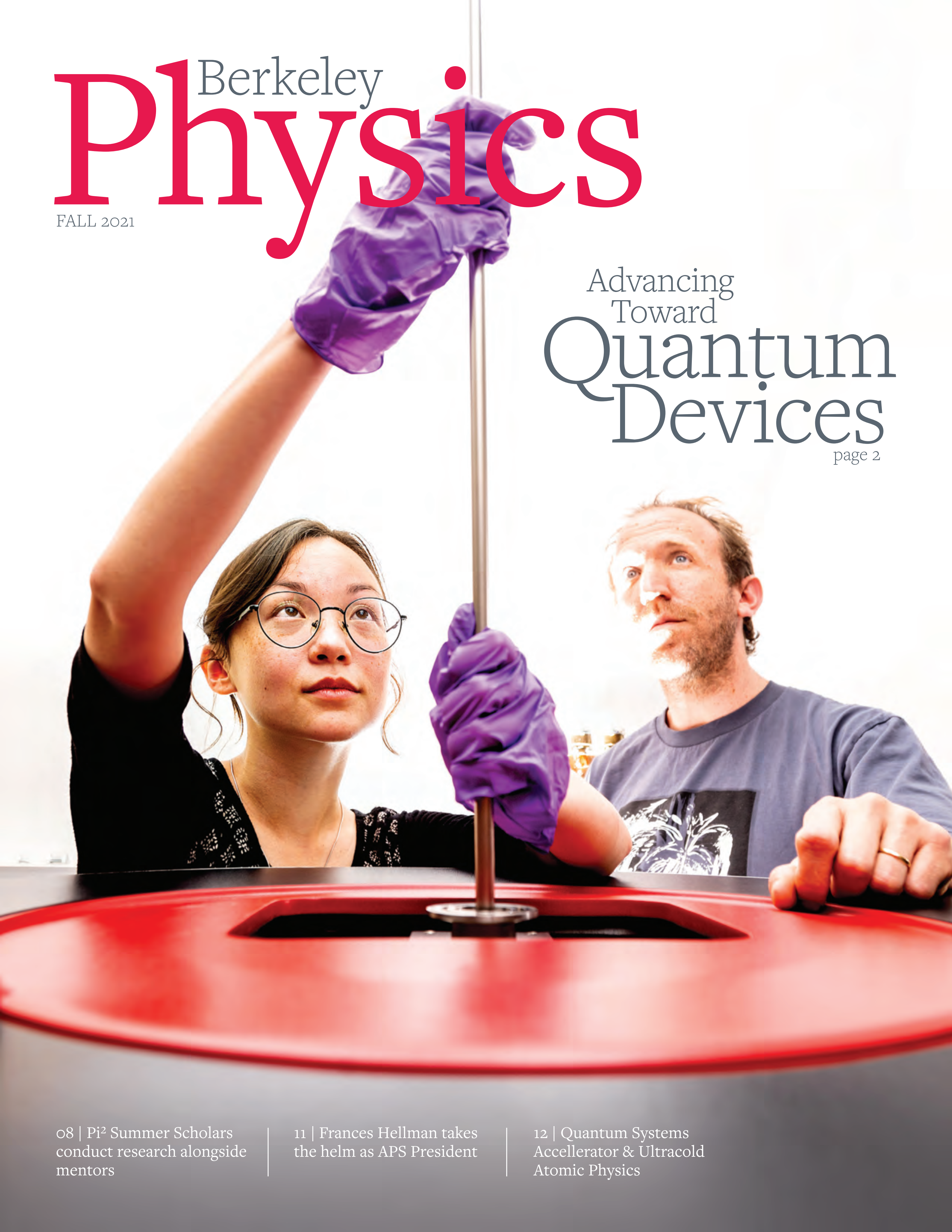
Berkeley

Physics

FALL 2021



Advancing Toward Quantum Devices

page 2

The study of physics is as much about understanding the essence of reality as it is about how reality itself can be transformed. This past year we grappled with many new realities in the ways we live, work, and connect with one another. As good physicists must, we accepted the truth and answered our challenges with determination. This has allowed us to return to our classrooms for the betterment of our instruction, expand our research programs so that they are more broadly inclusive, and help our department become more dynamic and creative.

This year we launched the Pi² Summer Scholars program, which supports undergraduates to pursue research over the summer (see page 8). The program rewards scholarship and leadership by partnering undergraduate scholars and graduate student mentors. Successful applicants are rewarded for the creativity of their proposal, for having a strategy for their personal growth as physicists, and for their commitment to creating a dynamic scientific community.

The coming year will see the launch of similar exciting programs for undergraduates, such as the MPS Scholars Program from the Division of Mathematical and Physical Sciences, and the Physics and Astronomy Discovery Arc program. These new undertakings exemplify our efforts to forge closer connections between students and faculty research groups.

Our researchers continue to work at the forefront of scientific study, attracting honors for work in quantum gravity, gravity waves, time crystals, and more. This year we welcome three new faculty: **Raffaella Margutti** in Astrophysics, **Eric Ma** in Condensed Matter Physics, and **Benjamin Safdi** in Particle Physics.

All of these accomplishments have been possible because our community has remained cohesive in the face of one of the most extraordinary episodes in human history. Together, we continue to open new horizons as we pursue our noble mission as physicists to push the boundaries of knowledge for humankind.

James G. Analytis, Chair

Berkeley Physics

ON THE COVER:
Postdoc Eran Maniv looks on as graduate student Shannon Haley loads a sample into a low-temperature measurement system in the Analytis lab.

OPPOSITE PAGE:
Top: Pi² scholars work in the E8 Lab; Right: Preparation of a sample rotator for loading into a refrigerator as cold as -271 C with a magnetic field of 14 Tesla; Lower left: Optical equipment in the E8 Lab.

BACK COVER:
Grad student Scott Eustice aligns a laser through a spectroscopic reference cell as part of the research in the E8 Lab.

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Published annually by the Department of Physics
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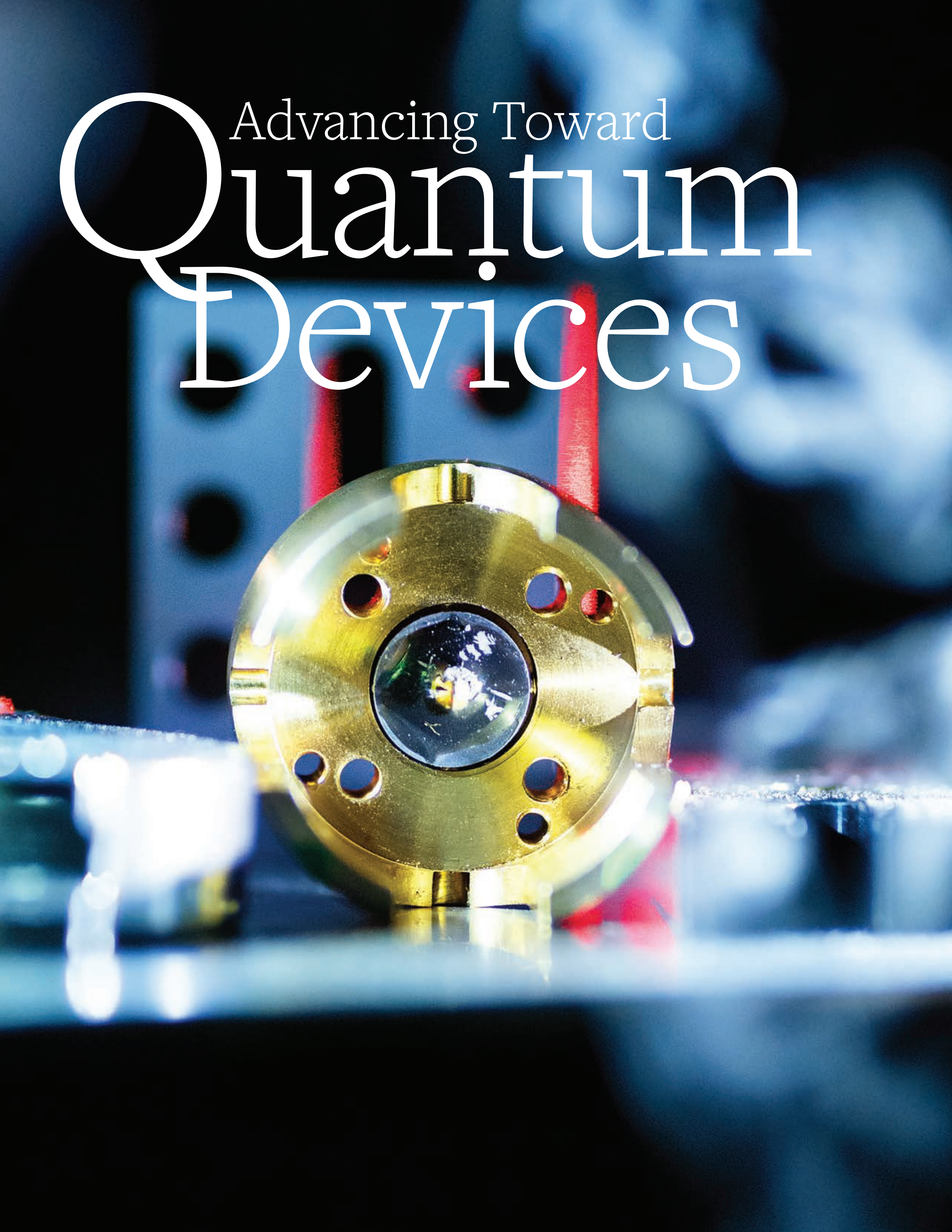
Advancing Toward Quantum Devices



The Future of Digital Electronics

PHOTOS BY NOAH BERGER

Silicon-based digital devices have been getting smaller and faster for decades. But the materials used in conventional digital design are rapidly nearing physical limits. That's because they operate based on the classical current-voltage behavior of electrons.

When dimensions shrink to the nanoscale, as they have in many of the materials used in today's devices, the rules of quantum mechanics become predominant. Classical dynamics are no longer paramount, and problems arise that are difficult and expensive to overcome.

To continue the trend toward smaller, faster devices and eventually realize the benefits of quantum computers and information systems, new materials are needed to create devices that take advantage of the quantum behavior of electrons.

This quest for new materials is at the heart of much of the research underway in Berkeley Physics. The following pages describe a few examples of work being conducted by four of the seventeen experimentalists in the Condensed Matter Physics and Material Science group.

Diamond anvils, like the one shown here, are used to compress materials and study phenomena such as structural phase transitions, magnetism, and superconductivity at extremely high pressures.

Spin Glass for Spintronics

Electrons have two important characteristics – charge and spin. The electron's charge, a familiar aspect of classical electronics, governs the flow of current through a wire or the on-off switching of a transistor. Spin, the angular momentum of an electron, governs magnetism. In a ferromagnetic material, all the electron spins line up in the same direction. In an antiferromagnet, the spin directions alternate. Spin is a purely quantum property that doesn't have a classical analog.

Spintronics refers to technologies that make use of both electron spin and charge. Antiferromagnetic materials have been identified as especially promising for spintronics applications that could far outperform existing digital devices.

A BREAKTHROUGH IN SPINTRONICS

A primary difference between conventional transistors and quantum versions is the switching mechanism. In conventional digital electronics, electric current switches on or off to create digital ones and zeros. In quantum devices, the switching is done by alternating from one quantum state to another.

Professor **James Analytis** currently holds the Charles Kittel Chair in Condensed Matter Physics, serves as the Chair of Berkeley Physics, and leads the Quantum Materials Laboratory research group. Members of that group are studying a class of antiferromagnetic (AFM) compounds with switching characteristics that are highly desirable for spintronics. The group has demonstrated that the compound iron niobium disulfide (FexNbS2) has better switching capabilities than any other known AFM switching system. The group also found that the compound's switching response strongly corresponds to the amount of iron included in the material.

In addition to an AFM phase, FexNbS2 has a coexisting, disordered magnetic phase known as spin glass. "Unlike a ferromagnet or AFM, where spins point in specific directions," Analytis explains, "a spin glass spin points, on average, in every direction. However, the spins of a spin glass are still glued to each other, just like the spins of a ferromagnet or AFM. This makes them move together."

Analytis and colleagues found that the collective rotation of the spin glass phase in FexNbS2 causes the AFM phase to rotate, and that this combined rotation is key to the its enhanced switching capabilities.

"This AFM switching, showing single-pulse rotated domains with high efficiency, has never been observed until now," says Berkeley Physics postdoc and project lead **Eran Maniv**. "This ability to control and significantly improve AFM switching is a breakthrough in spin-related technologies."

"What's exciting about our work," Analytis adds, "is the realization that you can have a class of materials where two quantum states, A and B, can have very different properties, but the energy needed to go from one to the other is very small. The result is very low power electronics."

ENHANCED BY DISORDER

Physics graduate student **Shannon Haley**, a member of the Analytis team, describes FexNbS2 as "a triangular lattice material that can store information more quickly, using less energy, than the RAM used in today's computers. We've found that when we change the material's structure just a little bit, making it more disordered, it does a better job of storing information."

"This finding," she says, "points to the importance of the spin glass, which is stronger when the material is more disordered. But that doesn't align with the original theory for how the switching happens. That theory says when we apply a current of electrons, the microscopic symmetries of the material make the current's spins prefer one direction, and those spins rotate the stationary spins of the AFM. We know now that the AFM is also being rotated by the collective motion of the underlying spin texture."

"In other words," Haley continues, "the spin glass might be amplifying the ability of the current to switch the material, but we still need to understand how the current is interacting with the spins at all. It's like seeing that a bunch of dominoes are lined up, but needing to know what tips the first one over."

Haley also creates specialized devices out of FexNbS2 to determine how spin information moves in the material. "The results so far have been dramatic," she notes. "When one part of the material is switched, a response is also measured tens of microns away. A huge distance for an electron."

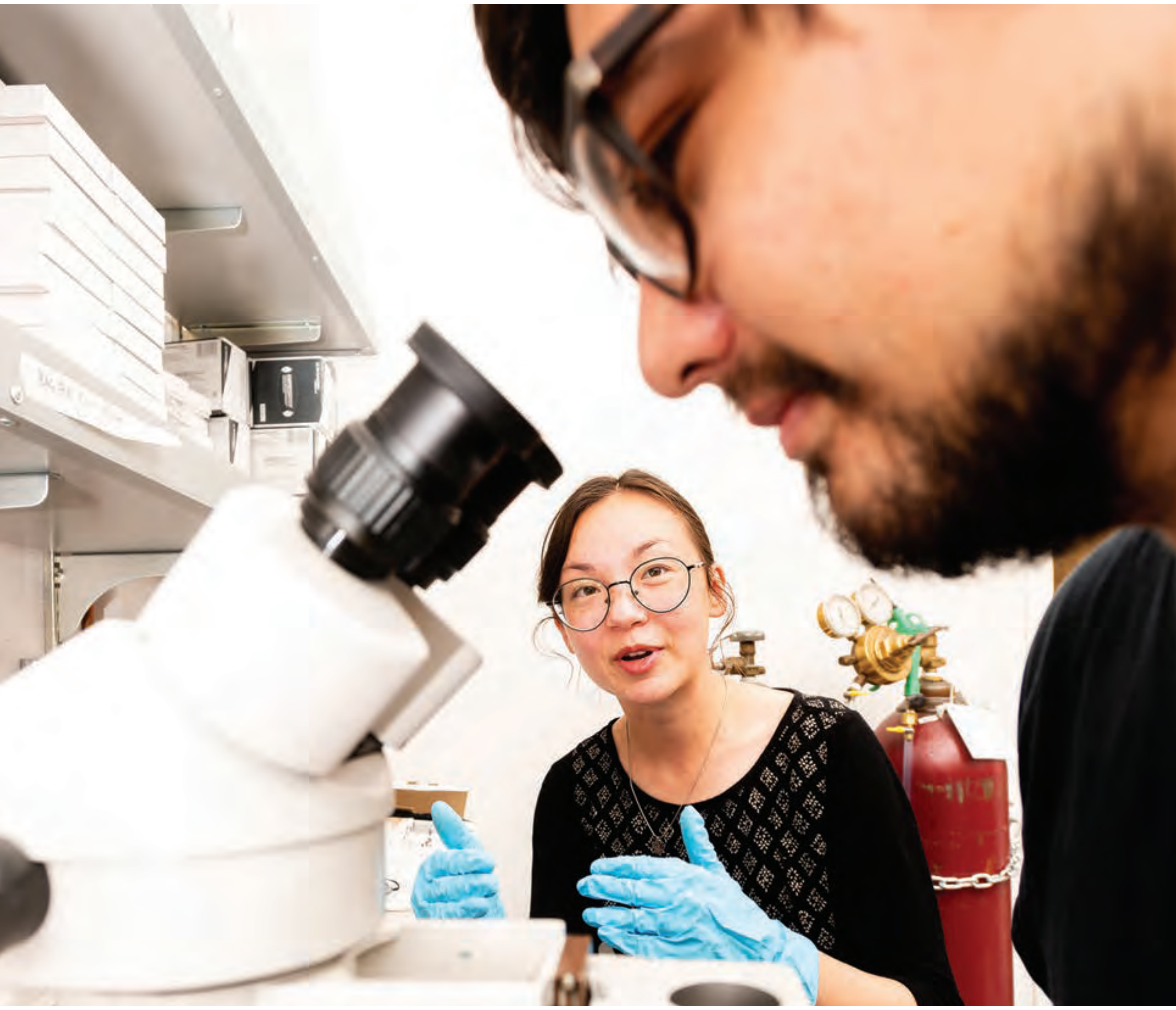
Energy Efficient Electronics

Professor **Ramamoorthy Ramesh** holds the Purnendu Chatterjee Endowed Chair in Energy Technologies in Materials Science and Engineering and Physics at Berkeley. He is also a Materials Senior Faculty Scientist at Lawrence Berkeley Lab and has been a member of the Berkeley Physics faculty since 2004.

Ramesh is well known for more than thirty years of contributions to the materials physics of complex functional oxide materials, from superconductors to ferroelectrics. He uses precise materials synthesis to create and explore emergent phenomena in solid state systems. He takes a global perspective when talking about his work – one of his primary aims is to help reduce global energy consumption by greatly increasing the energy efficiency of electronic devices.

EMERGENT PHENOMENA IN SOLIDS

According to Ramesh, operation of today's electronics consumes about five to six percent of primary energy worldwide. Primary energy is the total amount of raw energy, from renewable as well as nonrenewable sources,



Left: Shannon Haley (center), graduate student and member of the Analytis research group, with undergraduate Gerardo Gutierrez. Haley is also Gerardo's mentor in the 2021 Pi^2 Summer Scholar Program (see page 8).

Opposite: Layering of lead titanate, a ferroelectric compound, with its sister compound strontium titanate, which is not ferroelectric, exemplifies the highly precise materials synthesis methods used by Berkeley Professor Ramamoorthy Ramesh's research group. This level of precision leads to the formation of unexpected emergent behavior, including polar skyrmions as shown here, that hold promise for revolutionizing data storage systems.

that is available for all human endeavors. "Because of the exponential growth in AI, machine learning, microelectronics, and the so-called internet of things," Ramesh says, "the percentage of primary energy used by electronic devices could reach 25 percent by 2030."

"How can we use physics to change the world, to solve energy use and climate change problems?" he asks. "Today's silicon-based devices consume about 100 picojoules of energy per computation. Our research group uses physics as a pathway to the creation of new technologies that use far less energy." Ramesh's ultimate aim is to reduce computational energy costs by many orders of magnitude, down to one attojoule per operation. The only way this feat can be accomplished is by taking advantage of the quantum properties of materials.

MERGING LOGIC AND MEMORY

"If you look at your computer," Ramesh notes, "logic operations are done by the processor on one side and memory operations are done on the opposite side. There can be centimeters of distance between them, and as much as 70 percent of the energy the computer uses is devoted to moving information back and forth. What would happen if we merge the two?"

Ramesh uses a synthesis approach called Laser MBE to fabricate new materials, one atom at a time, layer by layer. His focus is on understanding the physics of precisely controlled multiferroic materials that could be used to make devices capable of simultaneously performing logic operations and storing information.

Multiferroics exhibit a range of quantum properties, including magnetism, which can be switched by applying a magnetic field, and ferroelectricity, switchable by application of an electric field. Ramesh is looking for multiferroic materials that would make it possible to control magnetism with extremely low-voltage electric fields.

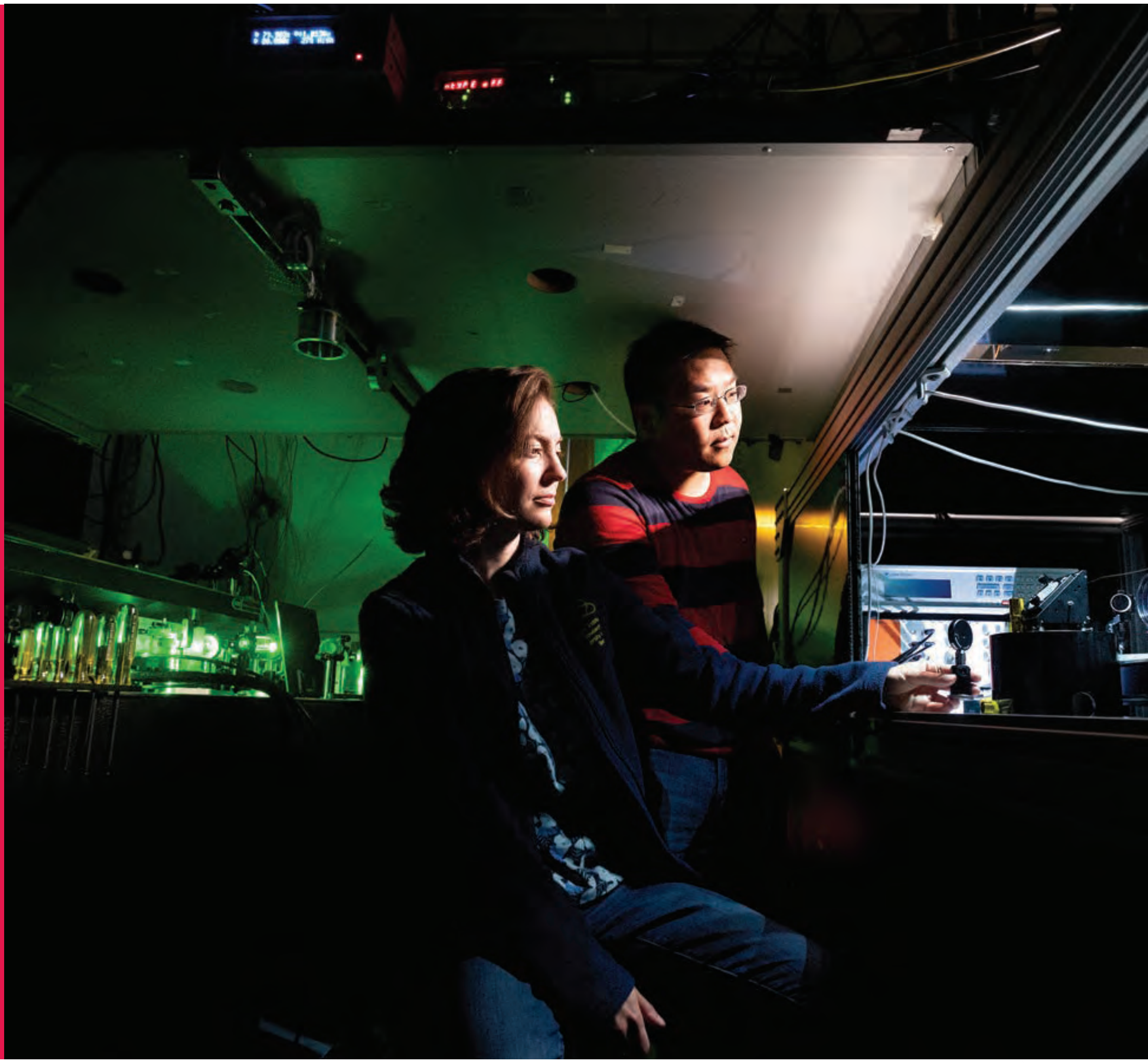
"Electric fields are generally a lot more energy efficient than magnetic fields," Ramesh explains. "If we can make a switch that uses only 0.5 volts to control a magnetic field, that's very trivial compared to the energy needed to use magnetism for the same purpose. Our goal is to get down to 0.1 volts, 100 millivolts, which would be the equivalent of one attojoule per computer operation."

Ramesh is currently working with bismuth ferrite, a multiferroic material his team discovered almost two decades ago that can be used to manipulate magnetism with an electric field. "So far, we've been able to reach 30 to 40 attojoules per switch," he reports, "far less than the 100 picojoule level available today. So already we are much more energy efficient than many other pathways. If this works, and if it scales up as a real technology, we could meet future energy needs with energy efficient computing."

"But many more innovations are needed," Ramesh cautions. "These devices still have to be manufactured, have to function in a technologically robust way, and be successfully sold as products. Physics alone is not

Right: Berkeley Physics Professor Norman Yao (right) and postdoc Emily Davis are pictured placing an optical diffuser into a widefield imaging setup integrated with a cryostat, in which materials at low temperature and high pressure are studied using spins embedded in diamond.

Below: Berkeley Physics Professor Zi Qiu devised a method for inducing skyrmion formation in Fe3GeTe2 (purple/yellow). This electron microscope image shows evidence of magnetic coupling to underlying layers of palladium and cobalt (orange). Skyrmions (contrasting dots) visible within the stripes of the Fe3GeTe2 are induced by the interlayer coupling.



enough, but unless we start with fundamental physics, we could never achieve the kind of reductions in energy use that can change the world."

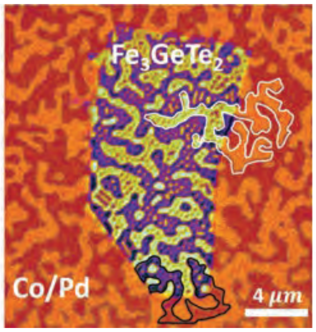
Spin Switching in Thin Films

Professor **Zi Qiang Qiu** has been a member of the Berkeley Physics faculty since 1993 and is also a faculty scientist in the Materials Science Division at Lawrence Berkeley Lab. His research group studies fundamental properties of electron spins in solids, using a process known as Molecular Beam Epitaxy (MBE) to fabricate ultrathin films. "This technology allows us to build nanoscale materials, atom by atom, layer by layer, and control their thickness with atomic precision," Qiu explains. "You have the freedom to create layers of different materials to make artificial structures."

"We grow the samples in my lab on campus," Qiu adds, "then measure their properties using facilities at Lawrence Berkeley Lab, including X-ray analyses at the Advanced Light Source and state-of-the-art instrumentation at the National Center for Electron Microscopy."

SPIN DYNAMICS

Electric current is the transfer of electron charge from one location to another. Spin current is the transfer of electron spin from location to location in a material. Qiu and his group are interested in synthesizing materials that can use spin current as the switching mechanism of local magnetization in quantum devices.



"In conventional electronics, the technology for switching local magnetization involves applying a magnetic field," Qiu says. "But everything is getting so much smaller, and it's impossible to make the magnet any smaller. If you can switch the local magnetization by flowing spin from one location to another, you can write information without having to use a magnetic field." This idea is still in the conceptual stages, but materials with this capability could lead to ultra-fast, very low-energy quantum devices.

Qiu probes the spin dynamics of the materials he synthesizes to learn how spin current is generated, how it propagates inside the material, and how it delivers angular momentum from one location to another.

Over the years, Qiu and his colleagues have developed an experimental method called Element-Resolved and Time-Resolved Measurement, an x-ray technique that can probe the properties of each separate layer of a nanoscale material. Previous methods were limited to measure-

ments of all layers combined. “Suppose a material is made of three layers, A, B, C,” Qiu explains. “We can tune the x-ray energy so that it will measure only the signal from A, and then tune it again to measure only the signal from B, and so on.”

Recent work led by **Qian Li**, one of Qiu’s former post-docs, used the method to study spin dynamics in a layered, ultrathin magnetic system composed of iron, cobalt, cobalt oxide, magnesium oxide, and other compounds. Results indicated that spin switching in this material can be achieved by flowing the spin current without flowing the charge current.

“The more materials you characterize,” Qiu asserts, “the more you can learn about how one electron spin switches another electron spin. Understanding this physical process can be very helpful for the design of future materials.”

SKYRMIONS AND VAN DER WAALS MATERIALS

Magnetic skyrmions are extremely tiny, topologically stable swirls of quantum spin that occur in some materials, and are quite promising for high-density, low-power spintronics devices. Van der Waals (vdW) materials are weakly bonded two-dimensional layers that do not form skyrmions, but have highly tunable electronic properties, another positive feature for spintronics. Some vdW compounds also have ferromagnetic properties, making them even more suitable for quantum electronics. Qiu is experimenting with multiple thin-film layers that could merge all of these characteristics into a single material.

In research published last December, his team announced they were able to induce the spontaneous formation of magnetic skyrmions in iron germanium telluride (Fe_3GeTe_2), a vdW material. They accomplished this by placing a layer of Fe_3GeTe_2 on top of a wedge-shaped layer of cobalt-palladium. Neither layer forms skyrmions on its own, but magnetic coupling interactions between them led to the formation of skyrmions in the vdW layer.

“This can happen in nanostructures,” Qiu notes. “You put A and B together at nanometer scale, and due to the interaction between them, you get some property that neither one has. I began trying van der Waals materials without knowing exactly what I would get. Sometimes you get a surprise.”

New Quantum Sensing Technologies

Professor **Norman Yao**’s group combines theory and experiment in research that encompasses condensed matter physics, materials science, and atomic, molecular, and optical physics. A Berkeley Physics faculty member since 2016, he has received many awards, including the 2020 George E. Valley, Jr. Prize and a 2021 New Horizons in Physics Prize.

DIAMOND-BASED SENSORS

One of the main efforts underway in Yao’s group is development of nanoscale quantum sensors based on nitrogen vacancy color centers in diamond. “Diamond in its native form consists of carbon (C) atoms bonded together in a tetrahedron,” Yao says. “We work with a very specific defect inside the diamond lattice, the nitrogen vacancy (NV) center. The defect is formed when one of the C atoms in the lattice is replaced by a nitrogen (N) atom, and that N atom is adjacent to a vacant lattice site (a missing C atom).”

“One of the main challenges associated with working with an individual quantum object, like an atom, is the ability to actually ‘trap’ them,” Yao goes on to explain. “Many modern efforts use forces generated by light for this purpose. Interestingly, solid-state materials can provide a different type of trap and diamond is a stable, durable house for these quantum defects. NV centers behave very quantum-mechanically in the sense that they can maintain coherent correlations for an extremely long period of time. And they are very sensitive to changes in magnetism, temperature, and pressure. Our group is using NV centers as nanoscale sensors that are ultrasensitive at very high pressures.”

Changes in pressure have important effects on chemical, electronic, magnetic, and mechanical properties of materials. Tabletop experiments that explore these phenomena use diamond anvil cells (DACs) to expose materials to very high pressures. A DAC consists of two faceted diamonds with very flat surfaces. A sample is placed between the two flat surfaces, and pressure is applied. Pressures up to millions of atmospheres can be achieved this way.

“The problem,” Yao notes, “is that it’s very hard to do any sensing under those conditions. How do you put a thermometer or a camera in a tiny high-pressure chamber?” His group makes a type of DAC that incorporates a thin layer of NV centers near the surface of the diamond that’s applying the pressure. “This layer of NV centers can sense how the material is changing,” Yao reports. “Suppose pressure of a certain magnitude causes a material to stop producing a magnetic field, changing it from a ferromagnet to a paramagnet. Using the NV centers we can precisely measure that change.”

The Yao group’s first paper on this quantum sensing device, published in 2019, launched many new collaborations, ranging from research groups studying rock magnetism to room-temperature superconductivity. Yao is also entering into collaborations with Analytis, Ramesh, and Berkeley physics professor **Robert Birgeneau**. “One thing we’re hoping to do together,” Yao says, “is use this device to literally take pictures of how skyrmion structures change as a function of pressure. That would be awesome.”

QUANTUM VS CLASSICAL SENSING

“In principle,” Yao notes, “quantum mechanics allows you to do much better metrology than is allowed by classical physics alone.” For example, measuring the temperature of a room at a specific moment with a single thermometer yields a much less precise result than using 100 thermometers and making a histogram of the results. Measurement sensitivity is a function of the number of sensors.

“In classical physics,” Yao says, “measurement sensitivity improves as one over the square root of N, where N is the number of sensors. In this case, the sensitivity of your temperature measurement using 100 sensors would improve by a factor of ten over a single sensor.”

“In quantum mechanics,” he continues, “sensitivity can improve as 1/N. For quantum sensors, if you can make them all entangled in just the right way, for 100 sensors you can get improvement by a factor of 100 over a single sensor. It’s something people are trying to harness, but it’s just really hard and we haven’t yet been able to do that. That’s a dream of mine.”

Pi² Summer Scholars

Over the summer, ten Berkeley Physics undergraduates became the first cohort of students to participate in hands-on research through the Pi² Summer Scholars Program. With generous funding from donors, each student researcher was awarded a stipend package in support of their work.

This new program is designed to increase research opportunities for undergraduate physics majors, especially those who might not have the financial means to support themselves while participating in research. The program also helps guide students through the often challenging process of finding a research position that fits their background and interests.

The Pi² Summer Scholars Program is a component of the Physics Innovators Initiative (Pi²), established in 2018 to enhance hands-on learning opportunities, update curriculum, and modernize student lab facilities for undergraduates.

"Involvement in research can be transformational for undergraduate students, " says Berkeley Physics professor **Feng Wang**, who currently serves as faculty lead for Pi². "Research experience gives students an opportunity to develop practical skills, explore the unknown, and experience the thrill of discovery. It helps them recognize their potential as physicists."

> "We aren't just recruiting good physicists with this program, we're also recruiting future leaders."

MENTORS AND MENTEES

Each undergraduate participant spends the summer months working one-on-one with a mentor who is a graduate student or postdoc already involved in faculty-led research. In addition to opening up new avenues of opportunity for undergraduates, the Pi² Summer Scholar Program benefits mentors by giving them valuable experience managing projects, setting goals for research teams, and guiding student learning.

Gerardo Gutierrez, one of this summer's mentees, is a senior who transferred to Berkeley Physics from community college in 2019. "I feel that I got into physics late in the game," he says, "and finding a way to get into research seemed kind of intimidating." He first met physics graduate student **Shannon Haley** at a campus research fair held online last year. She encouraged him to apply to the Pi² Summer Scholars Program. Shannon became his mentor and the pair worked together over the summer in the lab of **James Analytis**, Berkeley Physics professor and Chair of the department.

Their project involved the study of iron niobium disulfide, a material with strong potential for use in quantum storage applications. Haley taught Gutierrez how to grow the material in the lab, using a process known as chemical vapor transport, and then make changes to it by replacing small amounts of iron with atoms of cobalt and chromium. Their objective was to learn how these kinds of adjustments alter the material's behavior at microscopic scale.

Gutierrez says he enjoys learning new lab and computational skills and applying them. "Once I have the material," he explains, "I run some calculations to see if we have the kind of switching response we're looking for. If not, we go back and change it, based on the calculations, to see what would work better."

RECRUITING RESEARCHERS AND FUTURE LEADERS

Students interested in becoming Pi² summer scholars go through a two-step application process. First, they select projects from a list of opportunities offered by faculty and describe the reasons for their choices. Candidates are interviewed by potential mentors, and mentor-mentee partnerships are created based on mutual interests.

For the second step, with guidance from their mentor, each mentee writes a short research proposal. The mentor describes the project in detail by submitting a research plan and outlining how they will assist in the professional development of their mentee.

Each mentee also composes a brief leadership statement describing how they see themselves contributing to the promotion of scientific progress in the wider community. "We aren't just recruiting good physicists with this program," says Analytis, "we're also recruiting future leaders."

In his leadership statement, Gutierrez described how encouragement from his high school teachers gave him a sense of purpose and inspired him to pursue physics. "It made me realize physics was something I could base my life around," he recalls. "That kind of encouragement can do so much, but is not something every student receives." He has already begun giving back by returning to his high school as a paraprofessional educator.

Gutierrez notes that finding a research position through Pi² went more smoothly than trying on his own to find a professor whose lab was a good fit. "There are a lot of people looking for research opportunities," he says. "The Pi² process gives undergrads more of a chance."

Haley agrees. "It's important to have a system like this in place. It can be really intimidating to just cold email a professor. And unwritten steps or unspoken rules on how to get a research opportunity can hold people back who would otherwise become very good researchers." She also notes the importance of paid positions for undergraduates. "It means we're no longer artificially weeding out someone just because they have to work to support themselves."

Plans call for continuing the Pi² Summer Scholars program annually.

PHOTO: KEEGAN HOUSER

Graduate student and Pi² mentor Diego Novoa works on optical equipment in the E8 lab with undergraduate mentee Lely Tran.

2020-2021 Giving

654

Total Number of Donors this year

62%

Alumni

3%

Faculty, Staff, Current Students

2%

Corporations, Organizations & Foundations

32%

Friends

15%

Physics alumni who are donors

Physics alumni population | 7,031

Physics alumni who are donors | 1,084

Frances Hellman takes the Helm as APS President

On January 1, Berkeley Physics Professor **Frances Hellman** begins a one-year term as President of the American Physical Society. In preparation for that role, she has stepped down as Dean of the Division of Mathematical and Physical Sciences, a position she held for seven years.

As Dean, Hellman contributed on many fronts. She conducted a deep analysis of differential outcomes among students from different backgrounds, addressed the role of mathematics skills in student achievement, and created a program that provides paths to success for underrepresented minorities, including women, gender minorities, and first generation students, as well as community college transfers. Her efforts to recruit and retain the greatest faculty in the world ensure that Berkeley remains a global leader in basic scientific research.

PHOTOS: KEEGAN HOUSER

Professor Frances Hellman joined the Berkeley Physics faculty in 2005 and served as Chair from 2007 to 2013. She holds joint positions as Professor of Materials Science and Engineering at UC Berkeley and Senior Faculty Scientist in the Materials Science Division at Lawrence Berkeley Lab.

THE STUDY OF AMORPHOUS MATERIALS

As a condensed matter physicist, Hellman focuses on amorphous, noncrystalline materials. "Amorphous materials are underappreciated in the world of physics," she observes. "Compared with crystalline materials, they have been less interesting to physicists largely because their disordered structure makes them difficult to describe." But, she says, they have promising potential for materials science.

"Although amorphous materials don't have the same periodicity and symmetry as crystal lattices," Hellman notes, "they exhibit many of the same properties. Most of the mathematics used to describe the properties of materials – like electrical or thermal conductivity, or magnetism – rely on the periodicity and symmetry of crystal lattices. Yet the same math actually applies even when the material is not crystalline, not symmetric, not periodic. This tells us the principles that underlie materials properties are more universal than the math we've been using to describe them."

"Consequently," she asserts, "the study of amorphous materials broadens our view and offers a whole new palette from which to discover new materials."

NEW MIRRORS FOR LIGO

Hellman is an eminent expert on glasses – a class of amorphous materials whose atoms or molecules are arranged in haphazard patterns, as in liquids, yet bound together in ways that constrain motion among the particles and give rise to potentially useful properties. One example of her research on glasses is contributing to the hunt for a material that could vastly improve the sensitivity of LIGO, the Laser Interferometer Gravitational Wave Observatory.

LIGO detects gravitational waves by bouncing beams of laser light off high-precision mirrors, making measurements that are ten thousand times smaller than the width of a proton. To achieve this level of sensitivity, LIGO is extremely well isolated from external vibrations that could overwhelm tiny signals from gravitational waves. However, sensitivity is still affected by quantum vibrations generated within the atoms that make up the layers of glass used to coat LIGO's mirrors. In fact, these vibrations are the major source of signal noise in the current version of the LIGO experiment.

In her work with one type of glass, amorphous silicon, Hellman has developed innovative fabrication techniques that significantly reduce, possibly even eliminate, quantum vibrations. "The fact that we can make this problem go away in amorphous silicon gives us hope that we can make it go away in other materials," she notes, "including materials that could be used in LIGO's mirror coatings."

PLANS FOR APS

For her year as APS President, Hellman has set a number of priorities, one of which is to advocate for APS itself. "I believe in a professional society that supports its members, including early career scientists and, increasingly, those in industry or otherwise outside of academia. And I plan to interface with Washington to make sure topics of importance to physics stay on the agenda."

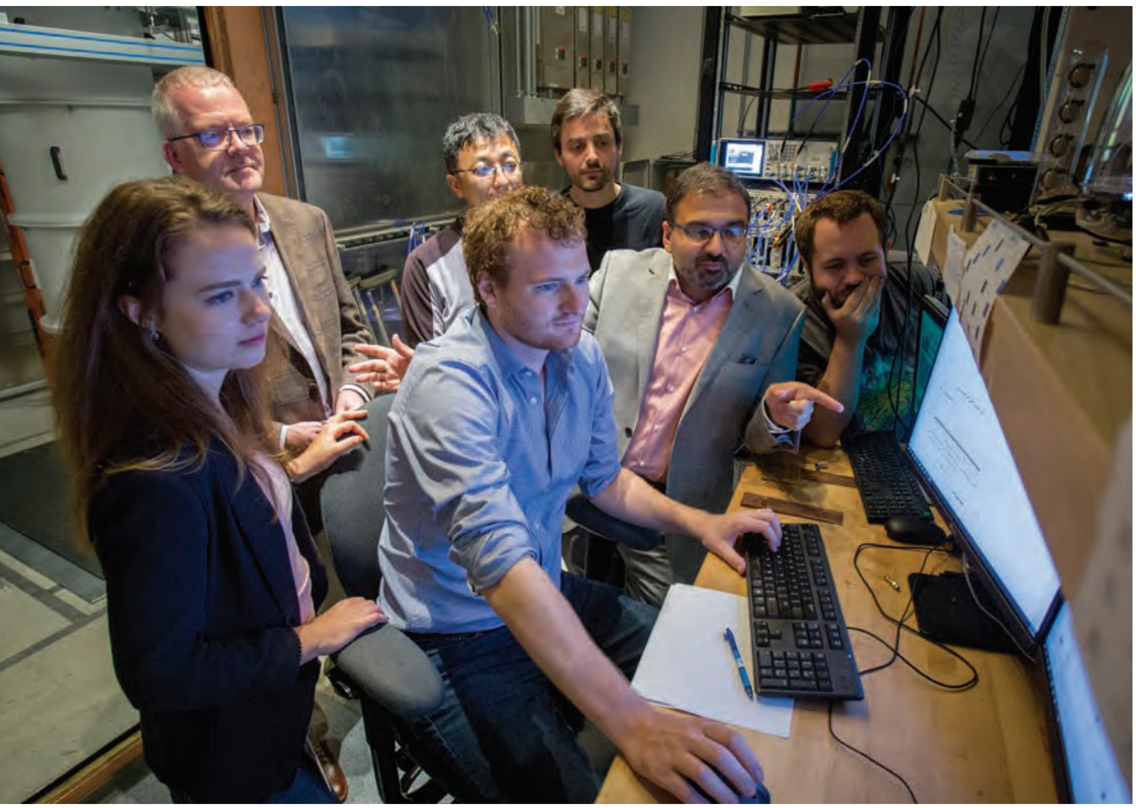
She also wants to find new ways for APS to increase opportunities for underrepresented groups. "It isn't ok," she says, "that there are so few Black physicists, or that women make up only 20-25% of our population."

Hellman has served for many years as a scientist in residence at the Exploratorium science museum in San Francisco. "I love helping people discover the beauty of science," she says. "I want to find ways for the physics community to better interface with the public, to help strengthen the public's trust in science."

The Quantum Systems Accelerator (QSA) is a new research center that aims to harness the advantages of quantum information science for the benefit of scientific discovery and society at large. It's a network of world-class research facilities, academic leaders, and industry partners working together to speed development and commercialization of quantum information systems, including quantum computers.

Quantum Systems Accelerator

Advancing quantum information science through collaboration



QSA is led by Lawrence Berkeley National Laboratory (Berkeley Lab), co-led by Sandia National Laboratories, and directed by **Irfan Siddiqi**, Berkeley Physics professor and faculty scientist at Berkeley Lab. "The global race is on," Siddiqi says, "to build quantum systems that fuel discovery and make possible the next generation of information technology."

QSA's core team of researchers includes dozens of leading scientists at 15 partner institutions who have pioneered many of today's quantum capabilities. QSA actively joins with industry and international programs to accelerate the pace of research and development and shepherd promising technologies from the lab to the factory.

"An overall goal is to foster US leadership in quantum information science and to develop the algorithms, quantum devices, and engineering solutions needed to deliver quantum advantage in scientific applications," says **Chris Spitzer**, Berkeley Physics alum and QSA's Associate Director for Operations.

EMPHASIZING COLLABORATION

"QSA brings together research on all parts of a quantum computing system," Spitzer continues, "from the materials it's built of, to the architecture of its quantum processors, to its algorithms and simulations. We want to maximize performance in the near term and then chart a pathway to the powerful quantum computing systems that we know are possible but don't yet know how to achieve."

"Too often," he adds, "different aspects of quantum research proceed in isolation from each other. People working on algorithms don't necessarily think about what a physical hardware system looks like or how it operates. People looking at processor design don't always think about the properties of the materials or potential sources of noise. The exciting thing about QSA is that it brings together groups who don't usually talk to each other. This process catalyzes new and unique ideas and identifies critical areas for development of practical quantum systems."

DEVELOPING A DIVERSE QUANTUM WORKFORCE

QSA and its broad network of partners are also preparing the future quantum workforce – from scientists, engineers, and technicians to nontechnical professionals and even new careers not yet imagined. Among these efforts is development of coursework and training materials for K-12 and community college students, graduate students, and postdocs. Apprenticeships are being created to open up opportunities for anyone interested in quantum science, including underrepresented populations.

"We're looking at the entire pipeline," Spitzer notes, "including resources aimed for working professionals who want to take skills developed in other fields and apply them to quantum science."

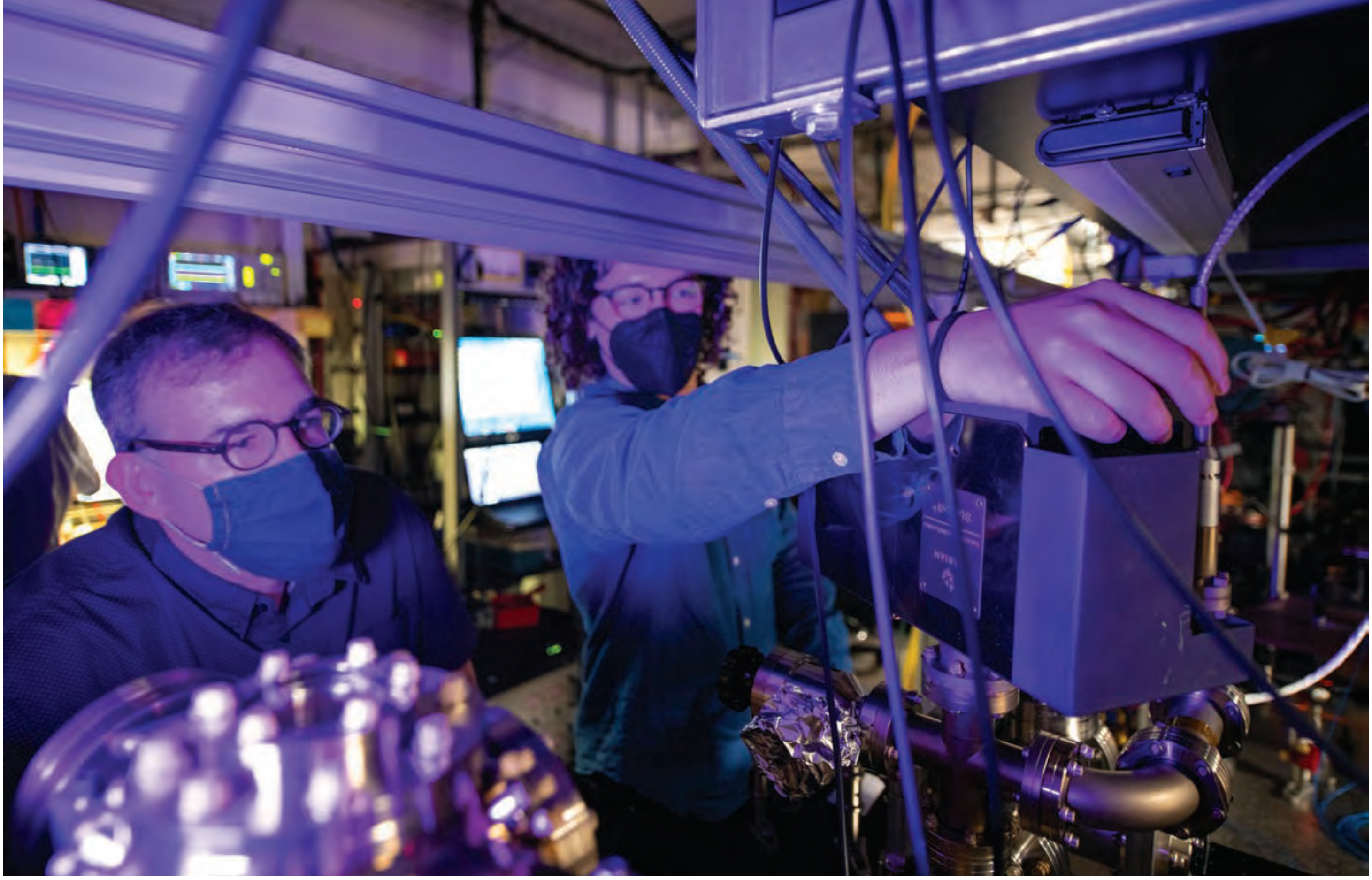


PHOTO: KEEGAN HOUSER

THE ONE STOP QUANTUM SHOP

A new web portal, the One Stop Quantum Shop, facilitates communication between QSA and the wider quantum information community. It serves as a central repository for technical data, publications, and software. It provides access to collaborative project information and offers connections to experts in quantum information. And it links the growing quantum community to resources on training, internships, events, and educational outreach programs. "It's a networking hub where anyone can go to learn what's needed to get involved in quantum computing," Spitzer notes.

QSA is one of five US Department of Energy (DOE) National Quantum Information Science Research Centers announced in August 2020. Planned funding by the DOE's Office of Science totals $115 million over five years.

Programmable Quantum Systems

The Quantum Systems Accelerator supports cutting-edge research across the country and around the globe. A number of Berkeley Physics faculty are among the scientists whose research includes QSA projects. Professor **Dan Stamper-Kurn** is one example. His Ultracold Atomic Physics group at Berkeley studies novel phases of matter governed by quantum mechanics.

Stamper-Kurn's research group uses beams of laser light to cool single atoms to near absolute zero, suspend them in a vacuum, and manipulate their interactions. "We create neutral-atom quantum systems that are complex and behave in highly controlled and significant ways," Stamper-Kurn says. "This is a very different kind of platform for computing. An atom-based quantum computer might turn out to be an ultra-high vacuum chamber supported by lasers that are turned on and off to orchestrate the system's operation."

Until recently, research on ultra-cold atoms has focused on two families of elements. Alkalis, on the left side of the periodic table, have simple, spherical atomic structures that are relatively easy to control with lasers, but limited in the kinds of interactions that would be needed for quantum computing. Lanthanides, at the bottom of the periodic table, are highly complex, with interesting and useful interactions, but extremely difficult to control.

"We decided to look for something intermediate," Stamper-Kurn reports, "and we have discovered that transition metals, elements from the middle of the periodic table, might be amenable to the kinds of tricks we use to cool atoms. No one had noticed this before."

Transition metals look especially promising because interactions between a light beam and an atom depend strongly on the polarization of the light and energy state of the atom. "That's an essential manipulation tool," Stamper-Kurn says. QSA supports Stamper-Kurn's efforts to bring the family of transition metals into quantum science and, ultimately, to develop a programmable quantum information system.

The group's initial experiments are focused on titanium. "We found that the energy state you need to start with for laser cooling is not the lowest energy state of the titanium atom," Stamper-Kurn notes. "But once the atom has been prepared, all the standard laser cooling methods should work. We see this pattern repeated in a number of other transition metals, roughly doubling the number of elements you can work with in these experiments. That's super exciting. It will make a really big difference."

Professor Dan Stamper-Kurn (left) in the E8 Lab lab with post doc Scott Eustice.

Opposite: Professor Irfan Siddiqi (second from right) and team at the Quantum Systems Accelerator. (Photo taken prior to March 2020)

PHOTO: LEE SANDBERG, INSTITUTE FOR ADVANCED STUDY

Q&A

In conversation with Theoretical Physicist Geoff Penington

You are among the recipients of a 2021 New Horizons in Physics Prize for calculating the quantum information content of a black hole and its radiation. What compelled you to look into this question?

The black hole information problem has been one of the central questions in theoretical physics ever since Stephen Hawking first posed it back in the 1970s. In everyday physics, information present at one time is always secretly there at all later times, even if it might be in a far less accessible form. For example, if you burn a book, the information previously written in the book becomes encoded in the location and velocities of air molecules, photons, etc. – impossible to access in practice, but in principle still present.

Hawking claimed that black holes are different: they truly destroy information that falls into them. And he had a calculation to back him up. In the decades since, physicists became more and more convinced that Hawking was wrong, but never had a direct calculation to prove it.

How did you go about making the calculation?

I was lucky enough to be thinking about the right set of ideas at the right moment, when we finally had enough technical tools and tricks to make progress – as evidenced by the fact that my co-winners independently derived the same results in a paper published the same day! Honestly, the moment I thought to apply the right mathematical machinery to the problem, it was immediately clear that it could explain a huge amount, even if the technical details took several months to wade through. Obviously, that was a very exciting moment. And I guess that excitement just kept growing, as each new calculation agreed with our expectations for how and when information should escape a black hole.

Do your findings mean that physicists are now able to describe the interior of a black hole? Is the information problem now resolved?

We certainly know a lot more than we did a few years ago. There's been a huge amount of progress on all sorts of aspects of the problem, of which my work is only one piece. But that progress has created new questions even as it answered old ones.

In particular, a central role in all this progress (including in my work) has been played by 'spacetime wormholes' – shortcuts between distant points in spacetime. But no one really knows whether these wormholes are actual physical entities or just a convenient mathematical fiction.

The same goes for the interior of a black hole: it's present in our calculations and we can describe it precisely, but there are very smart people who still believe that the interior can't actually be 'real' in a physical sense.

Is it possible that research focusing on the contents of black holes can resolve apparent discrepancies between the physics of gravity and quantum mechanics?

That is certainly the hope! Black holes are nice because they are easy to test out ideas on: mathematically we have pretty good control over their environment and behaviour. But eventually we want to properly understand the quantum mechanics of the big bang and, more generally, the quantum mechanics of cosmology. This will be much more difficult and is a central problem in fully understanding quantum gravity. However, if we can nail down the physics of black holes, hopefully it can prepare us to tackle those harder problems.

Geoff Penington is a theorist who joined the Berkeley faculty in July 2020 as the Arnold and Barbara Silverman Distinguished Professor in Physics.

N3AS: Extreme Astrophysics

Berkeley Physics is home base to a new Physics Frontier Center (PFC), the Network for Neutrinos, Nuclear Astrophysics, and Symmetries (N3AS). Supported by the National Science Foundation, N3AS is a multi-institutional astrophysics collaboration led by Berkeley Physics professor and Berkeley Lab staff member **Wick Haxton**. This network began in 2017 as an NSF theory 'Hub', one of the first two such entities created by NSF. Its elevation to a PFC is major expansion.

N3AS theorists work to connect observations of extreme astrophysical events to the fundamental physics that drives them. "The targets of our research are the billion-degree explosions produced by merging neutron stars or by supernovae," Haxton says. "Such events create conditions unlike any on Earth, involving exotic physics we'd like to understand better."

"For example," Haxton continues, "we've learned a lot of new physics from neutrinos in the past 25 years. Neutrino mass and mixing show that our standard model of particle physics is incomplete. But in extreme environments, neutrinos become even more interesting."

"Normally, as neutrinos travel, they neither interact with each other nor with other particles of matter," he explains. "But in the dense cores of supernovae and neutron star mergers, neutrinos are trapped, becoming highly entangled in a quantum mechanical sense. The neutrino oscillation phenomena we study on earth become more varied and exotic. Neutrinos carry almost all the energy of these explosions, helping drive them, and controlling the conditions under which new elements form. Their properties matter!"

INNOVATIVE TRAINING PROGRAMS

An important goal of N3AS is to train a new generation of researchers, giving them an opportunity to acquire the breadth of expertise needed in today's astrophysics. "N3AS creates a partnership of institutions that functions like a single, collaborative group," Haxton says. "Our postdoctoral fellows belong to the network, rather than to specific institutions, and have the resources to travel across the network, to collaborate in any area they wish to pursue."

Each three-year postdoctoral term is split between two host institutions, selected to help the young researchers develop versatility. The postdocs typically have several faculty mentors, and generally also work with each other. "Perhaps it's due to Zoom," Haxton notes, "but our postdocs work seamlessly as a team, building on the knowledge of each other, despite geographic separation."

"Astrophysics has become an `inner space-outer space' field that requires a knowledge of particle, nuclear, and many-body physics," he adds. "We are trying to help young researchers develop the breadth they will need to connect phenomena to the underlying microphysics."

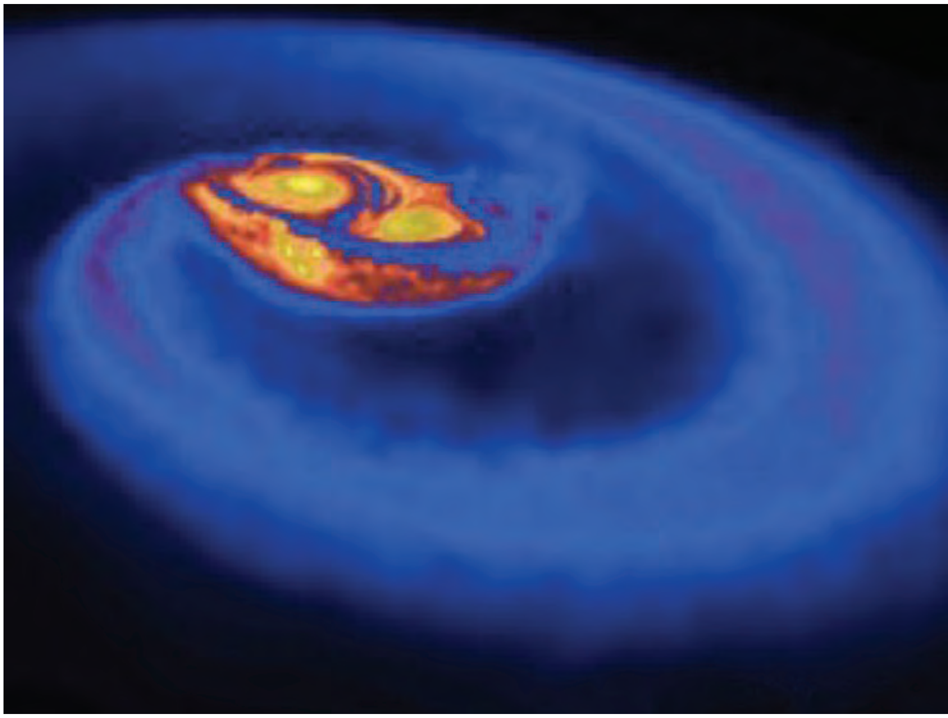


IMAGE COURTESY OF FRANCOIS FOUCART, U. NEW HAMPSHIRE

Simulation of the in-spiral phase of a neutron star merger during which the gravitational wave signal is generated. The connection between such gravitational wave signals and neutron star structure is one topic N3AS researchers are investigating.

N3AS has also started programs to help its postdocs develop professional skills beyond research, while at the same time helping others. "**Colette Patt** from the Dean's office pointed us to UC Transfer Pathways," Haxton says. "It's a program that connects undergraduate transfer students with research opportunities, which helps improve retention of students in STEM majors."

This past year N3AS postdocs, led by former N3AS-Hub Fellow and current Berkeley postdoc **Sherwood Richers**, organized such a program for undergraduates transferring to Berkeley Physics. "It is a win-win," Richer says. "As we learn to teach and direct research, the undergraduates are introduced to discovery science." Next year will see the expansion of the Berkeley program and the startup of a second effort at N3AS partner UC San Diego.

N3AS will also create an annual national Summer School for advanced graduate students and beginning postdoctoral researchers in astrophysics, something the fields of particle and nuclear physics have had for decades.

"It's a program that connects undergraduate transfer students with research opportunities, which helps improve retention of students in STEM majors."

NEW FACILITY IN PHYSICS SOUTH

The campus location for N3AS is on the third floor of Physics South. The area is currently being remodeled, with completion scheduled for the end of year. "The space improvements will give astrophysics theory more visibility in the physics department, connecting Physics South to theory colleagues and to the Berkeley Center for Cosmological Physics on the third floor of Campbell Hall," Haxton notes. "The remodel will make great use of the skybridge that connects these two areas."

Welcome Back!

Campus Reopens for the Fall Semester

After 18 months navigating the ever-changing challenges posed by COVID-19, Berkeley Physics reopened for the fall semester. Students and faculty are once again able to enjoy in-person instruction, research groups have been released from limitations on the number of people allowed to work together in laboratory spaces, and staff and faculty are returning to their campus offices.

In an open letter to the campus community, UC Berkeley Chancellor **Carol Christ** wrote, "As we've learned more about the SARS-CoV-2 virus and how it spreads, we've been able to resume in-person activities while mitigating the spread of COVID-19. We will continue to learn and adjust our response based on the latest science and public health guidance."

As of mid September, vaccination rates across campus had climbed to 97% for undergraduate and graduate students, and 90% for faculty and staff. "Many on our staff and faculty worked through the pandemic while following strict distancing and testing protocols," says **Roia Ferrazares**, Director of Administration for Berkeley Physics. "With these high rates of vaccination, we've been able to return to a more normal routine."

"It's been a joy to see our students walking the halls and gathering in our classrooms," she adds. "I don't take for granted the joy that casual greetings in the hallway bring me after 15 months of working from home."

Some of the pandemic protocols and restrictions that have been put in place on campus include face coverings, daily symptom screening, vaccinations, surveillance testing, and COVID prevention training.

"The pandemic has challenged us in so many ways," says Chancellor Christ, "and we continue to be humbled and inspired by the way our campus has stepped up to these challenges."

Postage Stamp Honors Berkeley Physics Alumna

The US Postal Service has released a Forever stamp commemorating the career of Berkeley Physics alumna **Chien-Shiung Wu** (PhD 1940). Wu was a nuclear physicist who did graduate and postdoctoral work at the Radiation Lab directed by Ernest O. Lawrence. She worked closely with Emilio Segrè.

Wu also worked at the Manhattan Project, where she helped develop an important process for separating uranium isotopes. She is best known for the Wu experiment, which proved conclusively that parity is not conserved under certain conditions of beta decay.

Nicknamed the "First Lady of Physics" and "Queen of Nuclear Research," Wu received many awards, including eight honorary degrees, the National Medal of Science (1975), and the Wolf Prize in Physics (1978). The stamp was issued in her honor on February 11, 2021.

Experimental Physicist Brooke Russell

Investigating the Physics of Neutrinos

PHOTO: PABLO DURANA

Brooke Russell is a Chamberlain Postdoctoral Fellow at Lawrence Berkeley Lab and a member of Berkeley Physics Professor Kam-Biu Luk's research group. In May 2020 Russell became the first Black woman to earn a PhD in physics from Yale University, and recently became a first-time mom.

Brooke Russell is Chamberlain Postdoctoral Fellow at Lawrence Berkeley Lab and a member of the research group led by Berkeley Physics Professor **Kam-Biu Luk**. Russell came to Berkeley in January 2020 to join an international collaboration called DUNE – the Deep Underground Neutrino Experiment – that seeks to answer fundamental questions about the nature of matter and the evolution of the universe.

Russell is helping develop a new technology that promises to revolutionize the study of neutrinos and other subatomic particles. "Neutrinos stand out as important to our understanding of nature, because they don't behave in the way we initially thought," she says. "For example, they oscillate, or transform from one type to another as they move through space."

DUNE is designed to detect and analyze neutrinos and antineutrinos emerging from a particle accelerator at the Department of Energy's Fermi National Accelerator Laboratory (Fermilab) near Chicago. The particles will pass through a 'near' detector at Fermilab before traveling to a 'far' detector at the Sanford Underground Research Facility in South Dakota.

"For this experiment, the accelerator will produce very powerful beams, either predominantly neutrinos or predominantly anti-neutrinos." Russell explains, "and send them across 1300 km of space. We'll compare data from the two detectors and ask, to what extent did neutrinos behave differently than antineutrinos? Answering that question might give us some understanding of why we live in a matter-dominated universe."

LIQUID ARGON PIXELS

The team Russell is working with focuses on the near detector. "We will have more signal than we know what to do with," she notes. "And the onus is on us, the people working on the near site, to produce a very precise measurement of the beam before it has undergone significant oscillation."

Neutrinos are extremely difficult to detect because they so rarely interact with other particles of matter. Most neutrino detectors are large chambers filled with tons of a purified liquid; DUNE uses liquid argon. Energetic particles entering the detector chamber liberate electrons from some of the argon atoms. A strong electric field is applied that forces the freed electrons to move toward the anode side of the chamber, where a 2D plane of wires acts as antennae for reading electrical signals. The read-out creates 2D images of each event that can be projected to 3D. The 3D images are then analyzed to pick out and characterize the neutrino interactions. "With DUNE," Russell cautions, "we'll be operating in such a high rate environment that projecting from 2D to 3D can create distortion."

Dan Dwyer, Berkeley Lab team leader for DUNE, and his colleagues, including Russell, are working on a modular technology called LArPix (Liquid Argon Pixels) that addresses this problem. It replaces the 2D plane of wires with arrays of metallic pixels that can be fabricated on standard electronic circuit boards.

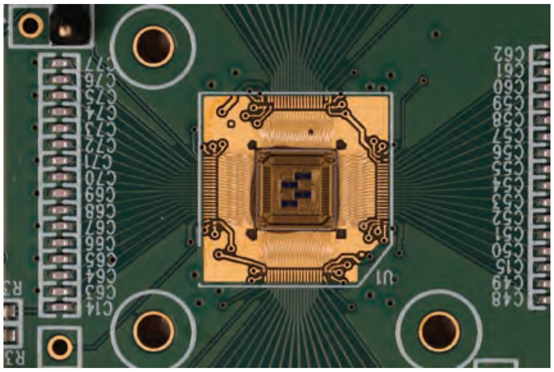


PHOTO: TIMON HEIM

Application specific integrated circuits (or ASICs) form the basis of the new Liquid Argon Pixels (LArPix) pixelated charge readout for the DUNE near detector.

"Dan has really revolutionized pixel readout technology for cryogenic noble liquid applications," Russell reports. "Since LArPix provides a true 3D image of each particle interaction, we'll be better able to cope with the significant signal at the near site."

"LArPix is a totally different detector design," she adds. "We just finished taking data on our largest prototype to date, and we're really excited because the data look fantastic."

"This is a big deal for particle physics," she continues, "and it's really what brought me to Berkeley – to work on LArPix with Kam-Biu and Dan."

Going Beyond Bias Training

Enhanced guidelines & principles benefit the Berkeley Physics community

In a push to provide better transparency on department governance and provide guidance on expectations and goals, Berkeley Physics has pursued numerous initiatives this past year. During retreats and workshops, faculty and staff read and discussed Assistant Dean **Collette Patt**'s May 2018 *Nature* article "Go Beyond Bias Training". Co-authored with two other Berkeley faculty, the article points out how ambiguities in performance goals and expectations can enhance expressions of unconscious bias and how such bias can in turn feed into student underperformance, especially underrepresented minorities. The initiatives described below sprang directly from those discussions.

Graduate Student Goals and Guideposts

Berkeley Physics chair **James Analytis**, head graduate mentor **Holger Müller**, and lead graduate advisor **Joelle Miles** worked with faculty and students to develop a clear map of goals and guideposts for graduate students to follow as they work toward their PhDs. Decisions were made regarding specific academic requirements and how to apply them consistently across all research groups.

"We established a better-articulated curriculum, so that students can assess their progress and experience a feeling of achievement as they cross specific milestones," says Analytis. "For example, each graduate student, at the end of their studies, will have the opportunity to give a sub-department talk in front of the faculty, a symbolic way to welcome them as peers. We also established intermediate milestones, such as written reports and poster presentations, to provide regular markers that enable students to understand their own progress."

Student Liaisons for Faculty Search Committees

In addition, the department updated guidelines for graduate students who are serving as liaisons to faculty search committees, to help solidify their role in the recruitment process. "Too often students feel unclear about how to contribute, or find themselves reinventing the process in the absence of clear instructions." says **Roia Ferrazares**, Director of Administration for Berkeley Physics. "Our aim is to engage students productively and ensure their perspectives and input are taken into account not only in hiring decisions, but also in admissions, instructional delivery, and the management of spaces we occupy as a community."

Community Principles

In November 2020, Berkeley Physics began formulating a set of community principles to guide students, staff, and faculty toward mutual understanding and positive interactions free from bias. "These principles are not a reflection on scientific ethics, reproducibility, objectivity, impartiality, and freedom of thought," says Ferrazares. "Rather, they are a series of aspirational statements reflecting the type of culture and work/study environment we wish to build and sustain. They describe the cultural norms to which we wish to subscribe, and describe the behaviors that contribute to Berkeley Physics remaining a respectful and welcoming space."

The principles encourage community members to honor each individual's identity, remain open to lifelong learning regardless of rank or experience, and follow appropriate avenues provided by the department for reporting concerns.

"We put a lot of thought into how these principles might be applied in everything we do," adds Ferrazares. "In particular, this process has helped us become more aware of improvements needed not only in how we communicate about planning goals and initiatives, but also how we listen to, and allow ourselves to be guided by, input from our community."

Posters and collectable cards describing Community Principles newly adopted by the Berkeley Physics community are displayed in the physics hallways.

Improving Equity & Inclusion for Graduate Students

In 2007, Berkeley Physics professor **Robert Birgeneau** and his wife, Mary Catherine Birgeneau, established a generous endowment devoted to the support of talented physics graduate students. This year the couple revised the purpose of the fund, dedicating it to promoting diversity, equity, and inclusion among graduate students in the department.

This enhancement of the Birgeneaus' initial vision was motivated by several factors, beginning with their realization of the paucity of underrepresented minority (URM) graduate students in the Berkeley Physics Department. "This meant that we have not been taking advantage of a huge reservoir of talented, creative people," says Robert Birgeneau. "We were further inspired by the Black Lives Matter movement and by our students' enthusiasm for the movement's aims."

"Our intention is that this endowed fund will grow significantly in size," he continues, "and that it will provide the department with the dedicated resources needed to identify and attract significant numbers of talented URM graduate students." The Birgeneaus will continue to donate to this fund and they hope that committed faculty, staff, and, where possible, students and their parents, will participate in a meaningful way.

The endowment has been renamed the Physics Graduate Student Equity & Inclusion Fund. Distributions will be directed not only toward the expansion of graduate research and professional development opportunities for underrepresented students. They also will be used to provide stipend support for high-achieving students committed to promoting equity and inclusion in the field of physics.

"I believe that this endowment will help to improve the representation of students of color in Berkeley Physics," says Department Chair **James Analytis**. "It is our hope to harness the enthusiasm and dedication our community has shown toward this effort. We all want to reach for an even better future for this department – a future that welcomes, engages, and supports our entire community, and launches a diverse array of physicists into the field."

Contributions to the Physics Graduate Student Equity & Inclusion Fund are welcome and can be made by visiting give.berkeley.edu/funddrive/209.

Alumni Updates

Harold Zarem (BA 1984) is running Holo Inc., a venture backed startup developing equipment, materials, and processes for additive manufacturing of metal parts. The company has developed a printer that prints parts from a metal-photopolymer slurry, which are then used to create a fully dense, pure metal part. He previously ran a polymer battery company called Seeo, which spun out of UC Berkeley, and a spatial light modulator company, Silicon Light Machines.

Steven R. Wilkinson (BA 1988) leads the Raytheon Technologies collaboration with the National Radio Astronomy Observatory and the Green Bank Observatory. The group is developing next-generation planetary radar. His team integrated a transmitter into one of the prime focus housings used for experimental testing on the Green Bank Telescope. Experimental results from November 2020 and March 2021 produced the highest resolution Synthetic Aperture Radar images ever taken of the moon from the ground.

Jose Menchero (MA 1991, PhD 1997) works as the head of portfolio analytics research at the Bloomberg San Francisco office. His research focuses on building financial risk models that describe the distribution of portfolio values at some future date, ranging from one day to one year.

Amit Bhattacharyya (BA 1992) works as the Head of Data Science for Vox Media and oversees the use of data and algorithms. He also teaches machine learning in Berkeley's online master's program in Data Science, offered by the UC Berkeley School of Information. Amit lives in the NYC suburbs with his wife and two teenage daughters and can be seen cheering on the Cal football team at non-conference away games.

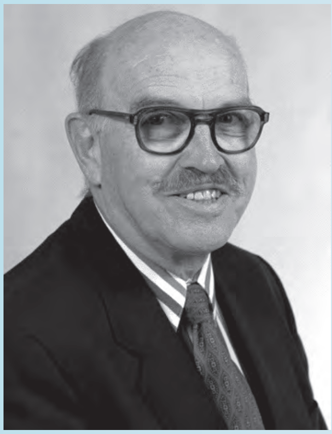
Joshua Miele (BA 1997) received a 2021 MacArthur Foundation Genius Grant to continue his inspiring work of designing accessible technologies for blind people. He is a blind adaptive technology designer and principal accessibility researcher at Amazon Lab126, contributing to effective solutions such as Braille compatibility with Fire tablets and a "Show and Tell" feature on camera-enabled Echo devices.

Jean Zoch (MA 2003) is currently a Data Scientist at Supercell working on games played by tens of millions of players around the world. Previously, he worked at a variety of gaming companies, including Activision, and spent nine years in consumer finance at FICO. As a graduate student researcher, he worked under Daniel Chemla with Chih-Wei Lai on Bose-Einstein condensation of excitons.

In Memory

Steven Weinberg (1933-2021), Nobel laureate and former Berkeley Physics faculty member, passed away July 23. He taught at Berkeley from 1960-1966, then moved on to teach at Harvard and MIT. Weinberg later became a professor and Jack S. Josey-Welch Foundation Chair in Science at the University of Texas at Austin. In 1979, he won the Nobel Prize in Physics with Abdus Salam and Sheldon Lee Glashow for their contributions to the theory of unified weak and electromagnetic interactions between elementary particles.

Weinberg was also a gifted spokesman and wrote several books, including "The First Three Minutes: A Modern View of the Origin of the Universe" (1977). Among his honors is a Special Breakthrough Prize in Fundamental Physics, awarded in 2020 for his leadership and contributions across particle physics, gravity, and cosmology. The prize includes a $3 million award.



Merlon L. "Lynn" Stevenson (1923-2021), a gifted experimental physicist, teacher, and administrator, died April 10. As one of two founding members of Luis Alvarez's research group at UC's Radiation Lab, Stevenson's career spanned much of Berkeley Lab's particle-physics history. In an era when data consisted of bubble-chamber tracks on film scanned by humans, traced on millimeter paper, and reconstructed using mechanical calculators, he contributed ideas and methods for analyzing those data. He initiated and contributed to many of Berkeley Lab's particle-physics projects over more than four decades. A dedicated teacher, Stevenson approached everything he undertook with tremendous enthusiasm and his sheer love of doing physics.

2021 Berkeley Physics

Students and Faculty At A Glance

Undergraduate Physics Majors

307 Total # of students

♂ 220 | 84 ♀ | 3 prefer not to say

130 BAs Awarded 2020-21

99 Transfer Students

Graduate Physics Majors

Total # of students 282

♂ 215 | 64 ♀ | 3 prefer not to say

38 PhDs Awarded 2020-21

29 Countries Students Are From

Physics Faculty

65 Active Faculty

33 Emeritus Faculty

23 Members of the National Academy

10 Physics Faculty Nobel Laureates

4 Active Nobel Laureates

1. George Smoot (Physics 2006)
2. Saul Perlmutter (Physics 2011)
3. Eric Betzig (Chemistry 2014)
4. Reinhard Genzel (Physics 2020)

Berkeley Physics Alumni Nobel Prize Winners

1955: Willis Lamb (BS '34, PhD '38)
1997: Steven Chu (PhD '76)
1998: Robert Laughlin (BA '72)
2000 in Chemistry: Alan J. Heeger (PhD '61)
2004: David Gross (PhD '66)
2006: John C. Mather (PhD '74)
2011: Saul Perlmutter (PhD '86)
2012: David J. Wineland (BA '65)
2017: Barry C. Barish (BA '57, PhD '62)

Berkeley Physics

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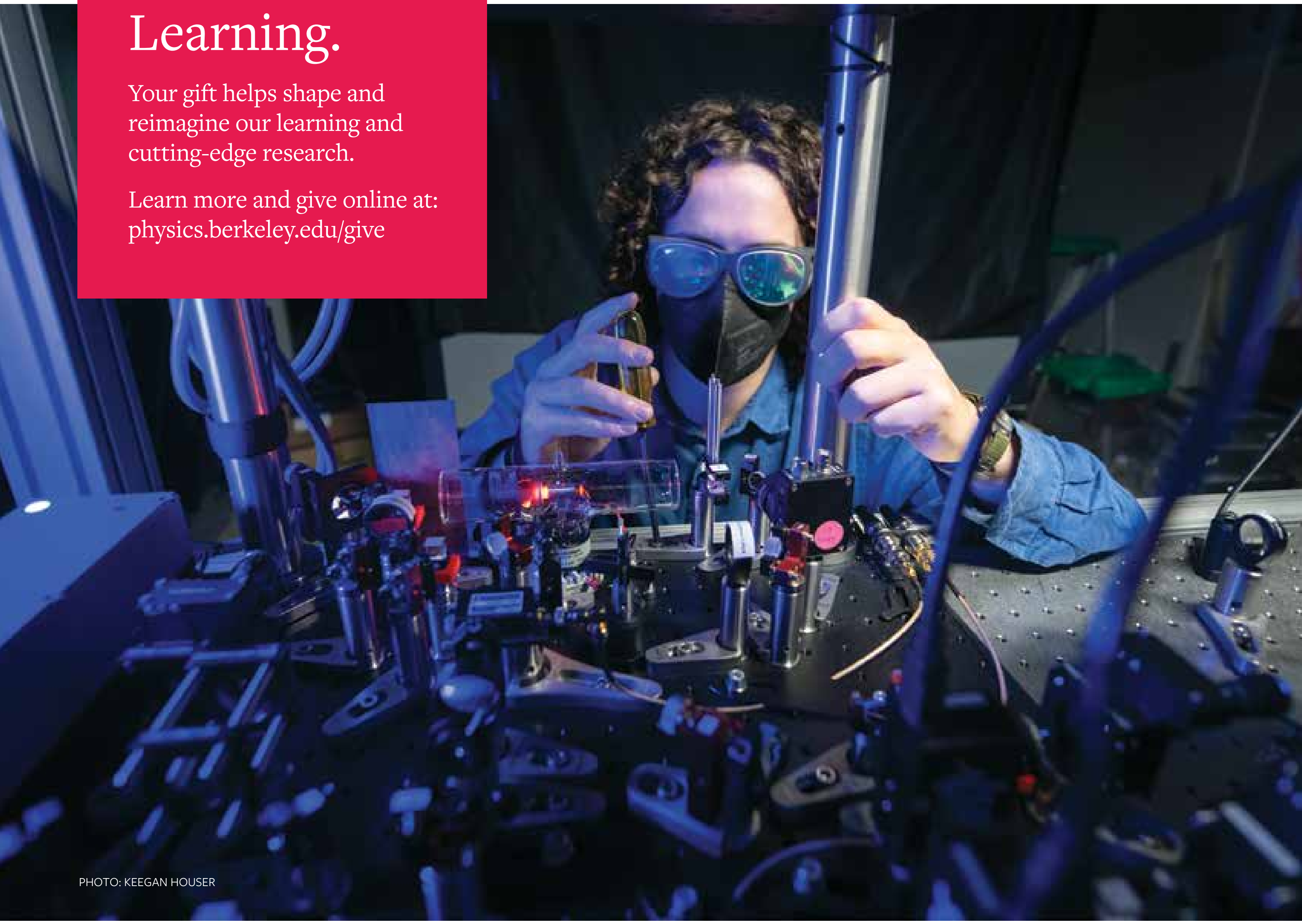

PHOTO: KEEGAN HOUSER

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