution of Washington in 1970.
Credit: AIP Emilio Segrè Visual Archives, Rubin Collection

Rubin, born Vera Cooper in 1928, was raised in a Jewish family in Philadelphia and Washington, DC. She was captivated by the cosmos and relentlessly curious. In an autobiographical article published in the 2011 *Annual Review of Astronomy and Astrophysics*, Rubin recalled her father helping her build a homespun telescope using a linoleum tube. "From my bed against a window, I had a clear view to the north sky," she wrote. "Soon it was more interesting to watch the stars than to sleep."

Throughout her schooling, Rubin faced the banal sexism all too common at the time for women interested in science. Her high school physics teacher ignored the few girls in class; a college admissions interviewer encouraged her to consider painting astronomical objects rather than studying them. Rubin was not deterred. "She took it all with courage, and with persistence," says Bahcall, who was a longtime friend and colleague of Rubin.

Rubin studied astronomy at Vassar College, married mathematical physicist Bob Rubin, and began graduate school at Cornell in 1948. She completed her master's thesis on the rotation of the universe, kicking off a long career investigating hidden galactic behavior, and a professor suggested Rubin present this research at a meeting of the American Astronomical Society (AAS) in 1950. There, she encountered a chilly reception. "I gave my memorized 10-minute talk, acceptably I thought. Then one by one many angry sounding men got up to tell me why I could not do 'that,'" she wrote.

In 1965, after obtaining her PhD and teaching and traveling with her family for several years, Rubin got a job in the Department of Terrestrial Magnetism at the Carnegie Institution of Washington. She met W. Kent Ford Jr., who was building a new spectrograph for collecting light data from far-away bodies. "Potentially, this pioneering technique could increase by tenfold or more a telescope's ability to record the spectrum of a faint object," wrote Jacqueline Mitton and Simon Mitton in the 2021 biography *Vera Rubin: A Life*.

Rubin and Ford put the instrument to work measuring the velocities of stars in M31, the Andromeda galaxy. As planets in our solar system grow more distant from the Sun, their orbital velocities decrease. The stars in M31 were expected to do the same the further they were from their galaxy's center, where the light was brightest and the mass expected to be the greatest. These speeds could be calculated based on spectroscopic data and plotted graphically on a sloping rotation curve.

> In the June 1980 paper, Rubin wrote, "The conclusion is inescapable that non-luminous matter exists beyond the optical galaxy."

But the curve Rubin plotted for M31 trailed off in a nearly flat line: the orbital velocities of stars far from the galaxy's center did not decrease. It was as if the galaxies contained unseen mass, allowing them to rotate at the observed speeds without spinning out of control. "I remember thinking that there must be some mechanism for speeding up stars that moved too slowly or slowing down stars that moved too fast," Rubin recalled.

Between 1976 and 1986, Rubin and Ford undertook an ambitious observational survey of many other spiral galaxies. "She was very persistent in accumulating more and more data," Bahcall says. The team published nearly 50 papers during this time. In their most influential, which appeared in the June 1980 issue of *The Astrophysical Journal*, Rubin charted the rotation curves of 21 spiral galaxies spanning a range of sizes and luminosities. All of them had flat rotation curves extending far from their centers. In the paper, Rubin wrote, "The conclusion is inescapable that non-luminous matter exists beyond the optical galaxy."

These observations, paired with work by theorists and radio astronomers, showed that if the rules of Newtonian physics were to hold true, there must be a large amount of unseen mass in these galaxies. Today, the widely accepted thesis is that galaxies are full of dark matter, and up to 85% of the mass in the universe is made of it.

What dark matter actually is, however, remains a mystery. Experimental physicists the world over search for it, and scientists have spent countless hours debating its identity. While Rubin's work helped ask this question, Bahcall says that she remained "agnostic" about its answer. "Scientists too seldom stress the enormity of our ignorance," Rubin wrote in the preface to *Bright Galaxies, Dark Matters*, her collection of papers published in 1997.

Throughout her decades-long career, Rubin continued to chart galactic phenomena. She also was a mentor to and champion of young astronomers, especially women who still faced obstacles in the male-dominated field. Rubin often contacted the organizers of conferences to admonish them if their speaker lineup did not include enough women, Bahcall says. Along the way, she and her husband

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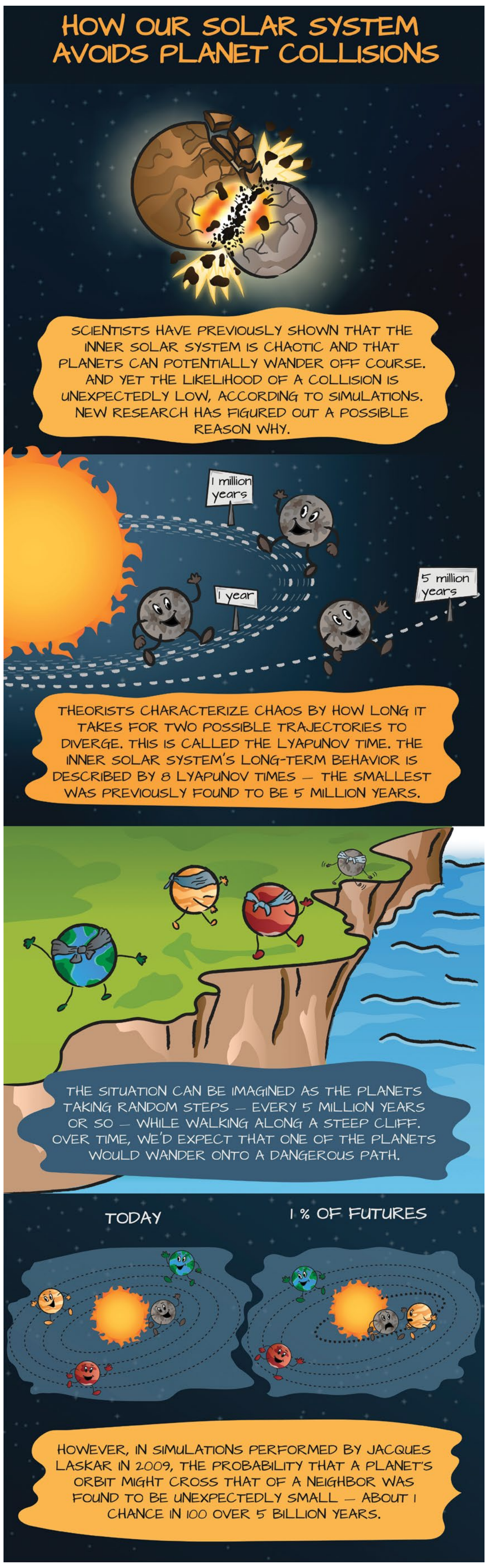

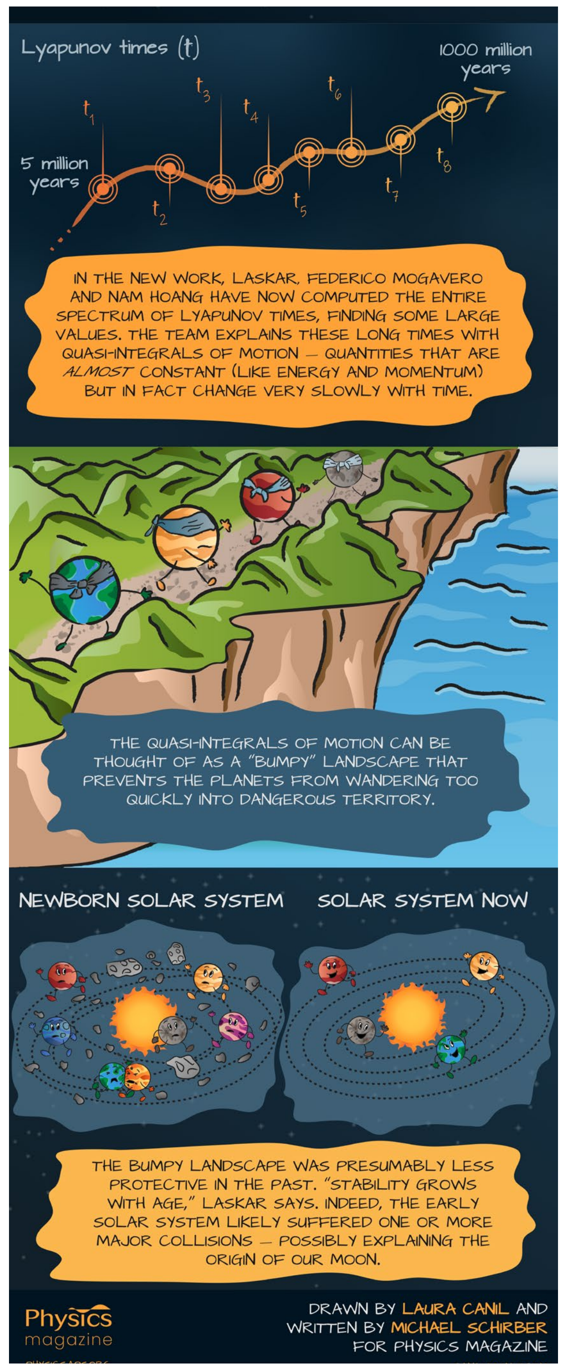

For more stories about physics research and the physics community, read ***Physics Magazine*** online at physics.aps.org and ***APS News*** online at aps.org/apsnews

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water vapor, can destabilize the electron beam.

"It doesn't have to be much," says Calvey. Just a few trillionths of a standard atmosphere — much closer to the pressure of gas in space than here on Earth — is enough to cause problems. The electron beam can ionize residual gas molecules in its path, causing the beam to spread out and eliminating the main advantage of fourth-generation technology: a tight, focused beam.

The next generation of light source technology, enabled largely by new storage ring designs, could bypass some of these problems — and deliver up to three orders of magnitude more light, says Volker Schlott, a senior scientist at the Paul Scherrer Institut, which operates the Swiss Light Source (SLS) in Switzerland.

The first major design change in the shift to fourth-generation technology is a storage ring with a smaller internal opening, says Schlott. At the SLS, he says, the opening in the new ring will be just 18 millimeters in diameter, less than one-fifth the size of the facility's current third-generation storage ring. This change is possible because of a non-evaporable getter coating on the inside of the ring. This special coating, also used at CERN, is designed to trap residual gas molecules, to keep them out of the beam's path. It's key to making the storage ring more efficient.

Scientists have also tweaked the magnets that confine the electron beam in the storage ring. Smaller, more compact magnets, arranged in a much denser "lattice," consume less power during operation, explains Schlott. And with a smaller storage ring cross-section, the magnets sit closer to the beam, bathing it in a stronger magnetic field.

Additionally, some of the electromagnets will be swapped for permanent magnets, similar to refrigerator magnets, "which have no electricity consumption," says Christoph Steier, lead of accelerator systems for the Lawrence Berkeley National Laboratory's Advanced Light Source (ALS) upgrade project. "Even more importantly, the permanent magnets do not need any liquid helium for cooling," he says — an increasingly scarce and expensive resource.

As a result of these and other changes, "all of these facilities will become much more power-efficient," says Schlott. His team estimates that "SLS 2.0" will guzzle 40% less power. At the ALS, Steier anticipates a more modest reduction — in part because the ALS is adding an additional accelerator, known as an accumulator ring, that will offset the energy savings of the fourth-generation upgrades.

Even so, energy efficiency isn't the main motivation for the upgrades. Instead, it's the promise of scientific discovery. "[Scientists] really like asking questions that can't be answered with the present technology," says Calvey.

Some light sources are also tuned to deliver infrared light, in addition to x-rays. Because biological molecules absorb infrared light at specific frequencies, based on their composition and structure, scientists can use infrared light to study everything from space dust to living cells, says research scientist Stephanie Corder. She says the ALS upgrade could even open the door to new scientific approaches: "Two-color multimodal capabilities," for example, could allow scientists to use both x-rays and infrared light to study samples, all at the same beamline.

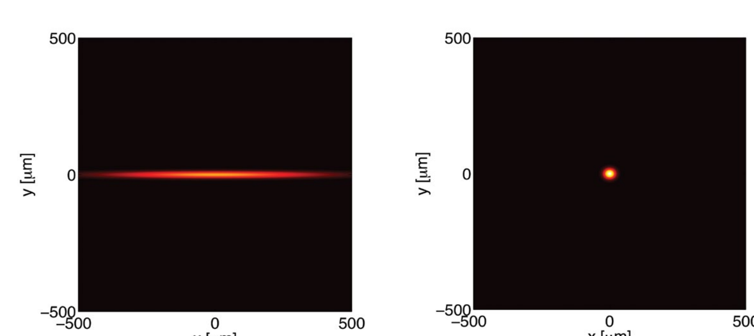
Other efforts aim to speed up research. Today at light sources, figuring out what to study in heterogeneous samples — like the microbial communities in permafrost, say — is typically very time-consuming. That's why Elizabeth Holman, a postdoc at Stanford University who specializes in infrared spectroscopy, has collaborated with Lawrence Berkeley staff to develop an autonomous, adaptive data acquisition system, now deployed at one of the ALS's infrared beamlines, that can drastically speed up data collection. In the future, Holman says the technology will "be adapted for real-time data acquisition and analysis of dynamic experimental systems," such as live cells, "allowing the researcher to adjust their sampling parameters on-the-fly."

The Advanced Photon Source, where Calvey works, went dark just one week after the April Meeting. Schlott says the SLS is scheduled to go dark this fall, and Corden says the ALS will be taken offline in 2025. The ALS and Advanced Photon Source upgrades are funded by the US Department of Energy, while the SLS upgrade is funded by the Swiss government.

With much brighter light, the scientists collecting data at light source beamlines will be able to complete their experiments in far less time — and at much higher spatial resolution.

"It's opening a whole new world," says Calvey.

Liz Boatman is a staff writer for APS News.



A simulated profile of the electron beam of Berkeley Lab's Advanced Light Source today (left) — and the highly focused beam (right) that will be available after the upgrade, substantially increasing its brightness. Credit: Cristoph Steier/Berkeley Lab

Clean Energy continued from page 2

"Research is telling us that solar and wind can be deployed more quickly and at lower cost if projects are structured to address the concerns and meet the needs of these hosting communities," Rand explained. He noted that developers are moving in this direction, but reaching alternative energy targets will require many more communities to agree to live near power plants.

If the United States succeeds at generating enough power from alternative sources, transmitting it to consumers will take a significant investment. The grid was designed to accommodate fewer, larger, and more centralized power plants, but the future looks "wildly different," Rand said. Given the new landscape and rising electricity demands, the country will need to build thousands of miles of new transmission lines. But there's no coordinated strategy and the current trend is in the opposite direction, he told attendees.

Arjun Makhijani, president of the Institute of Energy and Environmental Research and an invited speaker in a different session, sees opportunities for physicists to help solve the transmission problem. Instead of focusing on new lines, he suggests going back to the basics: How can we get electrons where they need to go, when needed, using existing tools and new technology? The answer may be a combination of strategies like distributed energy, demand response, seasonal thermal storage, and grid optimizing technologies — but we need people to model this, Makhijani says.

Modeling aside, Rand acknowledges these challenges are not strictly scientific. But we need science and engineering experts to "engage with the social aspects," he said. "We need to make sure that we're not just staying in our disciplinary silos and that we're thinking about interdisciplinary solutions to these problems that are really complex."

To do this, he encourages scientific meeting organizers to invite social scientists to share different dimensions of problems at their meetings. He also encourages scientists to tie their work and motivation to pressing social issues, advocate for key policy changes, and engage with their local communities.

"We have a long way to go," Rand says. Still, he remains cautiously optimistic. "We're actually doing pretty well if you look at the growth rates of these technologies."

Kendra Redmond is a writer based in Minnesota.

APS Honors Members for Outstanding Science Policy Advocacy

BY TAWANDA W. JOHNSON

In an op-ed published last August in *The Houston Chronicle*, Jacinta Conrad sought to teach readers why Congress must make it easier for international scientists to study and work in the US. But writing the article taught her something, too: the power of the human story.

"I had undervalued the power of personal stories in an op-ed," Conrad, a chemical engineering professor at the University of Houston, recalled about her experience working with APS to craft the piece. "I learned how to incorporate a story as a hook into a technical argument."

APS honored Conrad and eight others, all APS members, with the 5 Sigma Physicist Award for outstanding science policy advocacy in 2022. Recipients demonstrated substantial, impactful advocacy actions with APS Government Affairs throughout the year.

The other awardees are Ray Orbach, professor at The University of Texas at Austin; Michelle Bailey, research chemist at the National Institute of Standards and Technology; Lauren Aycock, senior systems engineer at Ball Aerospace; William Halperin, the Orrington Lunt Professor of Physics at Northwestern University; Anshu Sharma, a PhD student in computer science at William and Mary University; Frances Hellman, professor of physics and materials science at the University of California, Berkeley; Ralph Kelly, who earned his PhD in electrical at the University of New Mexico; and William Connacher, a materials science and engineering PhD student at the University of California, San Diego.

Orbach co-chaired a joint Optica/APS report that investigated ways to reduce emissions of methane, a powerful greenhouse gas, from oil and gas operations. "The results of our proposed solutions can, in the short term — one to two decades — make a significant contribution toward [combatting] global warming," he said.

Bailey, who served as a committee member for the methane report, valued the opportunity to "share this information in different forms, including a public webinar and an international workshop," she said — forms that spurred productive discussions among diverse groups.

Aycock's research on sexual harassment in STEM helped APS's efforts to combat the problem, including by shaping anti-harassment provisions that were successfully included in the CHIPS and Science Act. "I hope to see measurable, positive change in the culture of scientific research," she said.

Halperin advocated for congressional action on the federal helium supply, discussed the challenges with helium price and supply for the research community, and more. Kelly made 27 connections with Congress through APS's action center, and Connacher made 24, on topics like combating sexual harassment in STEM, teacher preparation, and research funding.

Sharma, too, made 24 connections with Congress, on topics like methane emissions and US missile defense testing. "There are still issues on which there is potential to move members of Congress," he said. "Through advocacy, we can build community with fellow scientists and citizens," an important step toward policy success.

Hellman, who served as APS's president during 2022, authored multiple letters to Congress that supported APS priorities, including developing data guidelines to improve the measurement of LGBTQI+ representation and experiences in US physical sciences.

"I think we had some amazingly positive outcomes in 2022," she said.

To learn more about the winners and the award, visit aps.org/policy/5-sigma.cfm.

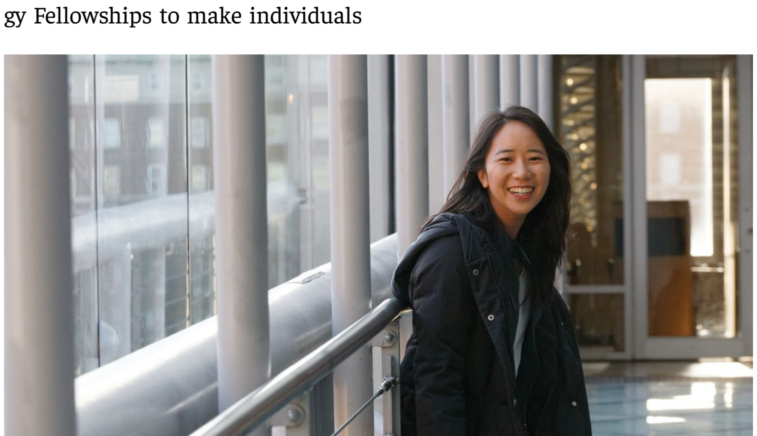
Tawanda W. Johnson is the Senior Public Relations Manager at APS.

APS Selects 2023-24 Congressional Science Fellow

APS is thrilled to announce the 2023-24 Congressional Science Fellow, Sophia Chan. Chan received her doctorate in chemical engineering from Columbia University in 2022, and her bachelor's degree in chemical engineering from the University of California, Berkeley, in 2017. She is currently a Science and Technology Policy Fellow for the California Council on Science and Technology.

APS sponsors the fellowship under the umbrella of the American Association for the Advancement of Science (AAAS) Science & Technology Fellowships to make individuals with scientific knowledge and skills available to members of Congress, few of whom have technical backgrounds.

In turn, the fellowship program enables scientists to broaden their experience through direct involvement with the policymaking process. Fellows work directly with congressional leaders and staff for a year, usually from September to August. They also complete a two-week orientation in Washington, DC, interview on Capitol Hill, and then choose a congressional office or committee.



Sophia Chan

NSF Doubles Budget of New Technology Directorate

NSF is expanding its Directorate for Technology, Innovation, and Partnerships (TIP) — and working to quell the perception that TIP's new funding would otherwise have gone to existing directorates.

BY MITCH AMBROSE

The National Science Foundation has decided to use about half of the $1 billion budget increase it received from Congress for fiscal year 2023 to build out its new Directorate for Technology, Innovation, and Partnerships (TIP). TIP — NSF's first new directorate in more than 30 years — expands the agency's role in supporting "use-inspired" research and technology development, an area of interest for Congress.

The NSF's existing directorates are mostly divided by discipline — computer science or math, for example. TIP is different, organized instead around efforts to increase entrepreneurship, public-private partnership, and technological advancement across directorates. In other words, TIP aims to beef up NSF innovation.

When NSF created TIP last March, it funded the directorate with around $400 million pulled from elsewhere in NSF, like the Small Business Innovation Research program. Congress then formally authorized TIP through the landmark CHIPS and Science Act of 2022, which gave TIP a target budget of $1.5 billion for 2023, out of a recommended NSF budget of $11.9 billion. Ultimately, Congress fell short of those targets: It gave NSF almost $9.9 billion, and the agency has decided to allocate about $880 million to TIP — less than CHIPS Act ambitions, but still a hefty amount that effectively doubles TIP's budget.

Erwin Gianchandani, director of NSF's TIP Directorate, speaks at the agency's first ever Industry Partnership Summit on April 27. Credit: NSF

Other NSF research directorates, meanwhile, received relatively small increases in the latest budget cycles. For instance, the Math and Physical Sciences (MPS) Directorate budget is growing 4% to $1.7 billion — leading some scientists to raise concerns that TIP's growth may be squeezing other NSF programs.

"Even if you look at the budget increases that have been received to the core programs ... it actually feels like you're going backwards, because they aren't keeping up with the financial reality that we're in with 7%, 8%, 9% inflation rates," said Edward Thomas Jr., a physics professor at Auburn University, at the April meeting of MPS's advisory committee.

"There still is a lot of concern at the PI level [that] ... the creation of TIP is putting a lot of stress, and the core programs aren't actually growing at the same kind of paces to keep up," he added.

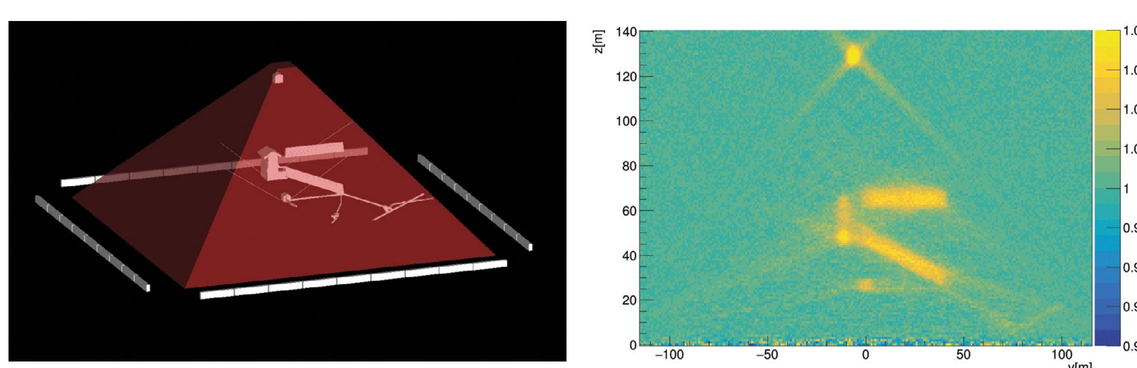
But MPS head Sean Jones stressed that TIP is supposed to work in tandem with existing programs, speeding up progress on ideas coming out of other directorates, like MPS. NSF Budget Director Caitlyn Fife said at the advisory committee meeting that part of TIP's budget is "going to support basic research activities back in the [other] directorates."

Other NSF staff reiterated TIP's popularity on Capitol Hill. Amanda Greenwell, who heads NSF's Office of Legislative and Public Affairs, noted that TIP's creation has broadened the NSF's base of supporters in Congress, saying that lawmakers beyond the "usual suspects" advocated for the agency in the push to pass the CHIPS and Science Act.

"We need to know where the pain points are and be able to talk about the tradeoffs and other issues, but

NSF Budget continued on page 5

Muon Telescope continued from page 1



A model of the Great Pyramid (left), which includes its known structures and the "big void" another team found in 2017, as well as a space at the top theorized by some researchers to be a second King's Chamber. Ehrlich used this model in the muon tomography simulation, to determine whether the telescope design would be able to observe the voids in the model. The simulated results (right) revealed the same structures as the model — confirmation that the telescope design would work. Credit: EGP Mission

By then, Bross was leading a new muon-based research program at Fermilab, known as Mu2e, short for "muon to electron conversion," to explore the physics of the muon decay process. Ehrlich was focused on Mu2e's cosmic ray veto detector, whose design Bross planned to use in the new muon telescope. Bross tapped Ehrlich for help.

Cosmic-ray muons with kinetic energies of 10 to 200 GeV before reaching the pyramid will provide optimal data for analysis, says Ehrlich. That's because a muon can be elastically scattered by interactions with large atomic nuclei, like those of the calcium atoms in the pyramids' limestone walls; higher-energy muons are less affected by elastic scattering, while low-energy muons often don't make it through at all.

The telescope will be constructed of eight muon detectors, housed in two-by-two arrays inside two temperature-controlled cargo containers. To collect the data needed to reconstruct a full 3D model of the Great Pyramid's interior, the team will position both detector arrays to face the pyramid for about one-and-a-half months, before moving the setup to a new location and repeating. The team estimates that a full scan will take about two years.

Then, the datasets from each location will be combined to reconstruct the complete 3D image — and possibly reveal new structures inside the pyramid, says Ehrlich.

"I was extremely excited to hear that they wanted to undertake this effort," says Los Alamos National Laboratory scientist John Perry, whose early research involved a similar technology. The "Exploring the Great Pyramid project" is a big task, Perry says, because the team will be "deploying detectors in an environment that might be relatively challenging," like intense sun and high winds.

Perry himself knows something about muon detection in harsh environments. When a giant tsunami flooded Japan's Fukushima Daiichi Nuclear Power Plant in 2011 and caused a reactor shutdown, his team at Los Alamos, led by Konstantin Borozdin, reached out to Japanese scientists with an idea. Could muon detectors reveal whether the reactors' radioactive cores were still intact? In 2017, a team of Japanese researchers used muon imaging to figure out the answer: A significant portion of the fuel debris was missing from the damaged reactor cores.

Bross and Ehrlich, meanwhile, are pushing forward the Exploring the Great Pyramid project, despite facing funding challenges in the wake of the COVID-19 pandemic. At the April Meeting, Ehrlich showed his most recent simulations, demonstrating the impressive spatial resolution of the team's current telescope design — easily enough resolution to find new chambers or passageways.

With the muon telescope's proof-of-concept in hand, the team is preparing for the next steps: fabrication, and then deployment.

"When we have the first full tomographic reconstruction done," Bross says, he'll be thrilled. "And once we do the Great Pyramid, we could move on to other pyramids."

Liz Boatman is a staff writer for APS News.

Letter to the Editor: 2022 Nobel Laureates

Responding to "The 2022 Physics Laureates Share Their Stories in Stockholm," by Abigail Dove, published in the February 2023 issue of APS News.

Your interesting account of the 2022 Physics Nobel lectures in the February 2023 issue includes a couple of misleading statements which I would like to correct. It is not quite true that quantum entanglement as a fact of nature was only accepted after Clauser's and Aspect's experiments. At the time of Clauser's 1970-72 experiment, almost all physicists strongly believed that the results of any such experiment would obey the laws of quantum mechanics, which imply entanglement, and that there was no point in doing such an experiment. Clauser, in thinking there was a good chance that the results might violate the laws of quantum mechanics, was very much in the minority, which is why he was so "cash-strapped." It was only because Charles Townes had the insight that the experiment was worth doing even if its results were almost a foregone conclusion, and persuaded a reluctant Eugene Commins to fund the experiment in 1970, that the experiment was done.

But it is true that in 1970 very few physicists realized just how bizarre quantum entanglement is. Almost no one had heard of and understood Bell's theorem, published just six years before, which had motivated Clauser to do the experiment. And almost no one knew at the time that Clauser was doing his experiment. I was a first- and then second-year grad student in the Berkeley physics department in 1970-72. I knew there was a postdoc in the department named John Clauser, and I knew who he was, but I had no idea what he was working on. I only learned about Clauser's experiment decades later, from a physics history book. The few people who did know about Clauser's experiment mostly did not consider it a respectable thing to work on. That was still true in 1982, when Aspect dared to do his experiment only because he had job security.

John Clauser, one of the three recipients of the 2022 Nobel Prize in Physics, gives a talk at APS March Meeting 2023. *Credit: American Physical Society*

Aspect's contribution was not merely to produce entangled pairs of photons more quickly and get better statistics. He introduced a dramatic new element: The two entangled measurements were done outside each other's light cone, so it was impossible in principle for information to flow from one to the other. Aspect did not doubt that his results would obey the laws of quantum mechanics. But this new twist caught people's imaginations, and made them realize just how bizarre quantum entanglement is. Suddenly, almost all physicists knew about Aspect's experiment and were talking about it. The field became respectable, and Zeilinger and others started working in it, and discovered that it had important practical applications. Townes, who died at the age of 100 in 2015, did not live long enough to see Clauser win the Nobel Prize, but he did live long enough to see the field develop, and to see Clauser honored for his early contribution to it.

— Michael Gerver (Raanana, Israel)

Letter to the Editor: Acknowledging the Limits of Science

Responding to "To Save Science, Talk With the Public," by Michael Smith and Don Lincoln, published in January 2023 in APS News.

The Back Page of the January 2023 *APS News* is very timely. Engaging with the public is an important responsibility of scientists. It is vital to remember that if we expect the people to respect us, we have to respect the people. We have to present science as science and not as some set of dogma that have to be accepted by the people on the authority of their "betters." Science is questioning, testing, and searching for truth and reality.

Recently, science has been presented to the public by politicians more often than by scientists. The phrase "settled science," coined by a politician, is a contradiction in terms. Such well-established theories as quantum mechanics and relativity are constantly being tested for the limits of their applicability. Even the principle of the conservation of matter was questioned in the Steady State Theory. If we are to regain respect and credibility with the people, we have to acknowledge the limits as well as the achievements of science.

credit: James Thew

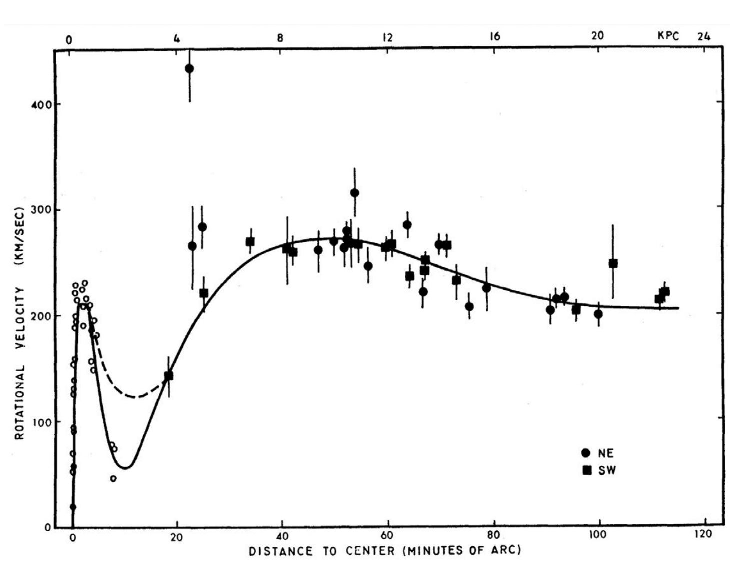
– Chester Sullivan (Iowa)

Vera Rubin continued from page 2

Bob raised four children, who all became scientists. When Rubin died in 2016, she was remembered as a transformer of modern physics and a beacon of light to many. "She was a very kind, compassionate, curious human being," Bahcall says.

In 2019, almost 70 years after Rubin faced that hostile crowd at the 1950 AAS meeting, the Society convened in Honolulu to agree on renaming the Large Synoptic Survey Telescope as the Vera C. Rubin Observatory. After its construction is complete, the Rubin Observatory will be the site of a 10-year survey of a mammoth swath of night sky. Bahcall sees this honor as the perfect tribute to Rubin, who cherished the many long nights she spent in observatories, peering through telescopes. "She loved being in the dome."

Tess Joosse is a science journalist based in Madison, Wisconsin.



Rotational velocities of the stars in the Andromeda galaxy, from a 1970 paper by Vera Rubin and Kent Ford. Instead of a downward slope, which would show that stars further from the star had slower velocities, the curve is nearly level — evidence for the pull of unseen mass, or dark matter. *Credit: V. Rubin and K. Ford,* Astrophysical Journal, *vol. 159, p.379 (February 1970).*

NSF Budget continued from page 4

we have a huge opportunity that we haven't had before," she said. "We are on the radar now."

And TIP's growth is poised to continue. Fife noted that NSF is seeking to increase the directorate's budget by 35% to $1.2 billion in fiscal year 2024, which would make it similar in size to the directorate for computer sciences and engineering.

"We're maturing it to be a full directorate, to be fair," she said, "because that's what we've set out to do."

Mitch Ambrose is Director of FYI. Published by the American Institute of Physics since 1989, FYI is a trusted source of science policy news. Sign up for free emails at aip.org/fyi.

Soft Robotics continued from page 1

Many origami folding patterns, like the Miura fold, raise interesting questions for physicists. *Credit: Rob Felt/Georgia Institute of Technology (Eureka Alert)*

Known as soft robotics, the field draws from many disciplines, such as materials science, biology, computer science, and even traditional crafts. Physicists have room to play around, from developing design principles to building the machines. At this year's March Meeting, researchers presented advances in the field in a session called Morphing Matter.

James McInerney, a postdoc at the University of Michigan, presented research on design principles for origami, the traditional Japanese paper-folding craft. McInerney traces contemporary scientific studies of origami to around the 1980s, when engineers realized they could use origami techniques to efficiently load objects to launch into space. Both NASA and Japan's space agency, for example, have used the so-called Miura fold to pack a solar panel array inside a rocket.

McInerney began studying origami as a graduate student, after discovering that it presented interesting unsolved problems in geometry. "Using origami, you change the form of a material," McInerney says. "Once you change the form, you change the function. The stiffness changes; the amount it bends in and out of the plane changes."

For example, researchers working with origami seek to control a property known as Poisson's ratio. A Poisson's ratio describes how a material behaves when you compress it along one axis. "Think of a banana," says McInerney. "If you squeeze it, it's going to pop in the other direction. That's a positive Poisson's ratio." Most materials are banana-like in this way, so researchers are interested in materials with a negative Poisson's ratio, meaning that when you squeeze it, it compresses along the opposite axis. The Miura fold, for example, imparts a negative Poisson's ratio to a sheet. When you compress it in one direction, the whole object collapses into a smaller volume.

McInerney is working to classify origami folds into "families" of crease patterns that share similar properties. He uses the periodic table of the elements as an analogy. He aims to show that certain geometrical patterns in origami result in similar material properties, just as elements with the same number of valence electrons share chemical properties. He is working with an experimentalist to validate his theoretical findings.

But when it comes to the craft itself, McInerney is less experienced. "In practice, I'm not a very good traditional origamist," he says.

In another talk, Anne Meeussen, a postdoc at Harvard University, presented her efforts to build robots powered by fluids instead of electronics. In a fluid-driven robot, for example, tubes might fill with fluid to reach some threshold pressure, spurring valves to open and the robot to move.

From a theoretical standpoint, fluids behave like electrons do in electronics. In fluidic robots, the flow of a liquid or gas stands in for the flow of electrons; pressure replaces voltage. "If you look at the equations that describe an electronic network versus a fluidic network, they look the same," says Meeussen, who has a background in theoretical physics. "The difference comes in when you start talking about applications." It's easier, for example, to design fluidic robots to be waterproof or robust to radiation, but electronics work much faster than fluid-driven machines.

Other researchers have demonstrated fluid-driven prototypes, including one group that used carbon dioxide gas to make a sweatshirt lift its own hood. But these efforts have tended to borrow design strategies from electronics, such as using sequentially and serially connected modular components to complete a task.

However, Meeussen's team is experimenting with a different design strategy. Instead of piecing together the robot component by component, as in conventional electronics, they start by simulating a random network of fluidic tubes. Then, they task a machine learning-inspired algorithm to remove tubes until the network achieves the intended goal, such as having the network move an object. The process is more akin to sculpting, as it involves removing unnecessary parts from the system, rather than building it up like Legos.

Meeussen presented a simulated fluidic network, designed using this strategy, that "learned" to classify three species of irises. She encoded properties of each flower, like petal length, into fluid pressures, which she inputted to the network. Each species of iris corresponded to a specific output pressure. The network learned which tubes to remove to produce the output pressure corresponding to the correct iris species — and it classified the species correctly 96.7% of the time.

With these promising simulations, Meeussen is working with mechanical engineers and roboticists to make a real-world prototype of a fluid-driven robotic arm. "It's been amazing to work with people with such different backgrounds and see how we can complement each other," she says.

Sophia Chen is a writer based in Columbus, Ohio.

THE BACK PAGE

It's Time to Rethink Alcohol at Work Events

Drinking in professional settings comes with risks and can alienate colleagues. There are better ways for physicists to socialize.

BY NATHALIE VRIEND

Many years ago, when I was a young graduate student in mechanical engineering and geophysics, I presented my first poster at an important conference. I was stationed at my poster, excited for discussion, when a colleague approached me with a beer in hand. I could smell alcohol on his breath, and he had clearly had too much to drink. For an hour, he loitered at my poster, asking inappropriate questions — and blocking my ability to talk to others, including potential collaborators or future postdoctoral advisors. I was deeply uncomfortable and uncertain what to do.

My story might feel familiar to many young scientists, and data confirms the relationship between alcohol and inappropriate behavior. Alcohol is linked to loss of inhibition, and research indicates that alcohol increases the risks of harassment, including in professional settings. A 2007 study found a significant association between the number of heavy-drinking male employees and a culture of gender harassment against women in a workplace. Of course, alcohol does not *cause* bad behavior on its own — any perpetrator is solely responsible for their actions — but its role as a risk factor is clear.

These statistics should concern all of us in physics, not least because the gender gap has persisted so stubbornly. In 2020, women earned just 1 in 4 physics bachelor's degrees and 1 in 5 doctoral degrees, and only 13% of last authors on research papers in physics — who tend to be senior — are women.

Whenever there is a strong imbalance in gender — e.g., in male-dominated fields like physics — harassment crops up more often, harming victims' sense of belonging and worsening imposter syndrome. In a 2018 survey of undergraduate women in physics, 74.3% of respondents said they experienced gender harassment or unwanted sexual attention in physics in the last two years.

Of course, harassment is an enormous issue — much bigger than drinking at work events. But given alcohol's links to poor behavior, it deserves thoughtful attention in any professional space.

I myself have experienced harassment on multiple occasions in professional settings, from colleagues who had too much to drink. As a result, I have become more cautious, sometimes leaving events where I feel unsafe — hardly the welcoming environment we aim to create in our scientific communities.

So why is drinking so prevalent in professional settings? In many ways, it's understandable. Work-life separation is difficult when your work runs into evenings and conferences often take place on weekends, so it's easy for professional events to spill over in social ones — often with alcoholic refreshments. In the academic world, you depend on colleagues for tenure letters, paper and grant reviews, and collaboration, and socializing at professional meetings is key to success. In the corporate world, networking can shape careers. Alcohol might seem to help break the ice with strangers or decompress after a stressful workday.

As a result, many scientists are comfortable with alcohol at professional events. For example, in a 2022 *Nature* poll of nearly 1,500 scientists, many respondents questioned the appropriateness of serving alcohol at work-related portions of scientific conferences, like poster sessions — but most still said they wanted to keep alcohol at conferences overall.

As scientists, though, it is not only our responsibility to do good research and advance our field, but to support the next generation of scientists. Science is more diverse now — in age, gender, sexual orientation, race, cultural background — than it was for millennia; we are moving away from the cliché of the cigar-smoking, whiskey-drinking clique of mostly white male scientists. I am not the only person not drinking alcohol — more than a third of US adults don't, perhaps for religious or cultural reasons, or perhaps simply because science has shown that alcohol is not healthy. Still others may be uncomfortable drinking in work settings because they are struggling with alcohol abuse; after all, nearly half of US adults who drink, drink too much, according to a 2018 study published in the *Journal of Substance Abuse*.

Alcohol at professional events can stymie efforts to create a welcoming community, and scientists and students of all generations deserve better. In academia, as well as in the business and nonprofit spheres, we senior scientists are responsible for inviting young, diverse people into the field and making them feel comfortable and confident. We are responsible for upholding professional conduct and setting the right example for the younger generation.

Luckily, there are plenty of creative ways to deemphasize or avoid alcohol in professional settings, while still socializing with peers and colleagues. First and foremost, an open-bar event can promote excessive drinking (it's free, after all!), so consider offering one or two free drink tickets instead. The location of a social event can send a strong message, too: Plan your team's next activity at a restaurant, bowling alley, or dessert shop instead of a bar or brewery. You could also head outdoors. In the past few years, I've hiked, surfed, scaled walls at a climbing gym, and even skied a glacier with colleagues. I had many inspiring conversations during these events, which led to prosperous new collaborations.

Even now, 15 years after attending my first conference, I still remember that intoxicated colleague and the uncomfortable situation he put me in, though he probably does not. However, I'm sure that it would mortify him to learn that his poor behavior — not his research — is what a young scientist remembered most.

As a woman in a male-dominated field, I've faced many roadblocks. Still, I love my job as a scientist, and I want my field to be as welcoming as it can be. Deemphasizing alcohol in work settings won't squelch inappropriate and unprofessional behavior entirely, or make physics perfectly ethical or welcoming. But might it be a start?

Nathalie Vriend is an associate professor in mechanical engineering at the University of Colorado, Boulder. She leads the Granular Flow Laboratory and has active projects in granular rheology and avalanching, as well as dune structure and migration.

For sources cited, visit go.aps.org/opinionalcohol.

Quantum continued from page 1

While quantum technologies have exploded, quantum education has not kept up, according to a strategic plan published by the National Science and Technology Council in 2022. To build the next quantum workforce, many experts believe, schools must inspire and educate kids in new, exciting ways — a driving motivation for initiatives like the National Q-12 Education Partnership.

In Foley's classroom, La Cour opened his virtual visit by recalling his own path to quantum physics research. He told the students that although he had first learned about quantum science in high school physics, he "didn't really get all that fired up about quantum at the time."

La Cour said it wasn't until college that he developed a deep appreciation for "the mystery" behind quantum physics. Before that, he held "this perspective that everything was precise and deterministic." Quantum physics, he said, "just blows this concept."

He asked Foley's students what they had learned about quantum physics so far in their AP Physics 2 course. In quantum physics, replied one student, "it seems like there's more we don't know than we do."

La Cour nodded, but added that "there are a whole lot of technologies that we're using right now that are actually based on quantum." He asked Foley's students if they could name any.

Hands shot up, and the students listed off technologies like electron microscopes and quantum encryption. La Cour added cell phones, which rely heavily on tiny transistors small enough that quantum effects become significant, and even Blu-ray movies.

For researchers working in this field, La Cour told the high schoolers, it's exciting to try harnessing "the unique properties of quantum systems and taking some of that 'mystery' … to solve really hard problems."

"Sometimes, people refer to this [work] as quantum 2.0," he said — the work of leveraging quantum physics to develop new technologies. Quantum 1.0, in contrast, refers to scientists' efforts over the last century to develop a fundamental understanding of quantum physics.

La Cour noted that physicists today would describe the three main pillars of quantum technology as quantum computers; quantum communications, including networking and encryption; and quantum sensing, like quantum clocks and electron microscopes.

"Some of these technologies are already here," he said. Others, like quantum computing, are still relatively new and changing rapidly, as researchers around the world race to study and improve these systems.

La Cour spent the next hour breaking down the concept of quantum computing for Foley's students, using a set of simulation packages — the EMANIM virtual wave simulator developed by Andras Szilagyi, and La Cour's own Virtual Quantum Optics Laboratory (VQOL) — to help them mentally construct and simulate a wave-based concept of the "qubit," or quantum bit. The qubit can simultaneously store 0s and 1s, unlike the bit of classical computing, which can only store a 0 or 1.

Foley said that La Cour's "interactive toolset" helped broaden the students' perspective on the practical implications of the science they've learned in his classroom this year. Of course, not all of it was easy. "The entanglement encryption portion of his presentation really stumped them," he said.

Even so, Foley said his AP Physics 2 students, who could pursue many fields in college, "enjoyed the experience of talking with a knowledgeable quantum physicist."

La Cour was happy to work with Foley's high school students through the Quantum To-Go program. "Young people," he said, "are uniquely poised to provide a fresh perspective and new insights toward a deeper understanding of the great quantum mysteries."

Are you a K-12 teacher, undergraduate professor, or homeschooling family looking for supplementary support on physics topics and careers? Check out the APS Physicists To-Go and Physics Quest programs for additional resources.

Liz Boatman is a staff writer for APS News.