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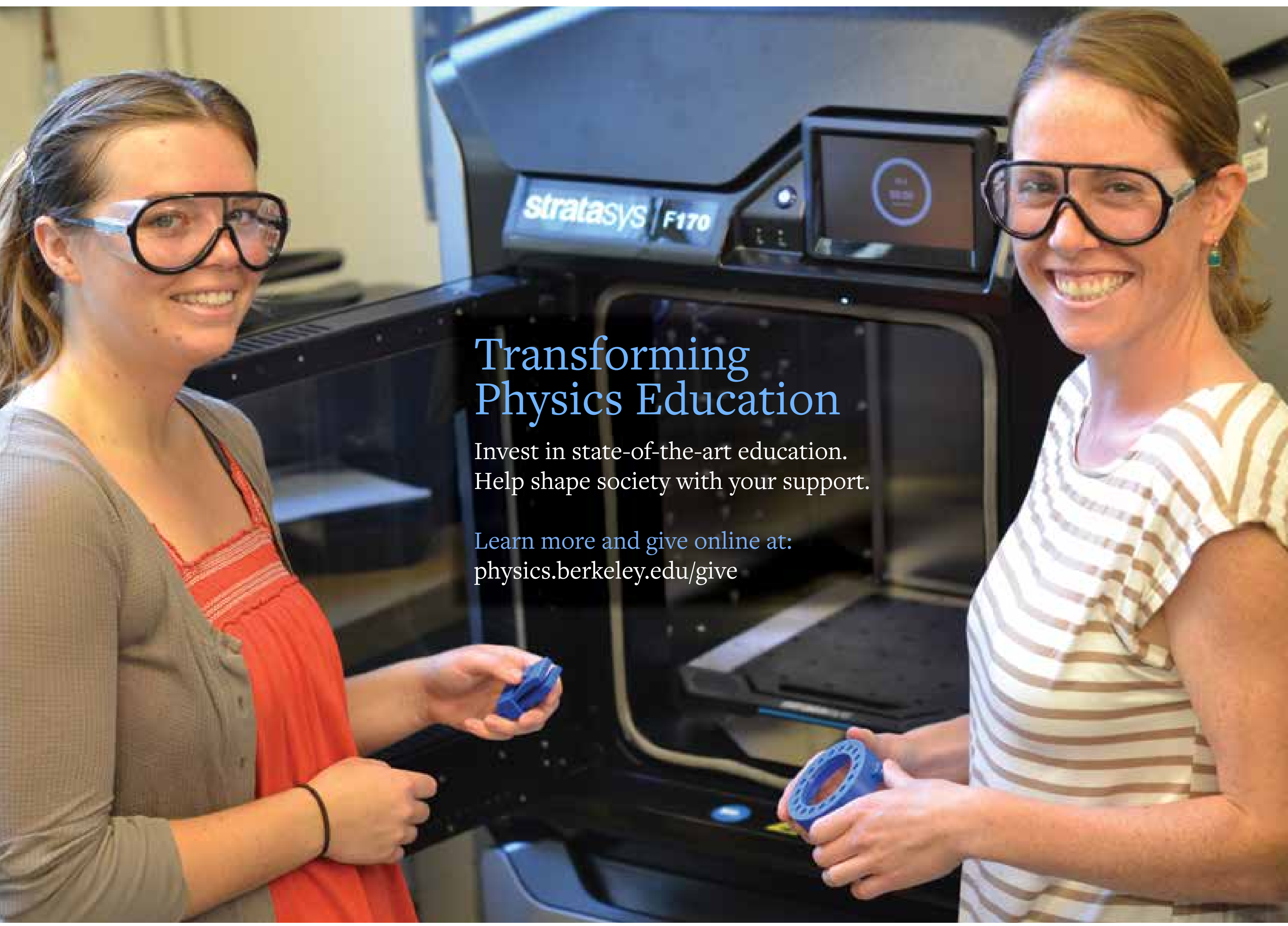
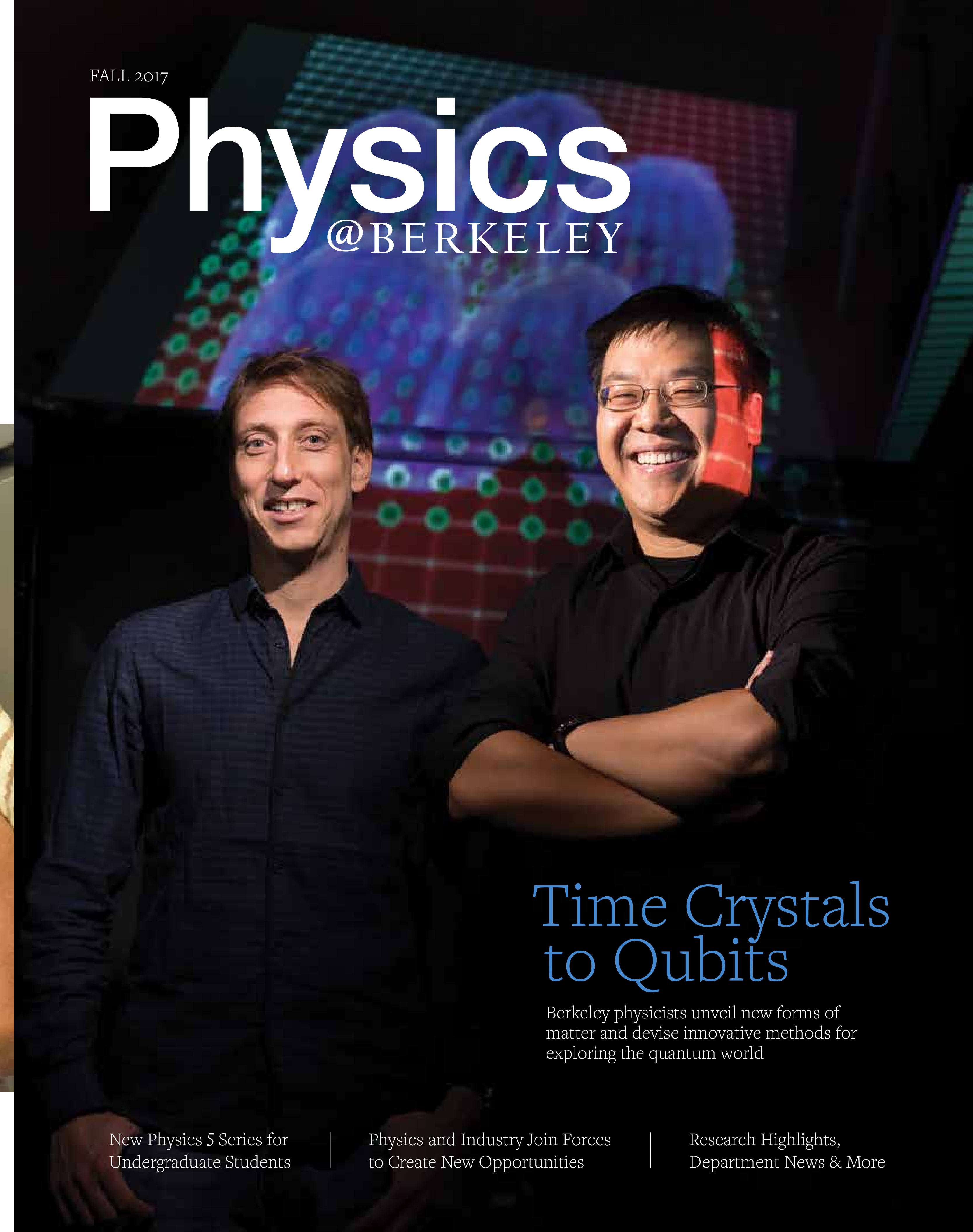


Physics @BERKELEY



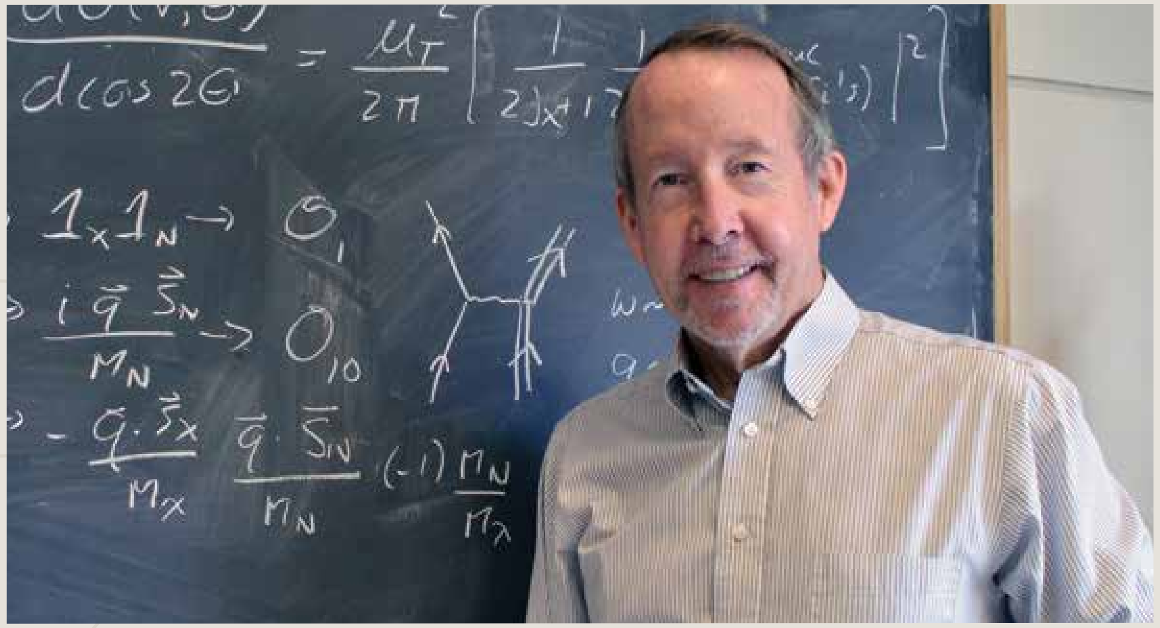


PHOTO: SARAH WITTMER

I very recently assumed the job of Physics Chair, taking over from Joel Moore, who generously served as interim Chair last year, and Steve Boggs, who ably guided our department before Joel. I am honored to follow them, and will do my best to live up to their high standards.

We are experiencing interesting times at Berkeley. Our new leaders, Chancellor Carol Christ and Executive Vice Chancellor and Provost Paul Alivisatos, face challenges ranging from free speech and student safety to budget deficits and insufficient student housing. Against this background, Physics continues to attract the finest students and most able young faculty. Two recent rankings define Berkeley's distinctive role. The 2017 Academic Ranking of World Universities placed Berkeley Physics second. In the New York Times 2017 College Access Index, which measures the graduation rate and support provided to lower income students, UC campuses remarkably hold six of the top ten places.

State of the Department: Berkeley Physics has advanced several initiatives during the past year. This spring, in support of a university-wide effort to strengthen the undergraduate experience, we launched the new Physics 5 laboratory series. Inspired by Physics 111, our capstone Advanced Lab course for juniors and seniors, Physics 5 brings freshman and sophomore physics majors the opportunity for hands-on design, construction, and operation of challenging experiments.

Another new course created this year, Physics 198, encourages continuing students to consider completing their education at a UC campus. This course is designed to help ensure the success of transfer students. We are very grateful to Claudia Trujillo, Amanda Dillon, and Jonathan Wurtele for designing and launching this program.

Many of our students, on completing their degrees, decide to use their physics backgrounds in the science-driven high-tech industrial world. We launched the Berkeley Physics Partners (BP^2) program to strengthen career development opportunities for students and create new research and innovation connections between our researchers and industry partners. We are very grateful to Rachel Schafer for helping us create this much-needed program.

Future Needs and Opportunities: Physics is housed in the historical core of our campus. Doing cutting-age science in buildings constructed in a different age can pose challenges. Recent modernization of our facilities, helped by state, foundation, and private support, includes the opening of Campbell Hall, new lab space focused on quantum-world challenges, repair of Old Le Conte masonry, and improvements in our machine shops. A great deal of work remains, particularly in updating instructional labs and shops, to accommodate our growing student population and research portfolio.

Our good fortune in attracting extraordinary young faculty continues, helped by generous donors who created "junior chairs" to aid our recruiting. New endowments and other private contributions will be essential to keep us competitive with private universities over the next decade.

I hope you enjoy reading the following descriptions of our Department's new efforts in research and instruction. I encourage you to contact us if you have any thoughts.

— Wick Haxton, Chair

Physics @BERKELEY

ON THE COVER: Berkeley theoretical physicists Ehud Altman (L) and Norman Yao. Behind them is a projection of an optical lattice—overlapping laser beams that can be used to control a quantum system.

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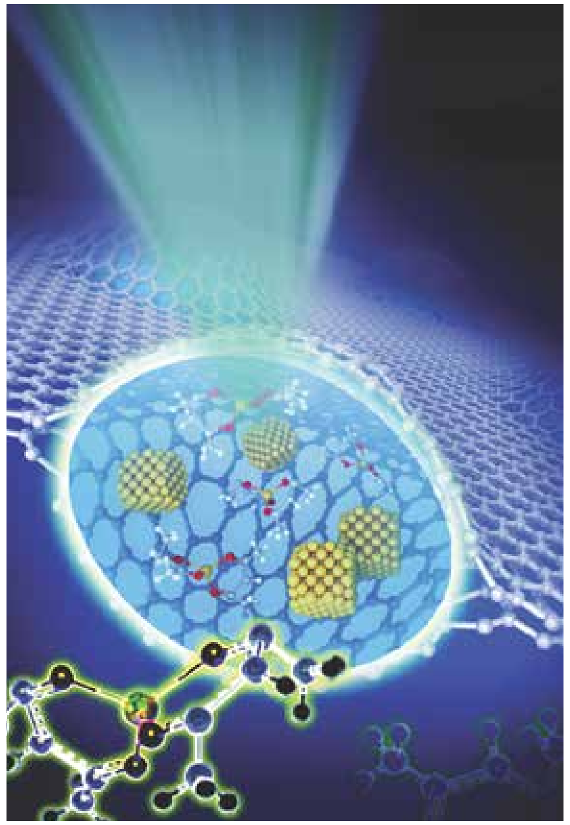
Research Highlights



COURTESY ZETTL RESEARCH GROUP, UNIVERSITY OF CALIFORNIA, LBNL

In a graphene liquid cell, opposing graphene sheets form a sealed nanoscale chamber that is transparent to an electron microscope beam. GLCs allow images of nanoscale events, such as chemical reactions, to be captured in real time at atomic resolution.

GRAPHENE LIQUID CELLS REVOLUTIONIZE ELECTRON MICROSCOPY

A technique developed in the research labs of Berkeley physicist **Alex Zettl** is enabling scientists to make unprecedented atomic-scale observations of physical, chemical, and biological processes that take place in liquids. The graphene liquid cell (GLC) technique uses single layers of graphene—the thinnest possible material, at one atom thick—to encapsulate liquid samples in a way that allows them to be viewed with transmission electron microscopes (TEMs).

The resolution of TEMs far exceeds that of optical microscopes. In place of light, TEMs use beams of electrons to "see" objects and movement at the nanoscale. But they typically can operate only in ultra-high vacuum conditions that cause liquids to evaporate, making it challenging to observe chemical reactions and other phenomena that occur in liquids. The GLC technique overcomes this problem by creating a tiny hermetically sealed liquid cell that takes advantage of graphene's high mechanical strength and transparency to electrons.

Zettl credits former graduate student Jon Min Yuk with the invention of the GLC.

STROBE ENHANCES REAL-TIME IMAGING TECHNOLOGY

UC Berkeley is helping to lead the National Science Foundation's new Science and Technology Center on Real-Time Functional Imaging (STROBE), which aims to tackle major scientific challenges by improving imaging technology. Potential applications of STROBE's research include development of batteries for renewable energy, artificial processes of photosynthesis, and low-power computing technologies.

"Our goal is to make it possible to see the atomic or molecular details and motions of complex and difficult-to-characterize materials that change in time," said **Naomi Ginsberg**, associate professor of chemistry and physics. She leads UC Berkeley's involvement in the network of STROBE scientists. "These materials range from biological to plastics, glasses, and materials used in electronics."

For example, an imaging system developed by Ginsberg's research group provides high resolution movies of samples in challenging liquid environments. CLAIRE—Cathodoluminescence-Activated Imaging by Resonant Energy transfer— combines the fast frame rates and nanoscale resolution of electron microscopy with the non-damaging properties of light microscopy so that even the tiniest biological samples can be imaged as they evolve in time. CLAIRE is also a valuable tool for resolving nanoscale instabilities in next-generation solar cell materials.

Physics and chemistry professor Naomi Ginsberg heads UC Berkeley's involvement in the new NSF Science and Technology Center on Real-Time Functional Imaging.

PHOTO: BERKELEY LAB/KELLY OWEN

PHOTO: POLARBEAR COLLABORATION

The POLARBEAR Telescope, built by a UC Berkeley collaboration led by physics professor Adrian Lee, is one of the telescopes included in the Simons Observatory in Chile.

NEW TELESCOPES TO PROBE THE EARLY UNIVERSE

The Simons Foundation has brought together research groups from UC Berkeley and several other institutions to create the Simons Observatory—an ambitious effort to look back in time to the very beginning of the universe.

The new observatory will study how the universe began, what it is made of, and how it evolved to its current state. It will detect and analyze B-mode polarization patterns in Cosmic Microwave Background (CMB) radiation. Patterns in the CMB arose in the early moments after the Big Bang and the density fluctuations associated with these patterns are thought to have evolved into the stars and galaxies we observe today.

The site for the new observatory, the Atacama Desert in Northern Chile, already hosts some of the highest-altitude telescopes in the world, including the Simons Array, a group of telescopes developed by Berkeley physics professor **Adrian Lee** and colleagues. The first of these, POLARBEAR, began searching for B-mode patterns in 2012.

Lee and his group are playing a leading role in design and construction of the new Simons Observatory by adding components to the Simons Array—a six-meter telescope, several 0.5 meter telescopes, and new cameras with state-of-the-art detector arrays. A documentary film about the observatory can be viewed at simonsfoundation.org.

CAGE SYSTEM VISUALIZES ELECTRICAL SIGNALING IN LIVING CELLS

Berkeley physicist **Feng Wang** and colleagues have developed a new graphene-based imaging system that can map tiny electric fields. Researchers anticipate the new method will allow for extensive and precise imaging of the electrical signaling networks in our hearts and brains.

The new imaging platform is called CAGE—Critically coupled waveguide-Amplified Graphene Electric field imaging device. The device simultaneously converts electrical signals from biological systems to optical signals that are sensitive to voltages of a few microvolts (millionths or hundred-millionths of a volt), all without perturbing the cells through chemical or genetic modifications.

"In collaboration with Stanford we have been able to use the system to see the action potential generated by the beating of heart cells," Wang said. "We are pushing further to see if this is sensitive enough to detect an action potential distribution. The ultimate goal is to detect action potential in neurons, in brain cells, to understand better how neurons communicate and how the brain works."

CAGE is sensitive enough to image the electrical signals of living cells.

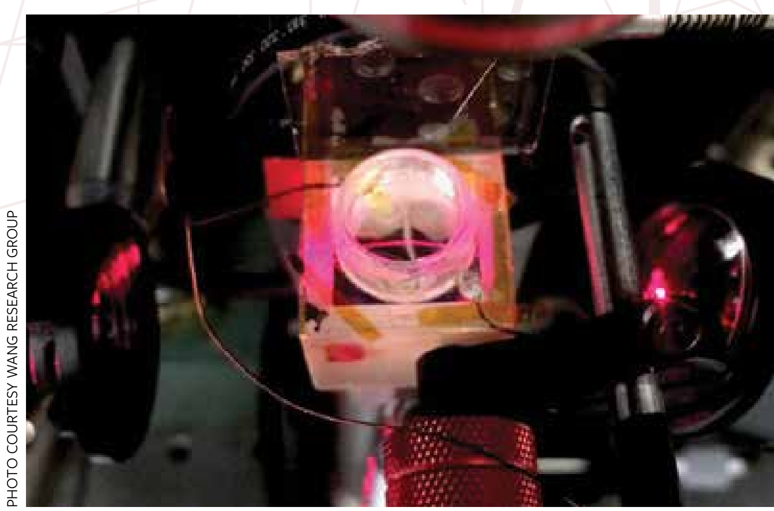


PHOTO COURTESY WANG RESEARCH GROUP

Time Crystals to Qubits

Berkeley physicists unveil new forms of matter and devise innovative methods for exploring the quantum world

PHOTOS BY NOAH BERGER

Berkeley physicist Norman Yao (R) in his lab, working on a diamond crystal with grad students Bihui Zhu (L) and Sacher Hsieh (center).

The world of quantum mechanics—matter at the scale of atoms and subatomic particles—is filled with seemingly implausible phenomena. A single particle can exist in several places at once or travel at different speeds simultaneously. Collections of particles can become so closely entangled that a change to one immediately changes the others. Particles can actively overcome energy barriers that exceed the total energy of the particles themselves.

Quantum dynamics refers to the behavior and evolution of many-body quantum systems—collections of quantum particles—over time. It's the quantum version of classical dynamics, and studying it presents quite a challenge. Quantum properties change or even disappear as a many-body system evolves, especially when observations or measurements are attempted.

Recent advances in theory and experiment are making it possible to overcome some of these challenges. Physicists are finding ways to manipulate quantum systems while preserving their quantum properties. New details are emerging, including how and under what circumstances a quantum system loses information or crosses over into classical dynamics.

Finding new ways to explore and control quantum phenomena is a goal shared by many Berkeley physics faculty, including theoretical physicists **Ehud Altman** and **Norman Yao**, They joined the physics faculty in the summer of 2016, bringing with them advanced expertise in atomic physics, condensed matter physics, statistical mechanics, and quantum information science.

Their efforts have helped unveil concrete examples of new forms of matter, reveal new details about how quantum systems evolve, and point to methods for extending the lifetime of quantum information, thus smoothing the road toward quantum computers.

BRIDGING THEORY AND EXPERIMENT

Altman and Yao both work closely with experimentalists who use ultra-cold atomic systems to investigate quantum phenomena. Since the 1990s, thanks to innovative experimental setups like those developed by Berkeley physics professors Dan Stamper-Kurn, Irfan Siddiqi, Holger Müller, Hartmut Häffner, and Dima Budker, physicists are increasingly able to isolate and control collections of atoms and ions.

Using beams of laser light, experimentalists are able to trap groups of particles, cool them to nearly absolute zero, and manipulate and measure them. These optical setups can effectively isolate a quantum system from the surrounding environment, enabling the exploration of intrinsic quantum behavior in very precise ways. And it's all done within the scope of a tabletop apparatus operated by a handful of researchers.

"Berkeley has a tremendously strong history in the development of these experiments, which have now really come to maturity," Yao notes. "I'd say ultra-cold atoms, molecules, and ions are truly the most well-isolated systems in the universe."

Altman agrees. "You're not taking a sample from a solid, which is very strongly coupled to the outside world," he says. "You're creating isolated collections of particles that are essentially alone in their own world and investigating them before they collapse into a classical state due to unwanted external influence. This allows us to do very controlled experiments and explore fundamental questions on the borders of statistical physics, atomic physics, and condensed matter physics."

NON-EQUILIBRIUM SYSTEMS

Altman continues, "If you take a collection of particles and let them interact freely with each other, given enough time they will usually thermalize, or attain thermal equilibrium, by exploring all the possible arrangements that can take place. This mixing process scrambles the relationships among the quantum particles in ways that render detailed original conditions irretrievable."

For all practical purposes, information initially stored in the system is lost. This loss of information has major consequences in current attempts to develop quantum computers and quantum information systems.

Experiments that isolate quantum systems enable theorists to test their ideas about whether and how a given quantum system moves toward equilibrium, to look for new properties that emerge from non-equilibrium states, and even to gain new insights about the fundamentals of quantum mechanics.

Yao points out that strong disorder in a quantum system can sidestep the march toward equilibrium and the scrambling of information. "We call this many-body localization," he says. "It means that different regions of a system are so unlike one another that they cannot reach equilibrium. It turns out that these highly disordered, non-equilibrium systems can both sustain interesting quantum dynamics over long time periods and lead to totally new types of quantum matter." In these systems, the push toward equilibrium driven by interactions among particles is curbed by disorder, slowing down the scrambling of quantum information.

PRESERVING QUANTUM INFORMATION

Altman is a world-renowned pioneer of theories on the quantum dynamics of correlations and information in many-body localized systems. He has made key contributions to research on high-temperature superconductivity and quantum magnetism as well as theoretical condensed matter physics.

Altman leads the theory component of an international collaboration that is already developing methods for preserving quantum information over long time frames. His research team explores methods of measuring particle-to-particle correlations that occur as many-body quantum systems evolve.

"In everyday life," he notes, "if you put sugar in your tea, it mixes, and you can measure an average quantity to show that the tea is sweeter. But you can't measure what happens with every particle."

"The scrambling of information that takes place as a quantum system moves toward equilibrium is effectively irreversible," Altman explains. "The initial information still exists, but when you let the system evolve, all the correlations among particles that account for this initial information are mixed over the entire sample in a very complicated way that you can never retrieve. While most systems we know behave in this way, recent breakthroughs in atomic physics have allowed us to produce systems that do not equilibrate even over infinite time periods."

For example, in 2015, in collaboration with colleagues in Europe and Israel, Altman developed a method to analyze the correlations between particles in a quantum system undergoing time evolution. For the experiment, a collection of many thousands of ultra-cold potassium 40 atoms were trapped in an optical lattice, a kind of artificial crystal of light created with overlapping laser beams. The lattice enabled researchers to precisely control interactions among the particles and regulate disorder within the system. Conditions of strong disorder prevented the onset of thermalization that otherwise would have destroyed any record of the system's initial conditions.

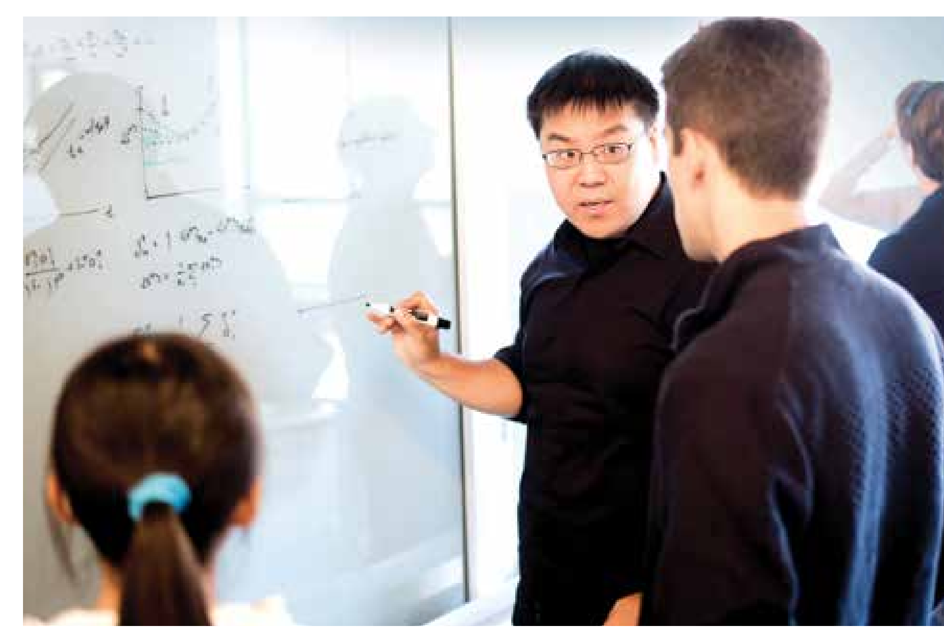
> The transition between a system that goes to thermal equilibrium and one that doesn't is fascinating, because it represents a sharp boundary between a quantum world and a classical world.

Altman and his team of theorists performed calculations and computer simulations to predict how the dynamics of the system is affected by changing the interactions between particles and the strength of disorder. In particular, they explored how the transition from thermalization to many-body localization can be tuned by changing these experimental parameters and how such a transition would be observed in the experiment.

"The transition between a system that goes to thermal equilibrium and one that doesn't is fascinating," Altman says, "because it represents a sharp boundary between a quantum world and a classical

Professor Ehud Altman (L) is a world-renowned pioneer in the exploration of quantum theory. He joined the Berkeley Physics faculty in 2016.

Assistant Professor Norman Yao (center) is a theoretical physicist who works with experimentalists to create new types of quantum matter.



world. In a thermalizing system all quantum correlations between the particles are rapidly lost and the system behaves like an everyday classical fluid, while in a many-body localized system quantum effects can be observed and persist essentially forever."

QUANTUM THERMALIZATION

Altman continues. "And even if a system thermalizes, there is a lot of richness in the different ways it can eventually reach equilibrium. Some systems scramble information quickly, and some scramble it slowly." In fact, string theorists have determined the maximum rate at which quantum thermalization can occur. "Thermalization in quantum systems has a dual description in terms of quantum gravity," Altman asserts. "If you think of black holes as quantum objects, then the information falling into them is scrambling at the fastest possible rate."

These days, Altman and his colleagues are working toward a systematic, computational approach to quantum dynamics. "The dynamics I talk about is the dynamics of creating entanglement between more and more atoms," he says. "What is the structure of entanglement that is generated as the system moves toward equilibrium? One of my goals is to develop an approach that keeps track of crucial correlations among particles while treating non-crucial correlations in a more average way."

"Focusing on how entanglement is generated in many-body systems and establishing connections between this process and the emergence of black holes in quantum gravity has led to recent breakthroughs in our general understanding of quantum dynamics'" Altman explains.

New ideas from his research group have already proved successful in classifying quantum many-body systems based on new dynamical principles. Such advances might even help in developing qubits for quantum computing. "The next stage is to apply these ideas to interesting physical scenarios and test them experimentally," he adds.

QUBITS AND QUANTUM SIMULATION

The harnessing of quantum dynamics has dramatic implications for advances in a broad array of scientific pursuits, from quantum information processing to condensed matter physics, sensor technology, and materials science.

As Yao puts it, "These new approaches toward stabilizing and understanding non-equilibrium phases of matter also imply new possibilities for designing quantum bits. Rather than needing ultra low temperatures or ultra high vacuums, stable quantum bits could emerge at the edge of "hot" non-equilibrium matter. One can also think about leveraging these approaches to develop more sensitive metrology devices. It's really a very exciting and fruitful time to be studying quantum dynamics."

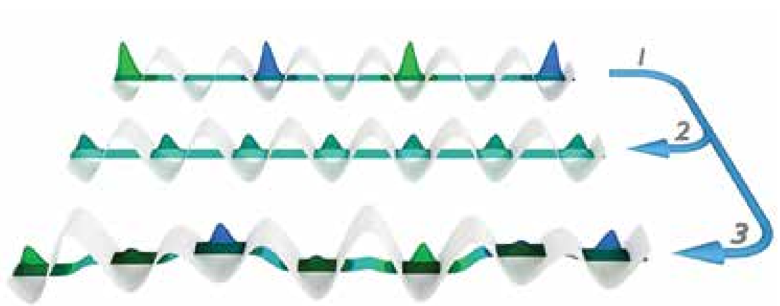


Diagram of a quantum system of potassium atoms trapped in an optical lattice. A density ripple imprinted in the system's initial state (1) is lost (2) as particle-particle interactions move the system toward thermal equilibrium. In the presence of strong disorder (3), created by trapping the atoms, the system was prevented from moving into equilibrium. As a result, information about the initial density ripple persisted. (UQUAM) Graphic: Michael Schreiber, LMU

Ehud Altman works with a student at the white board in the Cohen Interaction Center, Birge Hall.

"It's like playing with a jump rope. Somehow your arm goes around twice but the rope goes around only once."

Time Crystals:
A New Form of Matter

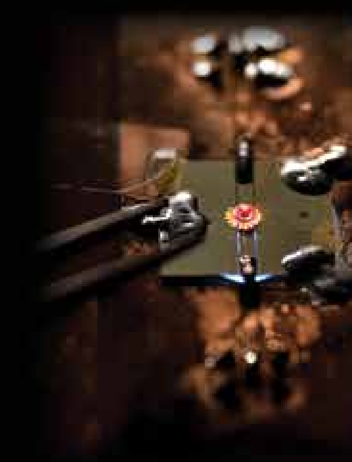
Assistant Professor Norman Yao and his colleagues made headlines early this year for their involvement in the creation of time crystals—one of the first concrete examples of a new phase of non-equilibrium matter. Time crystals are quantum-scale structures that move or pulse in a repeating pattern. Yao's group developed a blueprint that enabled two teams of experimentalists, using completely different experimental setups, to create and observe time crystals for the first time.

"Time crystals are not only a new phase," Yao explains. "They represent one of the first examples of an intrinsically out-of-equilibrium phase of matter. One simply can't find an analog for it in traditional statistical mechanics. You can't say it's 'similar' or 'like' another more common phase, such as a magnet or a superconductor or a metal or an insulator. For the last half-century we have been exploring equilibrium matter. Now, the doors are starting to open toward the exploration of a whole new landscape of non-equilibrium matter."

A team of experimentalists from the University of Maryland used the Yao group's blueprint to turn a chain of ultra-cold ytterbium ions into a time crystal. They targeted the chain with alternating pulses from two lasers. The first laser flipped the spins of the ions. The second laser caused the spins to strongly interact with each other.

Rhythmic repetition of the alternating laser pulses caused the ions to oscillate in a stable, repetitive pattern of spin flipping, but at twice the periodicity of the laser pulses. This characteristic is a hallmark of a time crystal—time translation symmetry is broken because the periodicity of the oscillation differs from the pulse rate of the lasers driving the system. Moreover, once the spin-flip oscillation pattern was set up, it remained rigidly stable even when experimenters made subsequent alterations in the periodicity of the laser pulses.

A separate experiment conducted at Harvard University used Yao's blueprint to create spin-flip oscillations in densely packed nitrogen vacancy defects in diamonds. In this case, the experimenters used microwave pulses to drive the system. The periodicity of the time crystal was again twice that of the microwave pulses.



"It's like playing with a jump rope," Yao said in an article in Nature News. "Somehow your arm goes around twice but the rope goes around only once."

Yao points out that the theoretical idea for a time crystal requires disorder within the system as well as quantum mechanics. He's currently exploring the possibility that time crystals can exist without disorder, perhaps even without quantum mechanics. "The answer might be yes," he says.

Over the summer, renovations in the basement of Birge Hall created a home for the department's Physics 5 laboratory courses. The new Physics 5 series is designed to give lower-division students the strongest possible start to their physics education.

Making a World-Class Education Even Better

PHOTOS BY KEEGAN HOUSER

The New Physics 5 Series for Berkeley Undergraduates

An exciting new course series for undergraduates has been added to Berkeley's already world-class physics program. The Physics 5 series offers freshmen and sophomores expanded opportunities for direct, hands-on experience in designing and conducting experiments, collecting quantitative data, analyzing results, drawing conclusions, and communicating outcomes. It is one more example of the department's efforts to ensure the strongest possible start to every student's academic career.

> "Taking Physics 5BL is like exploring, looking into what I would like to do in research or other career paths."
>
> Lara Osterthe, Physics Undergraduate

Berkeley Physics has long been recognized as one of the most prestigious educational programs in the world, consistently placing in the top handful of academic departments in physics and earning the #1 spot in both 2014 and 2015. Even so, the department recently spent several years exploring ways to better serve undergraduates and make sure they're provided with the knowledge and experience they need to succeed.

Physics professor **Yury Kolomensky** served as faculty lead in designing the new Physics 5 series. He says the primary goal was "to provide potential physics majors with a broad and mathematically rigorous introduction to physics—fundamentals that will best prepare them for advanced topics in the upper division sequence and for research opportunities within and outside of the department."

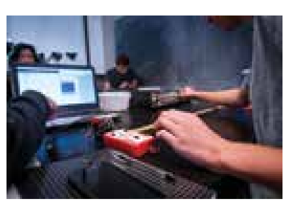
PREPARATION FOR PHYSICS 111

"The focus is on immersive learning," Kolomensky continues, "through a combination of traditional instruction in relatively small classes, interactive discussions, problem solving that teaches students to think like a physicist, and hands-on experimentation. We also wanted to make Physics 5 accessible to a broad cross-section of students, reflective of the diversity of backgrounds and previous educational experiences of the student body at Cal."

Dr. **Amin Jazaeri**, Director of Instructional Support, adds, "We realized that when students got to upper division courses, especially Physics 111, there was so much material they were expected to know but hadn't yet had enough exposure to. We decided to build a bridge with the Physics 5 labs."

Physics 111, also known as the Glaser Advanced Lab, is required of all physics majors. It is a two-semester lab taken during the junior or senior year. Physics 111 is renowned among Berkeley students and alumni as the most challenging yet rewarding physics course they experience as an undergraduate.

MORE TIME IN THE LAB



The new Physics 5 series consists of a three-semester lecture sequence, plus two semesters of laboratory classes that complement the lectures. Students spend five to six hours in the lab each week—a significant increase over previous lower-division offerings.

"The Physics 5 labs teach the students practical skills," notes Kolomensky. "How to make measurements, how to control and interface devices, how to take and analyze data. Besides providing better preparation for Physics 111, these skills are directly applicable to undergraduate research in our faculty labs. Real-life research never involves cookie-cutter recipes. These new labs give the students tools to succeed in a real research environment."

"Physics 5 is giving me a better idea of physics than other labs I've taken," says undergraduate Arani Acharya. "It's a lot more hands-on, a lot more numbers, and much cooler physical phenomena, like creating beats by combining sound waves."

Classmate Lara Osterthe agrees: "There is so much theory in physics, and it's exciting to see it in application. Taking the Physics 5 lab is like exploring, looking into what I would like to do in research or other career paths."

"These labs give students more time to conduct experiments, handle equipment, and collect and analyze data," reports Yi Chen, Graduate Student Instructor. "That's because each lab is a separate course, rather than part of a class that includes both discussion and lab sessions. Students are having fun and at the same time using more of the analytical part of their mind."

RESEARCH AND TEAMWORK

Physics 5 helps lower-division students move toward participation in faculty-led research early in their academic careers. "Students are exposed to many types of equipment that are also used in our research labs," says Jazaeri, "which gives them a better opportunity to join a research group and become actively involved."

> "This curriculum cultivates their analytical skills and makes them better problem solvers, in Physics and beyond."
>
> – Dr. Amin Jazaeri, Director of Instructional Support

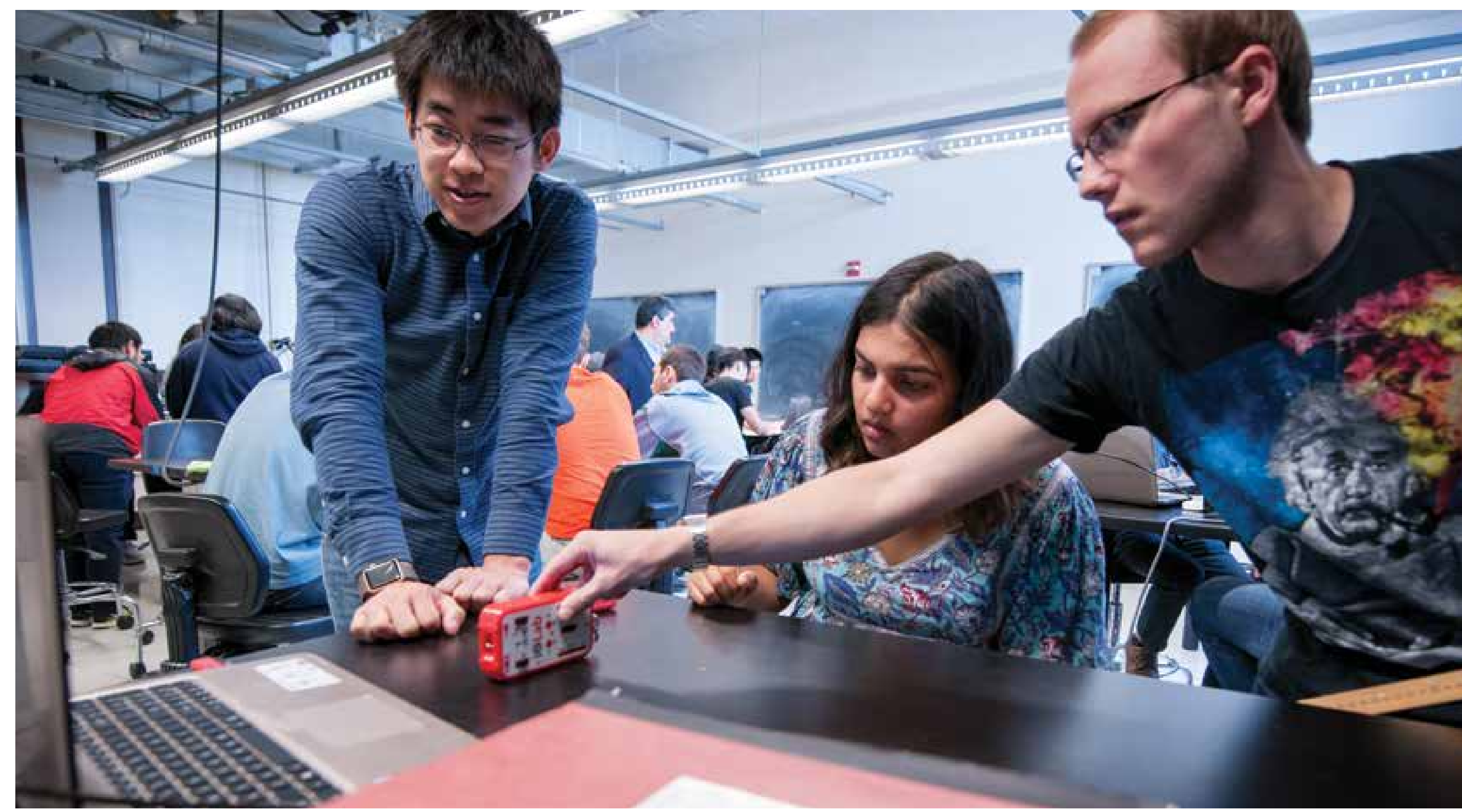
Associate Professor **Feng Wang**, who helped design the lab curriculum, says, "The Physics 5 labs connect students to both modern and historical experiments, and encourage students to be more problem-oriented and think more quantitatively."

Collaboration is an important component of research and a vital aspect of the Physics 5 labs. Students work in teams, sharing responsibilities not only for setting up experiments and collecting and analyzing data, but also for figuring out how to assemble and operate equipment, distinguish signal from noise, estimate errors, and communicate their thoughts and ideas to teammates.

ENHANCING THE UNDERGRADUATE DISCOVERY EXPERIENCE

In addition to Physics 5, and to further increase student exposure to quantitative physics, the department has incorporated two more courses into the lower-division curriculum. Physics 77, Introduction to Computational Techniques in Physics, teaches programming with examples from physics. Physics 89, Introduction to Mathematical Physics, covers a variety of important math topics.

All of these new courses reflect the Berkeley Physics Department's contributions to a campus-wide initiative called the Berkeley Undergraduate Discovery Experience. The initiative aims to increase immersive learning—an educational approach strongly linked to academic success. Across campus, in all fields of study, discovery experiences range from scholarship and research to entrepreneurship and community-oriented activities.



(Upper right) Amin Jazaeri instructs Physics 5 students in the temporary Physics 5 classroom.

(Lower Right) Students are encouraged to work together in small teams to gather and compile data.

(Left) Students use IOLab to measure frequencies of sound over distances and time.

Berkeley Physics At A Glance

Have a look at the students and faculty who make up Berkeley Physics

Undergraduate Students

337 Total # of students

258 | 79

113 BAs Awarded 2016-17

120 Transfer Students

Graduate Students

282 Total # of students

229 | 53

26 PhDs Awarded 2016-17

23 Countries Students Are From

Physics Faculty

63 Active Faculty

37 Emeritus Faculty

Active Nobel Laureates } 3

1. George Smoot (Physics 2006)
2. Saul Perlmutter (Physics 2011)
3. Eric Betzig* (Chemistry 2014)

* Eric Betzig will join UC Berkeley faculty on July 1, 2018

12 Endowed Chairs

19 Members of the National Academy

When Physics & Industry Join Forces, New Opportunities Emerge

Physicists possess the kinds of practical skills and high-level expertise highly coveted by today's private-sector companies—abilities like advanced problem solving, complex data analysis, cutting-edge computing expertise, and the fast and flexible thinking that can help a company adapt to a rapidly changing business environment.

Careers in Industry

Berkeley physics students and alumni often find fulfilling career options in the private sector. Here are a few examples of how skills acquired from their physics education have become a part of the lives of Berkeley alumni who now work in tech and industry.

KATYA SIMPSON (BA 2016) took her skills in programming, model design, and communications to a summer internship with Twitter, then joined the company full time as a Mission Critical Engineer. She points out that actively engaging in discussion sections as a student gave her the proficiency needed to explain her thought processes in mathematical and technical problem solving—an important skill when working as part of a team to deliver results.

JACKIE BROSAMER (PhD 2016) is using her extensive experience in problem solving and data analysis in her position as Data Scientist with Square, Inc., where she applies machine learning to web data and develops algorithms to evaluate credit risk. As a graduate student, she worked on the ATLAS experiment at the Large Hadron Collider.

"At Berkeley, I learned how to think critically about a problem," Brosamer says, "to break it down into smaller pieces, think about which tool might be applicable for different levels of complexity. It's a really practical approach, no matter what kind of problem it is."

YASAMAN BAHRI (PhD 2017) has brought her academic research experience to Google Brain. She completed two Google Brain internships while working on her PhD in theoretical physics, and now holds a post in the Google Brain Residency Program.

"Google Brain is very much an academic team," Bahri explains. "As a member, your task can be to conduct research and publish papers. You don't have to work on a product. That was a major attraction for me. I wanted something that was as close to academic research as possible, yet with the career flexibility that comes with working in industry."

ANDREAS BIRKEDAL (PhD 2003) acquired expertise in data analysis, computer programming, and construction and evaluation of theoretical models during his Berkeley years. "All of these skills have proven valuable in my work," he says, "I use them on a daily basis."

Birkedal is Vice President of Quantitative Research at Two Sigma Investments, a company that employs trading strategies based on artificial intelligence, machine learning, distributed computing, and other advanced methods.

"I design and test models to predict how the world's financial markets will behave," Birkedal explains. "Data analysis is involved in model discovery, testing, and monitoring. And since the amount of data needed to test a model is large, programming is an integral part of data analysis. The respect for scientific rigor and the scientific method that was reinforced during my time at Berkeley is at the heart of Two Sigma's approach to investing."

Eric Copenhaver, Alejandro Ruiz, and Kayleigh Cassella discuss research at a graduate student poster session.

Berkeley Physics Partnership

Two Sigma has joined a new program launched this summer by the Department of Physics that is designed to foster relationships between private-sector companies and Berkeley students and faculty researchers. The Berkeley Physics Partnership (BP²) offers companies a new pathway for recruiting top talent and staying current with cutting-edge research and technology.

"We joined BP² to engage with the distinguished faculty and students of Berkeley's world-class physics department," Birkedal says. "At Two Sigma we value diversity of thought, and our hope is to share new and challenging problems we work on at our company through internships as well as full-time opportunities."

BP² membership enables companies to reach out to students through on-campus recruiting sessions and career development talks, job and internship announcements, and attendance at special events, including student poster sessions. BP² members can also engage directly with research faculty who are working in areas of mutual interest, including spending time in research labs and attending campus-based workshops on the latest advances and important challenges in research and development.

For more information about BP², visit http://physics.berkeley.edu/bp2

PHOTOS: SARAH WITTMER

Tektronix, Inc. and CQCS

The relationship between Tektronix and Berkeley's Center for Quantum Coherent Science (CQCS) exemplifies a BP² partnership. Headquartered in Oregon, Tektronix, Inc. designs and manufactures test and measurement equipment, some of which is central to quantum science experiments under way at CQCS. The company joined BP² this summer.

Irfan Siddiqi, Berkeley physics professor and director of CQCS, explains that Tektronix and similar companies have a high level of interest in developing and supplying equipment needed for quantum physics research and quantum information technologies. "And on the researchers' side," Siddiqi says, "we are always interested in hardware that enables us to access new physical phenomena."

As a BP² member, Tektronix engineers spend time in the lab with CQCS researchers (above). "For the company's engineers," Siddiqi notes, "lab time is useful for learning about specifics, like issues related to measuring qubits or the functionality researchers would like in terms of running fast quantum gates," Siddiqi notes. "The benefit for us at CQCS is to learn how to make the best use of the hardware Tektronix offers."

Siddiqi also points out that BP² members like Tektronix will be invited to participate in periodic CQCS workshops that focus on open questions in quantum science. "Rather than simply showcasing past research," he says, "these workshops would emphasize what's happening now, what are the current issues, what are the interesting questions we're trying to answer."

Valued Attributes of a Physics Education

The physics curriculum at Berkeley develops critical thinking and quantitative reasoning skills that empower students to come up with creative approaches to solving problems. Valuable capabilities that transfer to workplaces in industry and technology include:

QUANTITATIVE DATA ANALYSIS
Expertise in processing large data sets and using appropriate analytical methodologies for reaching sensible conclusions

INSTRUMENTATION
Mastery of electronic instrumentation, advanced laboratory techniques, and the interfacing of computers with experimental apparatus

COMPUTER PROGRAMMING
Advanced software development skills that can be applied to construction of theoretical models, simulations, and other types of innovative new software, as well as enhancing existing software

COMMUNICATION
Proficiency in expressing complex ideas to peers, to cohorts in other fields, and to audiences with little or no technical background

INDEPENDENT DECISION-MAKING AND COLLABORATIVE TEAMWORK
Extensive experience in using analytical and critical thinking to design experiments, solve problems, interpret data, and work as part of a team

ACADEMIC RESEARCH
Experience in pursuing scientific inquiry through investigation and presenting written results for peer-reviewed publication

PHOTO: SARAH WITTMER

Leveraging a Physics Education into a Valuable Business

Marc Bensadoun (above right, PhD 1991) applied his training in experimental physics at Berkeley to the startup of his own company, Newfield Wireless, in 1995. Asked to identify skills acquired at Berkeley that were important to his success, Bensadoun lists several, from general physics knowledge and critical thinking to experience modeling microwave systems, data analysis, computer programming, and team management.

"Newfield was initially founded to help model, plan, and optimize mobile radio access networks," Bensadoun explains. Later, he expanded the firm by developing a Big Data platform capable of tracking millions of mobile devices in near-real time, 24/7, and virtually error free.

"For our single largest installation, we were processing 50 terabytes of data per day from over 100 million devices," he recalls. By 2014, when he sold the company to Tektronix Communications, Newfield boasted a 70-member engineering team headquartered on Telegraph Avenue in Berkeley.

Many of Newfield's software engineers came from a physics background. "Our software was pretty technical and a physics background proved to be a great fit for developing algorithms in geolocation and statistical methods, breaking them, and making them better," Bensadoun notes. " Having people with experience in physics helped create a culture of intellectual rigor and curiosity that made Newfield not only more competitive but also a great place to work."

"When I joined George Smoot's research group at Berkeley Lab in 1986," Bensadoun remembers, "it was part of the larger Luis Alvarez Group. Though retired, Alvarez held Monday Night Meetings at his house that included yet-to-be-reported news of relevance to the group, presented by a grad student. We learned how to come up to speed on a new topic, cold call anyone in the world, and interview them to put a story together. "

Bensadoun credits his Berkeley years with teaching him how to "ask the right questions, listen carefully, and figure out how to do a few important things better. Berkeley taught me how to think critically and how to overcome complex challenges—skills critical to my success."

Physics Career Intern Program

Until recently, most Berkeley Physics students have chosen to pursue graduate degrees after receiving their BAs. These days, however, more and more physics alumni are choosing to pursue careers in industry instead. To address this growing trend, Berkeley Physics has established the Physics Career Intern Program to help students explore career options.

Led by **Claudia Trujillo** and **Amanda Dillon** of Physics Student Services, the Physics Career Intern Program, is part of the overall Physics Undergraduate Career Initiative. "We hold workshops and focus on career-preparedness, including resume critiques, LinkedIn reviews, and alumni discussion panels." Dillon says. "We are hiring student intern mentors, so students will get their peers' perspective for career guidance."

PHOTO: AMANDA DILLON

Justin Joseph (right) and **Michael Sullivan** (left), two student interns hired in the Spring semester of 2017, have helped hit the ground running and set up the basic foundation for the program.

This fall, Joseph is providing information to students who are interested in pursuing a career in engineering. "I got intrigued about this program when I heard that Physics would like to strengthen its outreach for STEM- related careers," he says. Joseph is a junior physics major with plans to either join the industry workforce or pursue a Masters in Engineering. After completing intern training through Berkeley's Career Center this fall, he will hold regular office hours to meet with students for career counseling sessions.

CalDay & Commencement

(Upper left) Professor Steve Louie with graduating PhD student Diana Yuan Qiu.

(Lower left) Thomas Fitzpatrick, Mike Zhang, and Isabel Angelo share a smile on graduation day.

(Upper right) Society of Physics Students demonstrate experiments at the Information Marketplace.

(Lower right) Visitors on CalDay participate in hands-on experiments and faculty lab tours.

PHYSICS AND ASTRONOMY GRADUATES OF 2017

On May 16, 2017, Lower Sproul was bustling with excitement as Physics and Astronomy students waited to head inside Zellerbach Auditorium for their commencement ceremony. Hundreds of guests attended the ceremony with an impressive group of 143 graduates, of which there were 33 PhD's, 5 MA's, and 105 BA's.

Interim Chair of the Physics Department, **Joel Moore**, and Chair of the Astronomy Department, **Eugene Chiang**, led the proceedings. This year there were two student speakers, **Goni Halevi**, who received a BA in Astronomy, and **Unpil Baek**, who received a BA in Physics. Unpil also received the Physics Department Citation. This year's Principal Commencement Speaker was **Professor Lars Bildstein**, Gluck Professor of Theoretical Physics and Director of the Kavli Institute at the University of California at Santa Barbara.

The Lars Commins Memorial Award, given to **Chenhao Jin**, is intended to continue the legacy of experimental physics at Berkeley. It was created in honor of Lars Commins, an engineer and son of the late Berkeley Physics Professor Emeritus Eugene Commins.

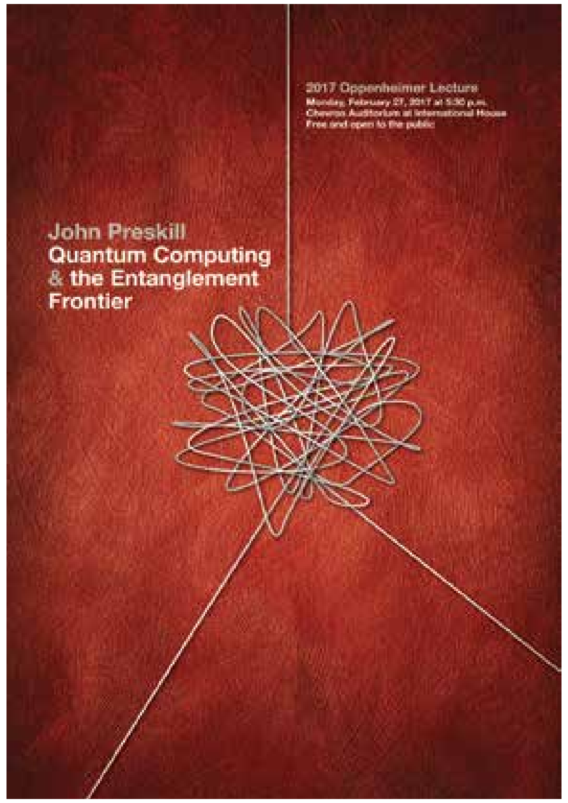
The Jackson C. Koo Award in Condensed Matter was given to **Diana Yuan Qiu**. This annual award was created by Koo's widow, Rose, and intended to recognize the accomplishments of a noteworthy graduate student in condensed matter physics.

CAL DAY 2017

On Saturday, April 22, UC Berkeley welcomed hundreds of visitors to its annual Cal Day event, a day-long open house that offers countless activities and opportunities for guests to explore the Berkeley campus. This year's Cal Day emphasizing the groundbreaking research and innovation being done here at Berkeley Physics, coincided with the March for Science. LeConte Hall was bustling with visitors as the Physics Department hosted numerous lectures, exhibits, and tours.

PHOTOS: SARAH WITTMER

Invited Lectures



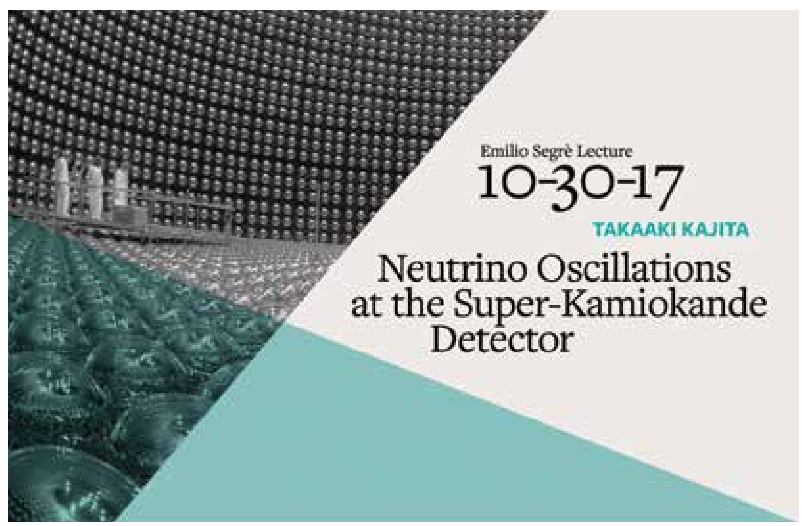
THE 2017 OPPENHEIMER LECTURE
Quantum Computing and the Entanglement Frontier was presented by John Preskill on February 27. Preskill serves as the Richard P. Feynman Professor of Theoretical Physics and Director of the Institute for Quantum Information and Matter at the Caltech.

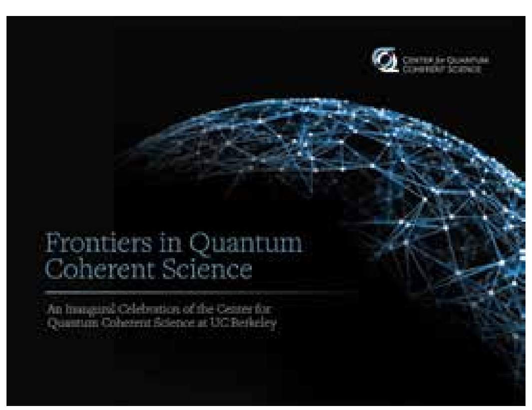
In his talk, Preskill focused on why he loves quantum entanglement, the elusive feature making quantum information fundamentally different from information in the macroscopic world. By exploiting quantum entanglement, he said, quantum computers should be able to solve otherwise intractable problems, with far-reaching applications for cryptology, materials, and fundamental physical science.

THE 2017 EMILIO SEGRE LECTURE
Neutrino Oscillations at the Super-Kamiokande Detector was presented by Takaaki Kajita on October 30. Kajita holds posts as Special University Professor and Director of the Institute for Cosmic Ray Research (ICRR) at the University of Tokyo.

In 2015, Kajita shared the Nobel Prize in Physics for his role in discovering atmospheric neutrino oscillations. Currently, he is project leader for the Kamiokande Gravitational Wave Detector Project, aiming to explore gravitational wave astronomy.

In his talk, Kajita focused on the discovery of neutrino oscillations and the implications of small neutrino masses. He presented an overview of both the current status and the future of neutrino oscillation studies.





FRONTIERS IN QUANTUM COHERENT SCIENCE
This conference, held on campus on January 9, explored the richness, complexity, and practical application of quantum mechanics, quantum states, and quantum systems. UC Berkeley's Center for Quantum Coherent Science organized the conference, pulling together, under one roof, scientists from the subfields of atomic and optical physics, condensed-matter physics, quantum information science, and high-energy and string theory. The gathering not only introduced a broad audience to this rapidly developing field, but also gave academic and industry leaders a chance to voice their opinion on the most promising, near-term quantum technologies.

L'Oreal Fellowship Awarded to Physics Postdoc and Mentor

L'Oreal USA has named **Sydney Schreppler**, a post-doctoral fellow in physics and a Berkeley Physics PhD, as one of five recipients of the company's prestigious 2017 For Women in Science Fellowships. The 29-year-old Schreppler, who builds and tests superconducting qubits for use in quantum computers will receive $60,000 to further her research.

L'Oreal USA grants these fellowships to women scientists who are at a critical stage in their careers, and has been doing so since 1998.

"I am really happy I am able to bring the award to Berkeley, because Berkeley has been very good to me during my PhD and my postdoc," said Schreppler. "There is a reason I stuck around here: I really like the physics department here and I love all the students and staff in the physics department. I am definitely grateful to the campus and the university." Schreppler has served as head coach for the campus' club women's lacrosse team.

In her spare time, Schreppler mentors young women majoring in science. This interest was one of the main reasons she applied for the fellowship: the L'Oréal awards not only honor women's contributions to research, but also promote mentoring. She said, "I want to emphasize my role as a mentor to younger grad students." In support of that aim, she is using some of the L'Oreal funds to hire a female graduate student mentee.

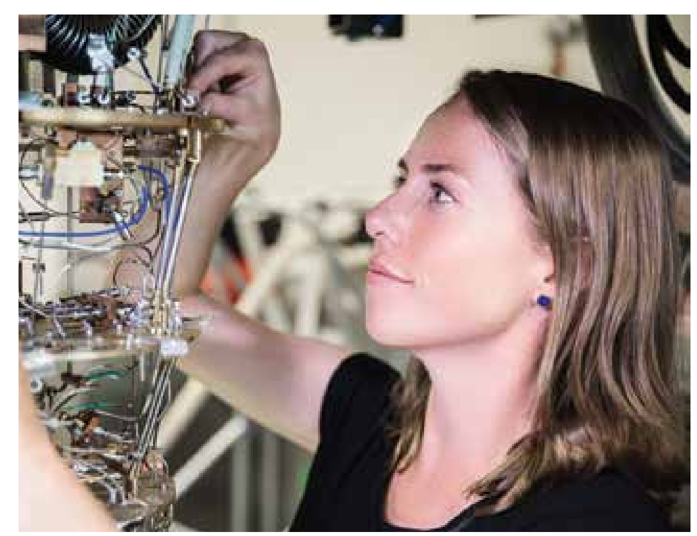


PHOTO COURTESY L'OREAL

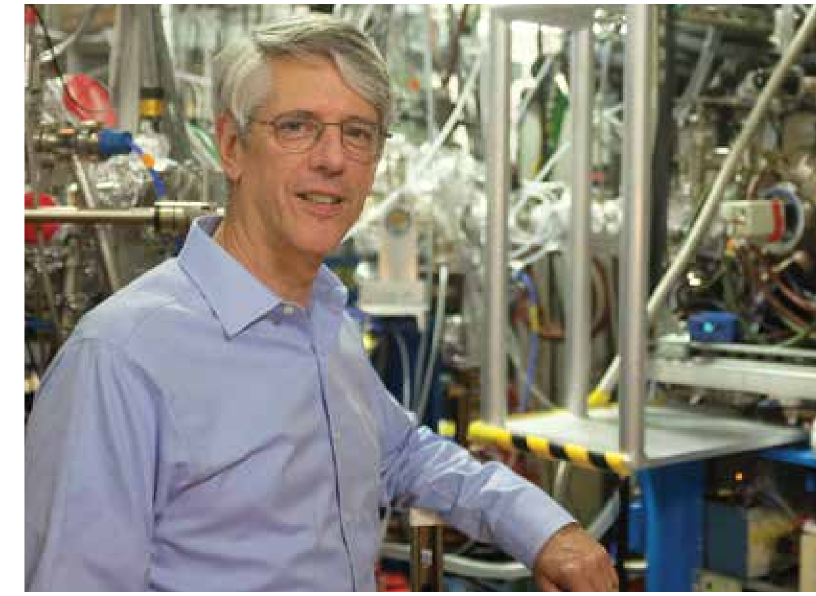


PHOTO COURTESY LBNL

Falcone to Become APS President

Berkeley physics professor **Roger Falcone** will take the post of President of the American Physics Society (APS) in January. He was elected APS Vice President in 2016 and became President-Elect this year.

Falcone served as Director of the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL) for ten years, and is stepping down from that role in January to return to campus and focus on his work with the APS.

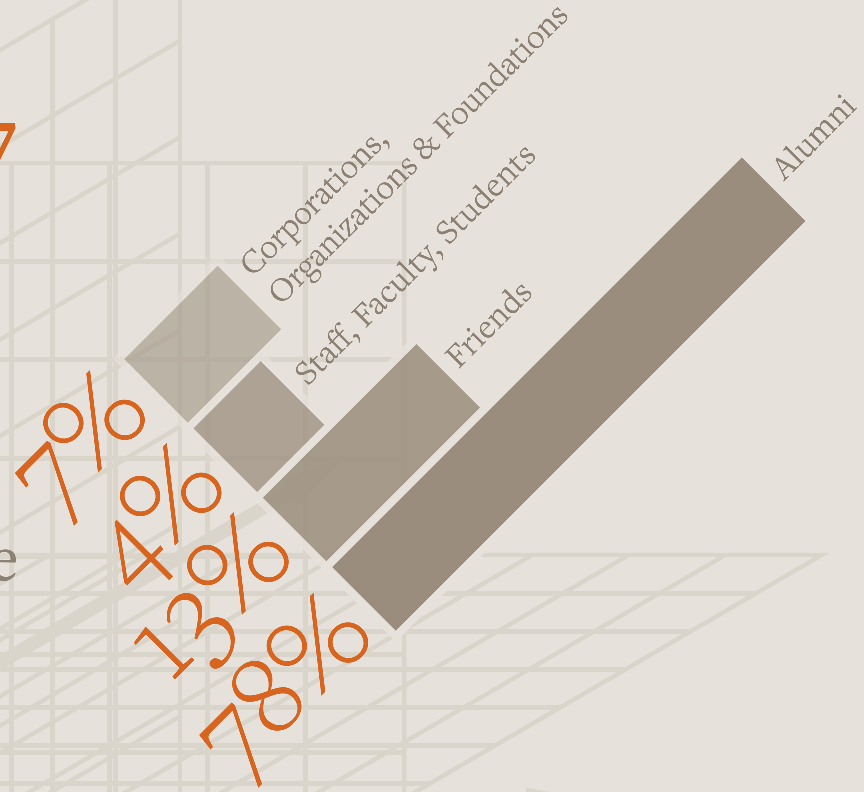
Falcone said, "My role will be to ensure continued success of APS publications, meetings, and outreach. It will also allow me to focus on advocacy in Washington. Uncertainties with the federal budget for future years could result in significantly reduced support for research. I want to strengthen collaborations among scientific societies, as well as with industry, labs, and universities, in reaching out to Congress, government agencies, and influential organizations, and try to maintain our nation's strengths and leadership in science and innovation."

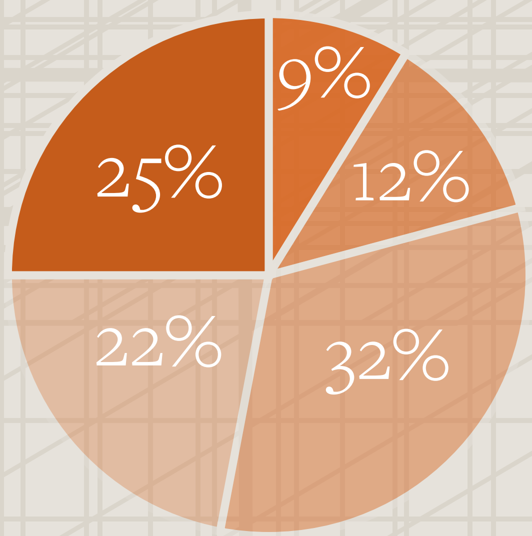
In his research, Falcone uses x-rays to study dynamic phenomena in condensed matter and atomic physics. Ultrafast x-ray pulses, measured in femtoseconds – one millionth of a billionth of a second – can probe the time-scale on which chemical bonds are formed or broken, or materials transition from one structural phase to another. Falcone's research group works at the ALS synchrotron at LBNL, the powerful NIF laser at Lawrence Livermore Lab, and at the LCLS x-ray laser at the SLAC Lab.

Falcone joined the Berkeley physics faculty in 1983, served as Chair of the Physics Department from 1995-2000, and became Director of the ALS in 2006. This year he was elected to the American Academy of Arts and Sciences.

2016-2017 Giving

Our Donors Are



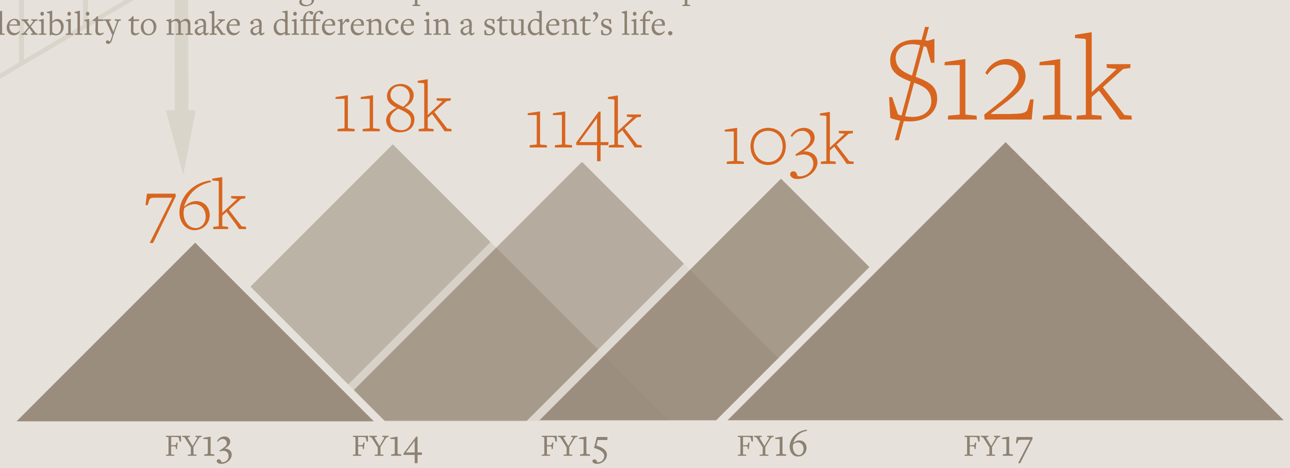


Our Donors Supported

- Faculty Chairs and Funds 25%
- Friends of Physics 9%
- Scholarships/Fellowships 12%
- Program Support 32%
- Research 22%

Friends of Physics Fund

Unrestricted annual fund gives department leadership the flexibility to make a difference in a student's life.



Barish Awarded 2017 Nobel Prize in Physics

Berkeley Physics alumnus **Barry Barish**, (BS '57 and PhD '62) has been awarded the 2017 Nobel Prize in Physics for the detection of gravitational waves, along with fellow Caltech physicist Kip Thorne and MIT physicist Rainer Weiss. Barish is Ronald and Maxine Linde Professor of Physics, Emeritus, at Caltech. He has run many huge physics collaborations during his career, ranging from neutrino experiments at Fermilab to the Superconducting Supercollider, a megaproject that was ultimately cancelled by the federal government.

One of Barish's most successful collaborations was the Laser Interferometer Gravitational-wave Observatory, called LIGO. In 2015 LIGO became the first experiment to detect gravitational waves, phenomena predicted by Albert Einstein more than 100 years ago.

About being chosen for the award, Barish told the New York Times, "It's a combination of being thrilled and humbled at the same time, mixed emotions. This is a team sport, it gets kind of subjective when you have to pick out individuals." LIGO, he said, is very deserving. "We happen to be the individuals chosen by whatever mechanism."

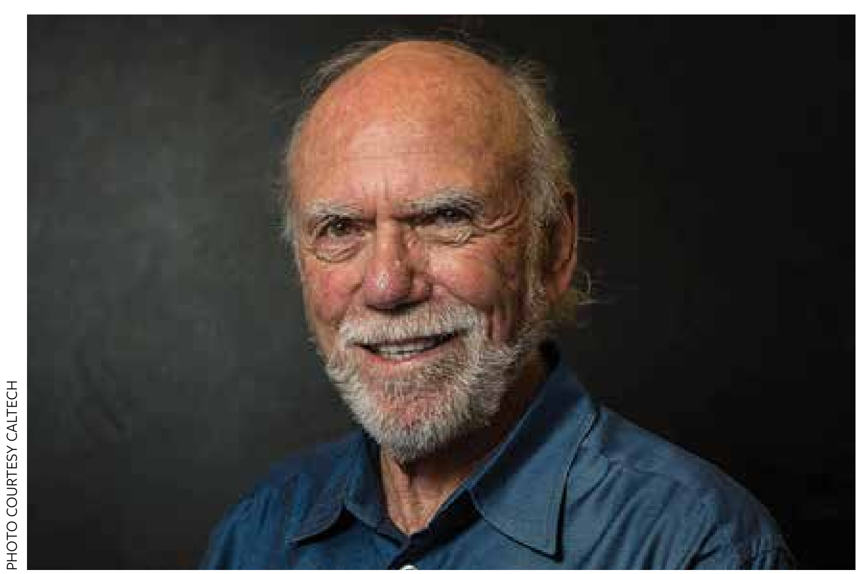


PHOTO COURTESY CALTECH

PHOTO: LINDA A. CICERO / STANFORD NEWS SERVICE

Persis Drell Becomes Stanford Provost

On February 1, **Persis Drell** (PhD '83) became provost at Stanford University. She was formerly Dean of Engineering at Stanford, the first woman to hold that position.

After receiving her PhD in atomic physics in 1983 at UC Berkeley, Drell became a postdoctoral scientist in high-energy experimental physics at Lawrence Berkeley National Laboratory. In 1988 she joined the physics faculty of Cornell University, moving to Stanford in 2002 as professor and director of research at SLAC National Accelerator Laboratory. Drell served as deputy director at SLAC from 2005-2007, then director until 2012. She became Stanford's Dean of Engineering in 2014.

In a press announcement, Drell said, "This is an opportunity to work with ... the entire campus community to advance our education and research and to continue enriching our culture at Stanford. For me, this is about helping our students achieve their potential to lead fulfilling lives and have an impact on the world, supporting our faculty in doing the brilliant research and teaching that also have an impact on the world, and addressing issues important to our community, including moving toward a professoriate that reflects our student body."

Stanford President Marc Tessier-Lavigne said Drell's experience, accomplishments, and values made her a perfect fit for the role of provost, who serves as the chief academic officer and chief budgetary officer for the university and works in close partnership with the president to provide overall leadership for the campus.

Alumni Updates

2010-2017

Sandra "Sandy" Miarecki (MA '10, PhD '16)
After serving as a pilot in the Air Force for 20 years, Sandy Miarecki became an Assistant Professor of Physics at the US Air Force Academy in January of this year. The journal *Nature* recently accepted an article she co-authored and plans to publish her PhD thesis results as well. Miarecki and colleagues succeeded in measuring the neutrino-to-nucleon cross section with up to 2000 times higher precision than previous measurements. Their work is also the first time Earth absorption of neutrinos has been measured. These achievements were made using cosmic rays for measuring neutrinos instead of traditionally-used accelerators.

2000-2009

David Strubbe (MA '07, PhD '12)
Strubbe recently accepted a new position as Assistant Professor of Physics at the University of California, Merced.

1990-1999

Steven E. Boggs (MA '94, PhD '98)
After serving as Chair of the UC Berkeley Physics Department from 2013 to 2016, Steven Boggs became Dean of the Division of Physical Sciences at UC San Diego (UCSD) in January. From 2001 to 2013 he served as Associate Director of the Berkeley Space Sciences Laboratory. Boggs also holds a faculty appointment in UCSD's Department of Physics and Center for Astrophysics and Space Sciences, as well as the Chancellor's Associates Endowed Chair in Physics. His research interests focus on the development of gamma-ray, cosmic-ray, and X-ray instruments to study complex physical processes.

1980-1989

Cynthia Larson (BA '82)
Cynthia Larson is the author of *Quantum Jumps: An Extraordinary Science of Happiness and Prosperity*, published in 2013. The book presents radical new ideas, she says, "namely that we live in an interconnected holographic multiverse where we jump between parallel universes and that we can utilize this reality to live our best lives."

David A. Smith (BA '81)
David Smith served as co-leader of the Fermi group at the Centre d'Etudes Nucleaires (Center of Nuclear Studies) de Bordeaux-Gradignan, France. His main research interest focused on the field of gamma-ray pulsars. He contributed to the discovery of over 200 gamma-ray pulsars and worked to catalog descriptions of the first 117 of those. These contributions were facilitated through use of the Large Area Telescope (LAT) on the Fermi satellite. Smith participates in community outreach lectures each month, typically working with high schools and astronomy clubs.

1970-1979

Wright "Tucker" Hiatt, Jr. (BA '76)
Tucker Hiatt directs the nonprofit Wonderfest, the Bay Area Beacon of Science. Wonderfest's mission is to inspire curiosity and a deep sense of wonder about the world. Wonderfest holds public science gatherings in the SF Bay Area and hosts online discourse and video media. To encourage middle- and high-school students to study physics, Wonderfest created "Physics Meets the Monsters" (PMM), a three-part short, animated video series Hiatt wrote and narrated.

1960-1969

Robert "Bob" Dickinson (BA '63)
Bob Dickinson served as CEO of California Micro Devices for nine years. The company was sold to ON Semiconductor in 2010. In 2011, Dickinson founded Argos Analytics, a company that provides cost-effective climate data services. Projects have included analyses of flood, drought, and heat wave risks as well as the creation of tools for analyzing future energy and drainage requirements.

Farewell

Faculty

Arthur H. "Art" Rosenfeld
Berkeley physics professor emeritus Arthur H. "Art" Rosenfeld passed away on January 27 at the age of 90. Popularly known as "the godfather of energy efficiency," Rosenfeld made numerous contributions to his fields of study, including founding the Center for Building Science at Lawrence Berkeley National Laboratory and cofounding the American Council for an Energy Efficiency Economy (ACEEE). He worked with the California Energy Commission to implement efficiency policies that would ultimately prevent over $75 billion in wasted power-plant investment. Some of Rosenfeld's many awards and recognitions include the U.S. Department of Energy's Carnot Award for Energy Efficiency (1993), the Enrico Fermi Award (2006), and the National Medal of Technology and Innovation from President Obama (2013).

Rosenfeld began his career as a physicist, receiving his PhD from University of Chicago for work he did with Enrico Fermi, and serving with the Luis Alvarez Group at UC Berkeley from the mid 1950s until 1974. Energy supply problems created by the oil embargo of 1973 inspired Rosenfeld to shift his focus to energy efficiency.

Leroy T. "Roy" Kerth (BA '50, PhD '57)
Berkeley alumnus and physics professor emeritus Leroy T. "Roy" Kerth passed away in November of 2016 at the age of 87. His career encompassed posts at UC Berkeley, the Fermi National Accelerator Laboratory, and the Stanford Linear Accelerator Center. Kerth contributed to numerous experimental research projects, including the first observations of the top quark, of charmed particles produced by muons, and of direct charge-parity-symmetry violation. Kerth was a well-loved and respected lecturer. When he retired in 1993, he was awarded the prestigious Berkeley Citation.

Alumni

Vernon J. "Vern" Ehlers (BA '56, PhD '60)
Former Congressman for the state of Michigan Vernon J. "Vern" Ehlers passed away on August 15. He was 83. In 1993, Ehlers became the first research physicist to be elected to Congress. While serving in the U.S. House of Representatives, he advocated for environmental protections and personally defended funding for the National Science Foundation.

Terry S. Mast (PhD '71)
Terry S. Mast passed away on June 5, 2016 at the age of 73. Mast worked at LBNL and at UC Berkeley's Space Sciences Lab as a research physicist studying new particle detector technologies and measuring cosmic ray elemental abundances. He later worked as a research physicist at the University of California Observatories at UC Santa Cruz.

Charles "Chuck" Thacker (BA '67)
Charles "Chuck" Thacker passed away in June. He was 74. Thacker was instrumental in the development of the first modern personal computer, the Alto, while working out of the Computer Science Laboratory at the Xerox Palo Alto Research Center (PARC). During his time at PARC, he helped create the now widely used and essential Ethernet local area networking system. In 1983, he was one of the founders of the Digital Equipment Corporation's Systems Research Center in Palo Alto where he worked on multiprocessor systems and led the creation of an experimental computer called Firefly. Thacker was awarded the Association for Computing Machinery (ACM) Turing award in 2009.