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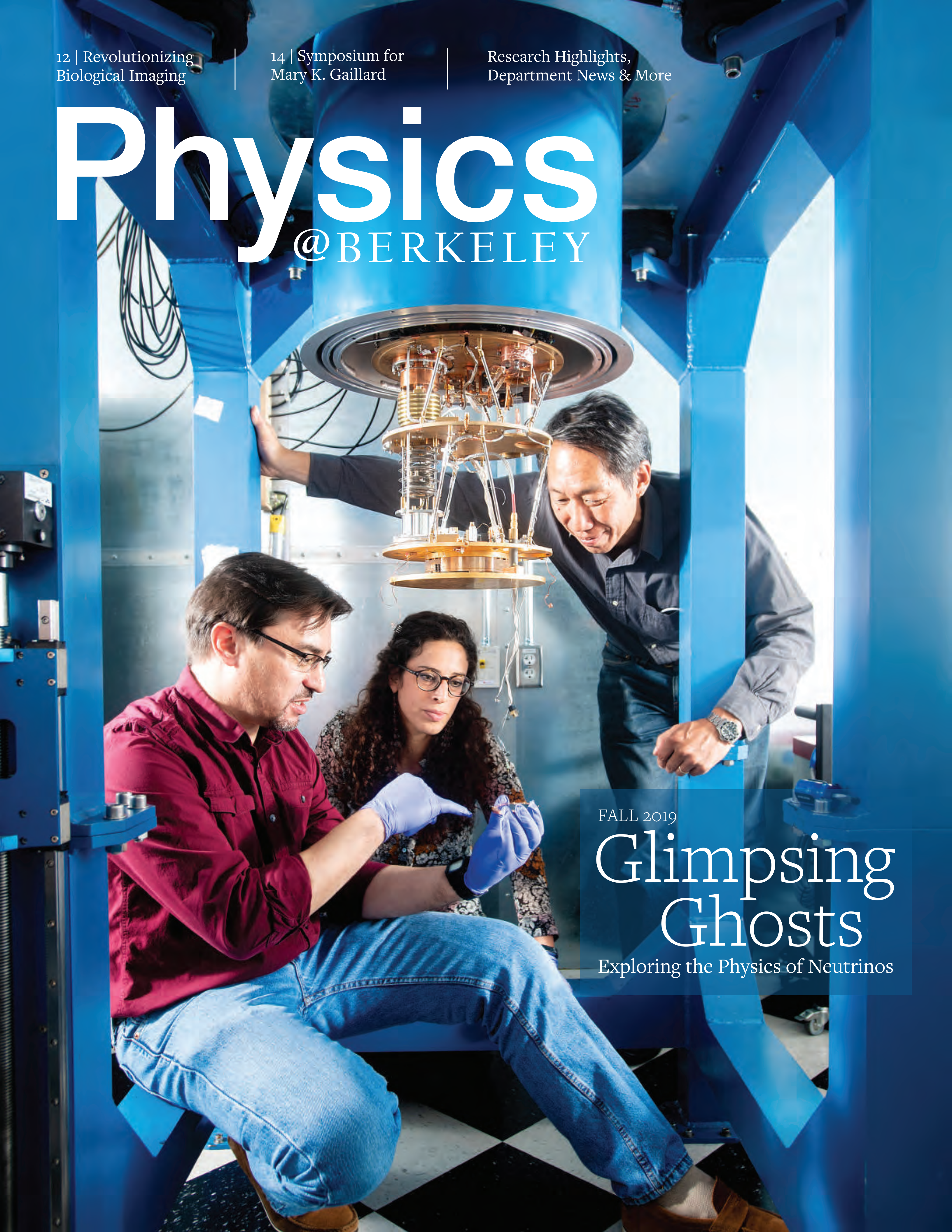
Physics @BERKELEY



FALL 2019

Glimpsing Ghosts

Exploring the Physics of Neutrinos

CHAIR'S LETTER

PHOTO: BEN AILES

Berkeley Physics is beginning the 2019-2020 academic year, welcoming 47 new graduate students from around the world and welcoming back 300 undergraduate physics majors, while preparing to teach an anticipated 8000 students who will enroll in at least one physics course. This fall we are hosting Visiting Miller Professor Nuh Gedik, MIT, and the following spring Visiting Miller Professors Laura Baudis, University of Zurich, and Michael Turner, University of Chicago. In September, we celebrated Mary K. Gaillard's distinguished and pioneering career at Berkeley with a symposium attended by many of the world's leading particle physicists, while on November 1 Jocelyn Bell Burnell presented the Segrè Lecture on "The Discovery of Pulsars." As always, we are keeping busy.

We recently learned that our Department's Frances Hellman, Dean of Mathematical and Physical Sciences, will be following in Roger Falcone's steps, joining the American Physical Society's presidential line and becoming the Society's President in 2022. In September Kam-Biu Luk was awarded the 2019 Future Science Prize, a major award that recognizes his pioneering work on neutrino oscillations. In August, Assistant Professor Norman Yao received the APS Valley Prize for work on time crystalline order. The Valley Prize is awarded annually to a young researcher whose work has dramatically impacted physics.

Our Department is also strengthening its international footprint through astrophysics and cosmology partnerships with Japan's national scientific laboratory RIKEN and with France's national laboratory system CNRS, both of whom are establishing visitor centers in Berkeley (see pp 16-17). Our Department has also become a popular "semester abroad" destination for international students who attend Berkeley for one or two semesters through our new undergraduate program, Berkeley Physics International Education (BPIE) (see p 16).

Berkeley Physics strives to continue as one of the nation's premier departments, while fulfilling its public university commitment to increased access and opportunity. Thank you for supporting us.

Wick Haxton, Chair

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Physics Professors Yury Kolomensky (left) and Adrian Lee (right) with postdoc Laura Marini examine components of the cryogenic equipment that will be used to cool the CUORE neutrino experiment (see page 4).

INSIDE FRONT COVER:
Close-up of the POLARBEAR telescope used by Professor Adrian Lee for research on polarization of the cosmic microwave background (see page 4).

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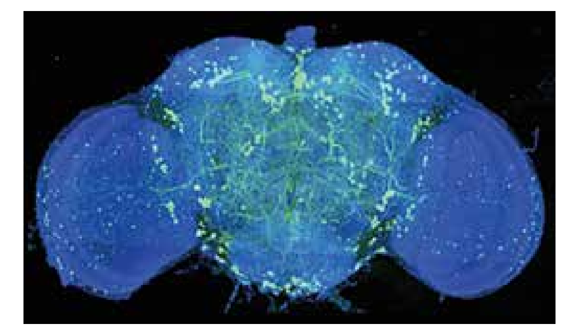

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Research Highlights

Simulation of a single polar skyrmion. Red arrows signify left-handedness. Other arrows represent the angular distribution of the dipoles.
CREDIT: RAMESH TEAM

Skyrmions for Next-Generation Data Storage

A team of researchers led by Berkeley physics professor **Ramamoorthy Ramesh** and Lane Martin, a professor in Materials Science & Engineering, has discovered materials that could lead to powerful data storage systems capable of retaining information even when the device is turned off.

"What we discovered is just mind-boggling," said Ramesh. The team is the first to observe polar skyrmions – quasi-particles that can be compared to tiny magnetic swirls – in a material with reversible electrical properties.

Skyrmions are textures made up of opposite electric charges known as dipoles. Researchers had always assumed skyrmions would appear only in magnetic materials, where special interactions between magnetic spins of charged electrons stabilize the twisting chiral patterns of skyrmions. So when the team discovered skyrmions in an electric material, they were astounded.

Now that the researchers have made a single electric skyrmion and confirmed its chirality, or handedness, they plan to make an array of dozens of electric skyrmions with the same handedness. "We want to see if we can electrically manipulate them," Ramesh said. "If we can somehow move them, write them, and erase them for data storage, that would be an amazing new technology."

New Experiments to Probe for Low-Mass Dark Matter

Dark matter makes up 85% of the matter in the universe. We don't know what it is made of, though we can witness its gravitational pull on the visible matter. Theorized weakly interacting massive particles, or WIMPs, are among the likely suspects comprising dark matter, but they haven't yet shown up where scientists expected them. So new experiments are being designed to look for dark matter in previously unexplored ranges of particle mass and energy.

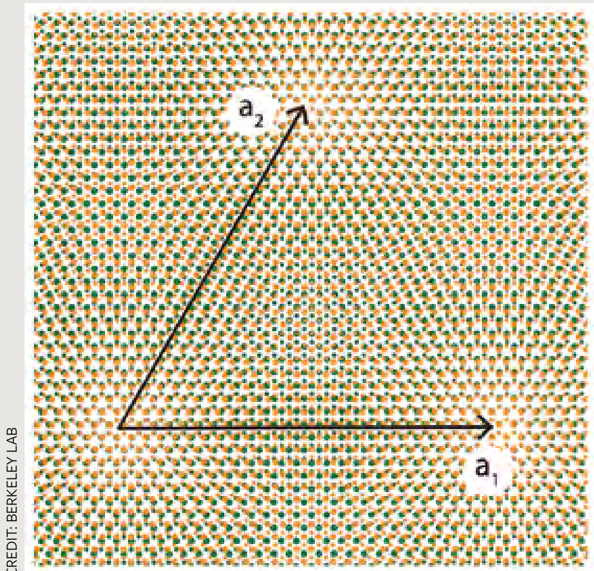
Dark matter-related research at Lawrence Berkeley National Lab (Berkeley Lab) and Berkeley Physics is highlighted in a new Department of Energy report, *Basic Research Needs for Dark Matter Small Projects New Initiatives*. It is based in part on a 2018 High Energy Physics Workshop on Dark Matter co-led by Berkeley physics professor **Dan McKinsey**, who is also a faculty senior scientist at Berkeley Lab.

"Berkeley is a dark matter mecca" primed for taking part in this expanded search, McKinsey said. He participates in direct-detection experiments, including LUX and LUX-ZEPLIN, that search for heavy dark matter particles such as WIMPS. He is also working on new low-mass dark matter detection techniques.

McKinsey is helping develop experiments that use superfluid helium to detect dark matter particles that preferentially scatter from atomic nuclei and gallium arsenide crystals to detect dark matter that scatters from electrons. In general, these experiments will search for dark matter particles with a mass less than that of the proton.

CREDIT: MARILYN CHUNG/BERKELEY LAB

Components of a low-mass dark matter detector that is now in development.



CREDIT: BERKELEY LAB

The twist angle formed between atomically thin layers of tungsten disulfide and tungsten diselenide acts as a "tuning knob," transforming these semiconductors into an exotic quantum material.

From Semiconductors to Quantum Machines

A new study led by Berkeley physics professor **Feng Wang** describes a method that could turn ordinary semiconducting materials into quantum electronic devices. Wang's team has shown how aligned layers of atomically thin semiconductors can yield super-thin devices with extraordinary electronic behavior. Such an advancement could help revolutionize a number of industries aiming for energy-efficient electronic systems – and provide a platform for exotic new physics.

"This is an amazing discovery because we didn't think of these semiconducting materials as strongly interacting," said Wang. "Now this work has brought these seemingly ordinary semiconductors into the quantum materials space."

Two-dimensional (2D) materials, which are just one atom thick, are like nanosized building blocks that can be stacked arbitrarily to form tiny devices. The new study used 2D samples of semiconducting materials to show that the twist angle between layers provides a "tuning knob" to turn a 2D semiconducting system into an exotic quantum material with highly interacting electrons.

The researchers plan to measure how this new quantum system could be applied to optoelectronics, which relates to the use of light in electronics; valleytronics, a field that could extend the limits of Moore's law by miniaturizing electronic components; and superconductivity, which would allow electrons to flow in devices with virtually no resistance.

Can Entangled Qubits Probe Black Holes?

When matter disappears into a black hole, all information associated with it is "scrambled," chaotically mixing with all the other matter and information inside and making it seemingly impossible to retrieve. But according to quantum mechanics, that information is never lost.

Quantum mechanical fluctuations at the edges of black holes create emissions called Hawking radiation that cause a black hole to shrink. Theoretically, all information can be retrieved from a black hole once it has shrunk by about half, but that process can take far longer than the age of the universe. However, it might be possible to retrieve infalling information significantly faster. By dropping an entangled qubit into a black hole and querying the emerging Hawking radiation, you could leverage entanglement to retrieve the infalling information significantly faster, providing a window into the abyss.

Berkeley physicist **Norman Yao** is working with a number of colleagues on this idea. "One can recover the information dropped into the black hole by doing a massive quantum calculation on these outgoing Hawking photons," he said. "This is expected to be really, really hard, but if quantum mechanics is to be believed, it should, in principle, be possible. That's exactly what we are doing here, but for a tiny three-qubit 'black hole' inside a seven-qubit quantum computer."

The team's work was published in the March 7 issue of *Nature*. Last October, Yao was awarded a David and Lucille Packard Fellowship for his research on new phenomena that arise in systems that are far from thermal equilibrium.

CREDIT: E. EDWARDS/JOINT QUANTUM INSTITUTE

Someday, entangled quantum bits, or qubits, may allow us to explore the mysterious interior of a black hole, as represented in this artistic rendering.

Glimpsing Ghosts

Exploring the Physics of Neutrinos

Using neutrinos as probes, investigators peer into the tiny world of atomic nuclei and out to the vast expanse of the cosmos to solve some of nature's biggest mysteries

PHOTOS BY NOAH BERGER

NEUTRINOS ARE EVERYWHERE. They account for as much mass as all the stars in the universe. They are as fundamental as electrons and quarks, but very rarely interact with other particles. They do not absorb or give off electromagnetic radiation. They have no electric charge. They are so difficult to detect they've earned the name 'ghost particles.'

Nonetheless, neutrinos have influenced the evolution of the universe from its very beginning. Once considered inconsequential, neutrinos are now heralded as guardians of some of nature's most closely held secrets. Learning more about them could explain the dominance of matter over antimatter and clarify the relationship between gravity and the strong, weak, and electromagnetic forces that hold atoms together.

NEUTRINO SCIENCE AT BERKELEY

Berkeley Physics has a prestigious history of contributions to neutrino science. Faculty-led research with collaborations like SNO, KamLAND, and Daya Bay have aided in the development of neutrino detection methods; the discovery that neutrinos come in three forms, or flavors, that morph into one another; and the consequent revelation that they have mass.

A nonzero neutrino mass, tiny though it may be – no more than one millionth the mass of the electron – doesn't fit the current Standard Model of Particle Physics. It's a finding that has spurred a multitude of studies now being conducted here at Berkeley and around the world.

Two of Berkeley's preeminent physicists are involved with separate inquiries that start from very different vantage points but share similar experimental methods and scientific goals. One goal is to measure neutrino masses with increasing precision. Another is to learn about the influence neutrinos have had on the birth and evolution of the universe.

Professor Yury Kolomensky uses atomic nuclei as his laboratory for probing properties of the neutrino. He leads the United States' participation in the CUORE collaboration (Cryogenic Underground Observatory for Rare Events) and a planned follow-on investigation called CUPID (CUORE Upgrade with Particle Identification). Housed deep underground at Gran Sasso, Italy, these experiments are designed to detect a type of radioactive decay that, though it doesn't involve neutrino emissions, could tell us about neutrino properties.

Professor Adrian Lee uses our universe – the evolution of the complex structures we see in the night sky – as his laboratory for probing

Physics Professor Yury Kolomensky leads Berkeley's contributions to the CUORE and CUPID collaborations. These experiments use detectors buried underground to make direct measurements of neutrino mass and to look for evidence that neutrinos serve as their own antiparticles. Pictured here with postdoc Laura Marini neutrino properties. He currently leads the Berkeley component of the POLARBEAR, Simons Array, and Simons Observatory collaborations. These experiments use telescopes positioned high in the rarefied atmosphere of Chile's Atacama Desert to measure polarization signals imprinted on the cosmic microwave background (CMB), including imprints made by remnant neutrinos from the Big Bang.

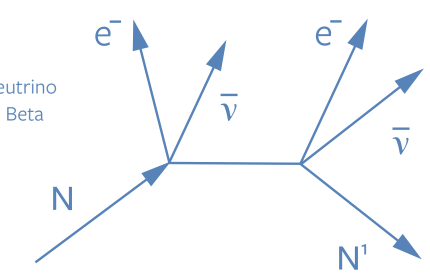
Experimental methods used by both researchers center on bolometer technology – cryogenically cooled detectors that are specialized for quantifying extremely small fluctuations in thermal energy.

NEUTRINOLESS DOUBLE BETA DECAY

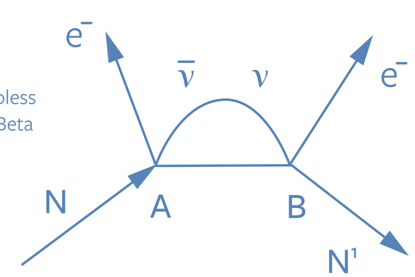
In his work with the CUORE and CUPID experiments, Kolomensky aims to detect a naturally occurring radioactive decay process known as neutrinoless double beta decay (NLDBD). Not yet observed, NLDBD is theorized to take place in the nuclei of certain atomic isotopes. It can occur only if neutrinos are Majorana particles – particles that act as both matter and antimatter.

Detecting NLDBD would prove that neutrinos are indeed Majorana, thereby giving credence to a theory that explains the abundance of matter over antimatter. "A process like this, in which particles transform into antiparticles," Kolomensky says, "is required for building up matter-antimatter asymmetry in the early universe." CUORE and CUPID are sensitive enough to detect minute differences between the energy of electrons released in standard double beta decay and the higher energy of electrons released in NLDBD.

Two-Neutrino Double Beta Decay



Neutrinoless Double Beta Decay



In two-neutrino double beta decay, an atomic nucleus (A) decays into a new nucleus (N). Two neutrons become protons, releasing two electrons (e^-) and two antineutrinos (ν). Decay energy is shared by the electrons and neutrinos. This process is allowed by the Standard Model of particle physics and has been measured in the laboratory.

In neutrinoless double beta decay, an antineutrino emitted from the first neutron is absorbed by a neutrino (ν) emitted by the second neutron. All decay energy is carried by the electrons. This process has not yet been detected and requires new physics beyond the Standard Model.

Detecting NLDBD would also enable a measurement of neutrino mass. This information could lead to new physics beyond the Standard Model, perhaps even the long-sought unification of the three forces that bind fundamental particles into atoms.

CUORE AND CUPID

CUORE – the Italian word for 'heart' – began full operation in early 2017. Researchers anticipate CUORE would need to observe about fifty atoms undergoing NLDBD during its five years of data collection to claim discovery. "Neutrinoless beta decay is a very rare process – if observed, it would be the slowest thing that has ever been measured," noted CUORE member and Berkeley physics alumna Lindley Winslow (PhD 2008). She is currently an assistant professor of physics at MIT.

> "Simultaneously measuring light and heat is one way to make sure the radioactive decay we see is actually the process we're looking for."

Kolomensky adds, "CUORE has the largest number of individual detectors of any device currently looking for this decay. Its sensitivity is also due to its mass, about 200 kg of the isotope tellurium-130 in a total detector mass of 750 kg, along with extremely good energy resolution and small backgrounds from environmental radiation."

CUORE is a block-shaped array of 988 tightly packed tellurium oxide (TeO2) crystals stacked in towers. When an atom in the 130Te isotope decays, the energy that's released creates vibrations in the crystal lattice. Each crystal is attached to a semiconductor thermistor that senses minute temperature fluctuations resulting from the vibrations. To protect the experiment from background noise created by other radioactive decays, the entire assembly is wrapped in lead shielding and cryogenically cooled to about ten milliKelvin.

"CUORE will take data for another three to four years," Kolomensky says, "and will be one of the most sensitive data sets in the world at that time. Our students are leading some of the double beta decay analyses, and several will write their PhD theses on results from CUORE."

CUORE's next-generation successor, CUPID, is a more powerful detector now in the planning stages. CUPID will continue the search for NLDBD events and gather increasingly refined data on neutrino properties.

"We want to keep essentially the same size and mass as CUORE," Kolomensky reports, "but with improved sensitivity and further reductions in background noise. In place of tellurium, we're looking at crystals that produce visible light as well as lattice vibrations when a radioactive particle deposits energy. Simultaneously measuring light and heat is one way to make sure the radioactive decay we see is actually the process we're looking for."

The most promising candidate for CUPID is lithium molybdate (Li_2MoO_4), a crystal that emits much more light when excited by electrons, as in NLDBD, than when excited by alpha particles from other radioactive

BOLOMETERS are ultrasensitive heat detectors that convert extremely small changes in electromagnetic energy into measurable changes in temperature. They are key elements in a wide variety of research endeavors in nuclear physics and cosmology, from mapping of the cosmic microwave background (CMB) to detection of radioactive decay processes like neutrinoless double beta decay.

"The concept is fairly simple," explains Berkeley particle physicist Yury Kolomensky. "If the heat capacity of a target is very small, then very small energy changes within that target can become relatively large temperature increases. If we know the heat capacity of the target, we can use the temperature variations to infer the total energy of an event."

A bolometer is usually composed of an energy absorber, a temperature sensor that measures the consequent rise in heat energy, and electronics that read out the temperature signal. All components are housed in cryostats that cool the experiment to within a fraction of a degree above absolute zero.

DETECTORS

For nuclear physics experiments like CUORE and CUPID, which are composed of crystalline materials, each crystal serves as a detector. Radioactive decay emissions create vibrations that in turn cause miniscule temperature changes in the crystal lattice.

For cosmology experiments like POLARBEAR, Simons Array, and the Simons Observatory, an array of lithographed antennas and superconducting sensors detect light from a telescope. Each pixel is designed to receive specific millimeter wavelength photons, and superconducting sensors detect the incident heat.

TRANSITION EDGE SENSORS

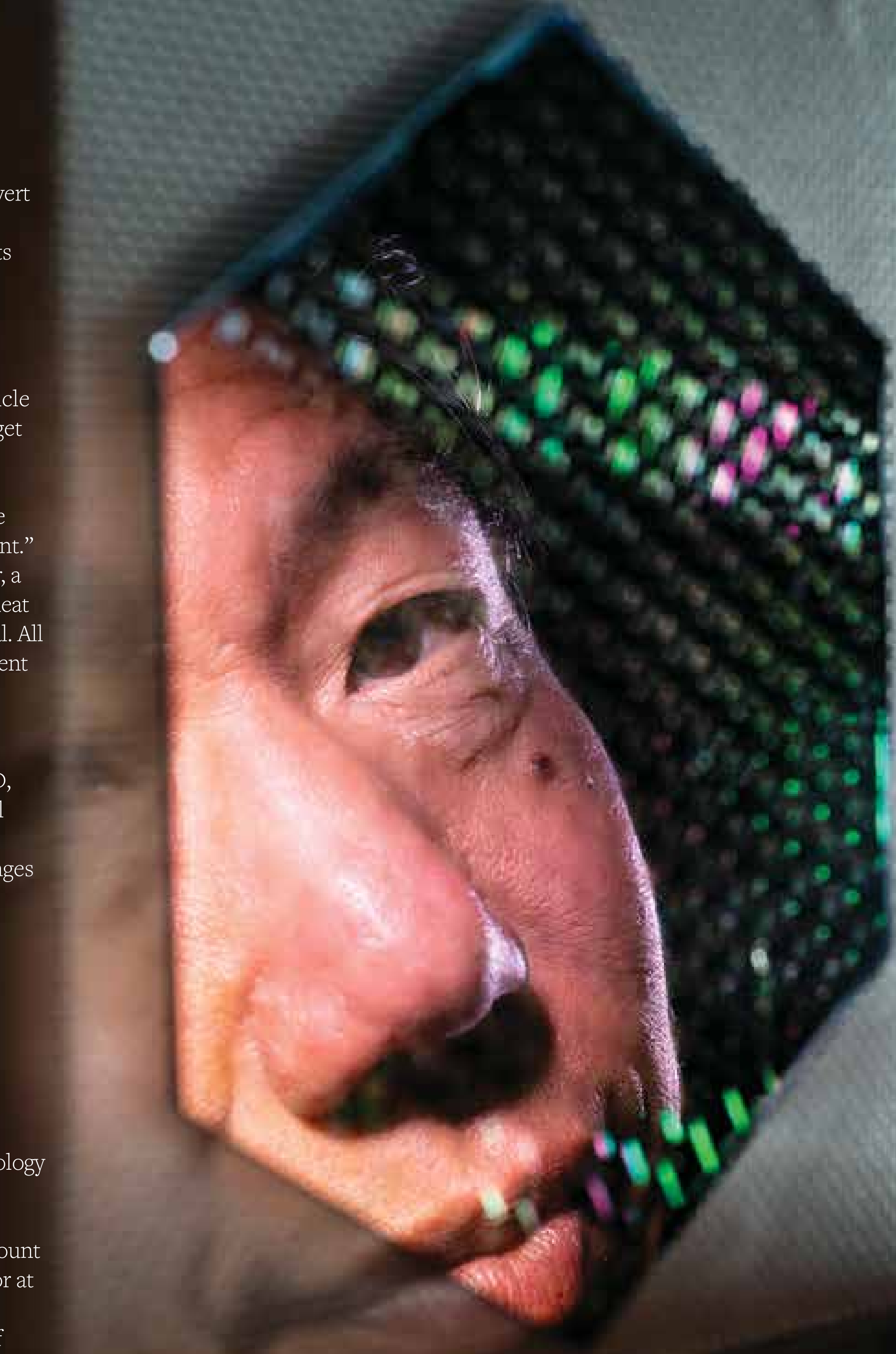
Bolometer designs used for particle physics and for cosmology experiments use superconducting transition-edge sensors (TESs) to monitor changes in temperature. TESs sit at the edge of superconductivity, sensing tiny changes in the amount of electrical power needed to maintain the superconductor at its transition temperature.

The antenna-coupled TES concept is the brain child of Berkeley cosmologist Adrian Lee, who first proposed the idea more than 20 years ago while working as a Berkeley postdoc in Paul Richards' laboratory. Lee also pioneered microfabrication techniques to help speed production of TES-containing devices. TES technology has now become central to nearly all CMB experiments worldwide.

MULTIPLEXING ELECTRONICS

Measuring the subtle signals Lee and Kolomensky are looking for requires hundreds, thousands, or tens of thousands of detectors, all operating at the same time. That volume presents a serious challenge for designing digital readouts.

In answer to that difficulty, Richards and Lee developed an innovative multiplexing technology that reads out many detectors simultaneously with a single amplifier and only a few wires. "Otherwise you end up running tens of thousands of wires out of your cryostat," Lee says, "which gets impractical and limits the sensitivity of your experiment."



POLARBEAR Bolometer Array

This six-inch silicon wafer holds a bolometer array of about 1100 photon detectors, each sensitive to two different wavelengths of microwave radiation and two different polarizations. Inset below shows a single pixel with its central antenna. For cosmological observations like POLARBEAR, Simons Array, and Simon Observatory, assemblies like these are housed in a telescope set up to receive CMB photons from the sky.

processes. “Also,” Kolomensky says, “the energy of molybdate in the double beta decay transition is higher than tellurium by about twenty percent. That’s enough to shift the energy of interest to a region where background radioactivity is very low.”

PARTICLE PHYSICS MEETS COSMOLOGY

CUPID’s design would also take advantage of advanced thermal sensing and multiplex electronics technologies that were originally pioneered by Lee and colleagues for cosmology research.

To measure temperature, CUPID would replace CUORE’s very precise semiconductor thermistors with even more sensitive superconducting transition edge sensors (TESs). “TES devices can detect temperature fluctuations with a sensitivity that’s an order of magnitude greater than semiconductor thermistors,” Kolomensky explains. “And TESs are inherently faster, which helps distinguish separate events that happen in the same detector.”

CUPID would also incorporate many more detectors – three to four thousand, compared with CUORE’s 988 – to boost the probability of encountering NLDBD events. To record data from so many detectors continuously and simultaneously, CUPID would use multiplex electronics adapted from systems that have been developed for mapping the CMB.

“Current plans are to start building CUPID in a year or two,” Kolomensky reports. “Then, once CUORE stops taking data, we’ll open the cryostat and replace the detectors. CUPID would hunt for another five to ten years.” Agencies from Italy, France, and the US are working together on a collaboration to support the experiment.

POLARBEAR, SIMONS ARRAY, AND SIMONS OBSERVATORY

While Kolomensky monitors atomic nuclei, Lee focuses on the far reaches of the cosmos. He has been exploring the CMB since 1994. These days, Lee and colleagues have turned their attention to faint polarization patterns – directional light that bears imprints of the infant universe from as early as a fraction of a second after the Big Bang.

“The presence of neutrinos in the very early universe created subtle distortions of the polarization signals from the CMB,” Lee explains. “By mapping these signals, we can infer what happened in the era before the CMB was emitted. We can see how the properties of neutrinos alter what we see on the sky, how they influence the way the universe starts and evolves.”

Lee and colleagues are also interested in swirly B-mode polarization generated when the trajectory of CMB photons have been altered through gravitational lensing as they traversed the universe, past the large-scale structures we see today.

B-mode data can place constraints on the sum of the neutrino masses, providing a complement to more specific neutrino mass measurements made by particle physics experiments like CUORE and CUPID. Also, polarization studies will help determine whether or not there are more than three neutrino flavors, and perhaps even disclose details about the inflationary epoch, that moment when the infant universe went through an exponential expansion.

In general, polarization patterns in the CMB could offer a peek into particle physics at energies far higher than any earth-bound particle accelerator could reach, perhaps revealing the presence of particles yet unknown and advancing the search for a unified theory of gravity and quantum mechanics.

FROM POLARBEAR TO THE SIMONS OBSERVATORY

Lee’s team began their B-mode explorations in 2012 with POLARBEAR, a 2.5-meter telescope that houses an array of 1200 polarization-sensitive bolometers. “The POLARBEAR detectors were a big advance in the state of the art,” Lee reports, “and did a very good job helping us understand the gravitational lensing signal in B-mode patterns.”

“Now we’re building the next stage,” Lee continues, “called the Simons Array. It’s made up of three 50-cm telescopes, each with an array of 7500 detectors, that will work in tandem. The Simons Array will be much more sensitive than POLARBEAR, able to look for the neutrino mass signal with much more sensitivity than we’ve ever had.” The entire three-telescope array should be operational by the end of 2020.

Even further improvements are underway. By 2022 a set of four new telescopes will be installed in Chile as part of the next-generation experiment called the Simons Observatory. “The Simons Observatory will have one large, six-meter telescope,” Lee says, “and three small 50-cm telescopes dedicated to searching for the inflationary signal.” Combined, the four telescopes will have a total of 60,000 detectors.

POTENTIAL FOR NEW PHYSICS

The work Kolomensky and Lee are doing has many features in common, from cryogenically cooled bolometer technology to shared neutrino science goals. Yet their research approaches come from what might be considered vastly different areas of physics.

“We have different perspectives,’” Kolomensky says, “yet we hope to answer similar questions. There is the likelihood that we’ll be able to corroborate one another’s findings. And if our experiments find contradictory results in some way, that would indicate some new phenomenon in physics that might not be possible for us to observe independently.”

Physics Professor Adrian Lee leads Berkeley’s participation in the POLARBEAR, Simons Array, and Simons Observatory collaborations. These experiments use high-altitude instruments to measure the polarization of the cosmic microwave background and glean details about neutrino properties and their influence on the evolution of the universe. Pictured here (l to r) are graduate students John Groh and Shawn Beckman, Professor Adrian Lee, and scientist Yuji Chinone.

2018-2019 Giving

551

Total Number of Donors this year

Our Donors Are:

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15% of Physics Alumni are Donors

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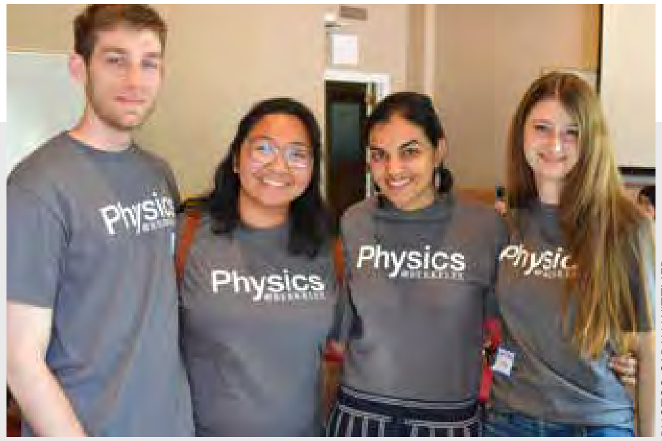


PHOTOS: SARAH WITTMER

CAL DAY 2019

On April 19, Berkeley Physics opened the doors of LeConte Hall to more than 2,500 students and their families. It was Cal Day, a university-wide event that takes place every April, inviting visitors to freely explore the campus and interact with faculty, university organizations, and current students from all departments.

Physics offered a variety of lectures, guided lab tours, and exhibits, including a live 3-D polymer printer demonstration. Professors from the department spoke on topics ranging from cosmic microwave background radiation to quantum materials, and undergraduate advisors gave counseling to prospective students interested in pursuing a physics degree. A Physics Resource Fair gave visitors even more opportunities to see the resources and student organizations that cultivate the vibrant learning environment at Berkeley.

CalDay & Commencement

Top right: CalDay student volunteers Myles McAvoy, Elicia Tiano, Namrata Ramesh, and Sophie Parsons.

Above right: A guest at the Hands-On Physics exhibit learns about the physics of rotation.

Right: Ph.D. graduates Paul Riggins, Kelly Swanson and Leigh Martin.

Below right: Claudia Trujillo, Director of Student Services is pictured here with commencement address speaker Lauren Tompkins.

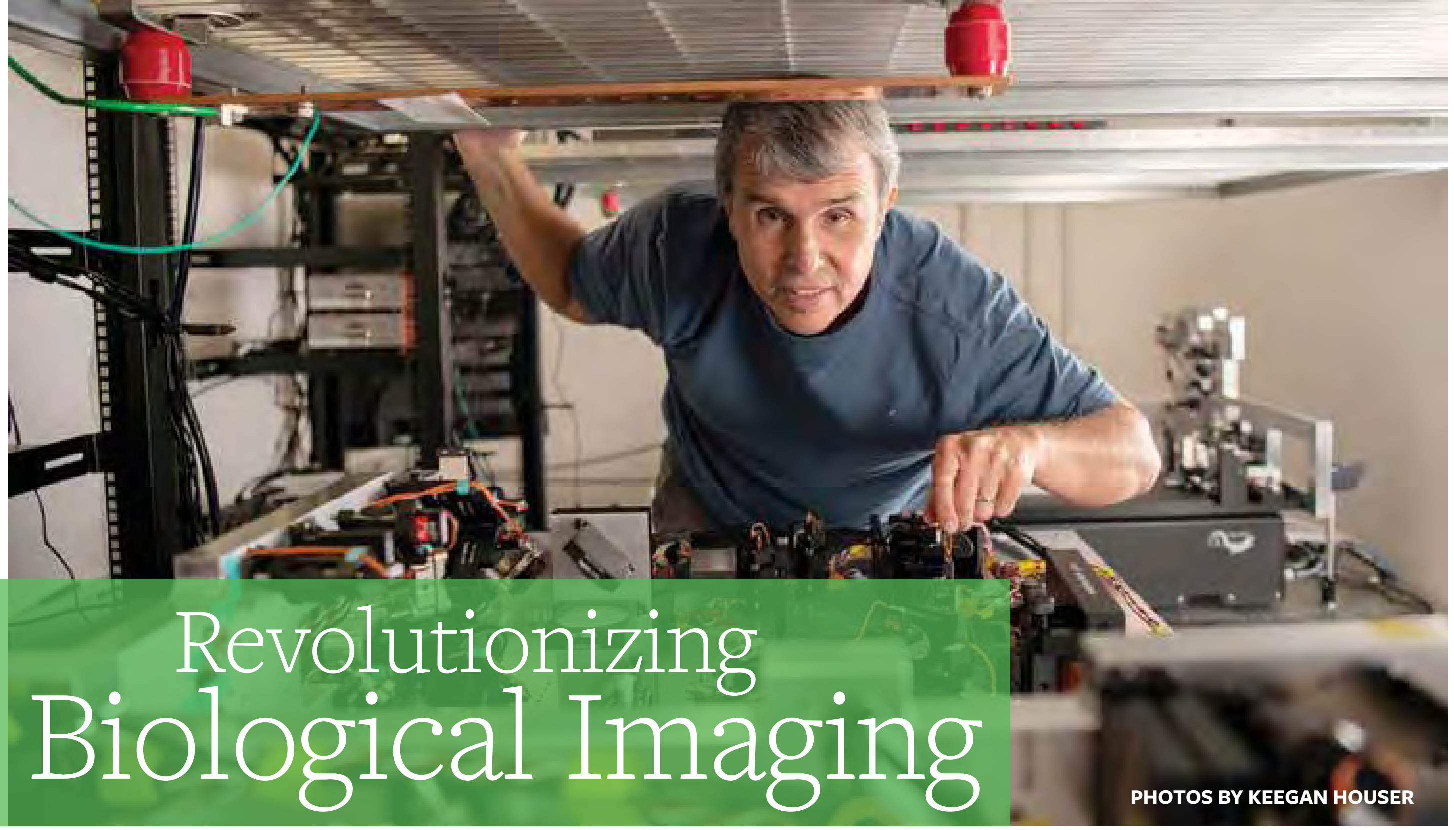
COMMENCEMENT 2019

On May 21, the Physics Department at Berkeley had the honor of witnessing 213 students receive degrees in physics. The degrees – 138 BAs, 33 MAs, and 42 PhDs – were presented in Zellerbach Auditorium during the 2019 Physics and Astronomy Commencement ceremonies.

Wick Haxton, the Chair of the Physics Department, began the proceedings by welcoming students and their families. The 2019 student speaker was **Sijia Zhao**, who graduated with a BA from the Department of Physics and was awarded the Physics Department Citation. Following her speech was the 2019 commencement speaker, **Lauren Tompkins**. Tompkins is an assistant professor of physics at Stanford University and received her BA and PhD in physics from UC Berkeley.

The Lars Commins Memorial Awards in Experimental Physics, established in honor of engineer Lars Commins, son of the late Berkeley Physics Professor Emeritus Eugene Commins, were awarded to **S. Matthew Gilbert** and **Victoria Xu**. **Leigh Martin** received the Jackson C. Koo Award in Condensed Matter to celebrate the accomplishments of a noteworthy graduate student in condensed matter physics. Koo received his PhD in Physics from Berkeley in 1969.

After the ceremonies, graduates and their families took photos and enjoyed a reception in the courtyard between LeConte and Birge Halls.



Revolutionizing Biological Imaging

PHOTOS BY KEEGAN HOUSER

New microscopes reveal what's never before been seen

Above: Nobel laureate and Berkeley physics professor Eric Betzig with the "Swiss Army Knife" microscope that combines the revolutionary imaging modalities he has developed. The microscope is a central component of the new Advanced Bioimaging Center on campus, established by Betzig and directed by colleague and collaborator Gokul Upadhyayula.

Berkeley Physics recently welcomed two new faculty members who are leading a renaissance in optical microscopy. Melding principles from physics, chemistry, engineering, and data science, they've developed advanced fluorescence microscopy technologies that deliver high-speed, high-resolution, 3-D imaging of living cells and tissues. These new tools are powerful enough to yield unprecedented detail, yet gentle enough to avoid altering or harming the living systems under study.

Professor **Eric Betzig** is a self-described inventor with a PhD in physics from Cornell and a remarkable history of technological breakthroughs. He shared the 2014 Nobel Prize in Chemistry for his role in developing super-resolution fluorescence microscopy – a technology that uses light to control the fluorescence of individual molecules and track the pathways of proteins and other macromolecules as they function inside living cells. That innovation was first introduced in 2005, and since then Betzig has continued to invent new kinds of microscopes with a variety of advanced capabilities. He holds the Eugene D. Commins Presidential Chair in Experimental Physics at Berkeley.

Associate professor **Na Ji** is a world-renowned biophysicist who develops imaging technologies for neurobiological research and studies neural circuits in the brains of live animals. Ji is responsible for major advances in the use of adaptive optics, an approach initially developed for telescopes, to significantly increase the sharpness of microscope images. Ji is a Berkeley alumna who received her PhD in 2005 for work in physical chemistry and nonlinear optics with Berkeley physicist **Yuen-Ron Shen** as her advisor.

Both Betzig and Ji came to Berkeley from the Janelia Research Campus of the Howard Hughes Medical Institute. They have created and are co-teaching a new microscopy course for Berkeley graduate students, Modern Microscopy for the Modern Biologist, offered for the first time this fall.

EXAMINING NEURAL CIRCUITS

Ji's research focuses on neural circuit dynamics in the mouse brain, specifically the regions processing visual information. "Properties like visual perception are generated by many neurons working together to form neural circuits," she explains. "To understand how the brain works, we need to know how neurons communicate at individual synapses, which are very small, on the order of one micron. We also need to measure neural activity at larger, millimeter scales, because that's how big a neural circuit can be."

Accomplishing this requires a non-invasive imaging system that can penetrate beneath the surface of the brain of a live animal, into deeper layers of nerve tissue. "Once we go a few hundred microns deep," she says, "the light that will form the image gets degraded by intervening layers of tissue."

Ji uses a version of adaptive optics to address the problem. It's conceptually similar to the technique used by astronomers to correct for distortions in starlight caused by Earth's atmosphere, but requires new implementations due to the more complex optics of the opaque brain. "Translating that method into microscopy is what I did at Janelia and what I am working on now," she notes, "finding ways to measure how the light is distorted by the brain and then correct it."

Ji worked with Betzig on this approach as a postdoc in his lab at Janelia, from 2006 to 2010, before taking leadership of her own group. "She improved this idea greatly in her own lab," Betzig says, "and uses it to record neural activity deep in the cortex with much greater accuracy and reliability than previously possible."

Another physics concept Ji uses is the Bessel beam – the same sort of light used in bar code scanners. "It's a pencil-like beam, which we scan quickly in two dimensions to probe activity in a volume at high speed," she explains. It enables rapid imaging of neural activity, which takes place on millisecond time scales.

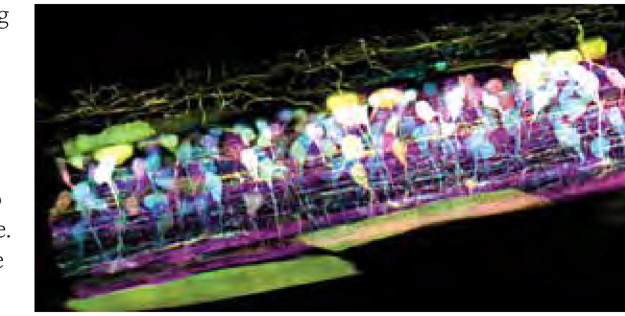
THE ADVANCED BIOIMAGING CENTER

Over the past ten years or so, Betzig has developed several new kinds of microscopes to support the diverse needs of modern biological studies. These innovations include:

- super-resolution microscopes that balance resolution with imaging speeds up to hundreds of frames/second,
- lattice light-sheet microscopes that non-invasively image 3D subcellular dynamics across whole cells over hundreds of time points,
- adaptive optical systems borrowed from astronomy that can image neural activity deep in the brains of living mice, or cell motility and organelle dynamics deep in developing embryos,
- a combination of expansion microscopy and lattice light-sheet microscopy that provides nanometer-scale resolution of proteins in millimeter-scale specimens, such as the brain, kidney, or tumors.

At Berkeley, Betzig has helped to found a new center where biologists can come to use these imaging technologies and learn how to apply them for specific research goals. The Advanced Bioimaging Center (ABC), headed by his long-time collaborator and new Assistant Professor in Residence Gokul Upadhyayula, aims to attract scientists from all over the world, promoting creative collaboration on the Berkeley campus and beyond.

"The ABC will house a diverse set of pre-commercial microscopes," Betzig reports, "including our latest – a 'Swiss Army Knife' that combines all of the imaging modalities developed in my lab over the past decade. It's a single, versatile instrument for live imaging at all length scales, from single molecules to whole organisms."



CREDIT: T. LIU ET AL./SCIENCE 2018

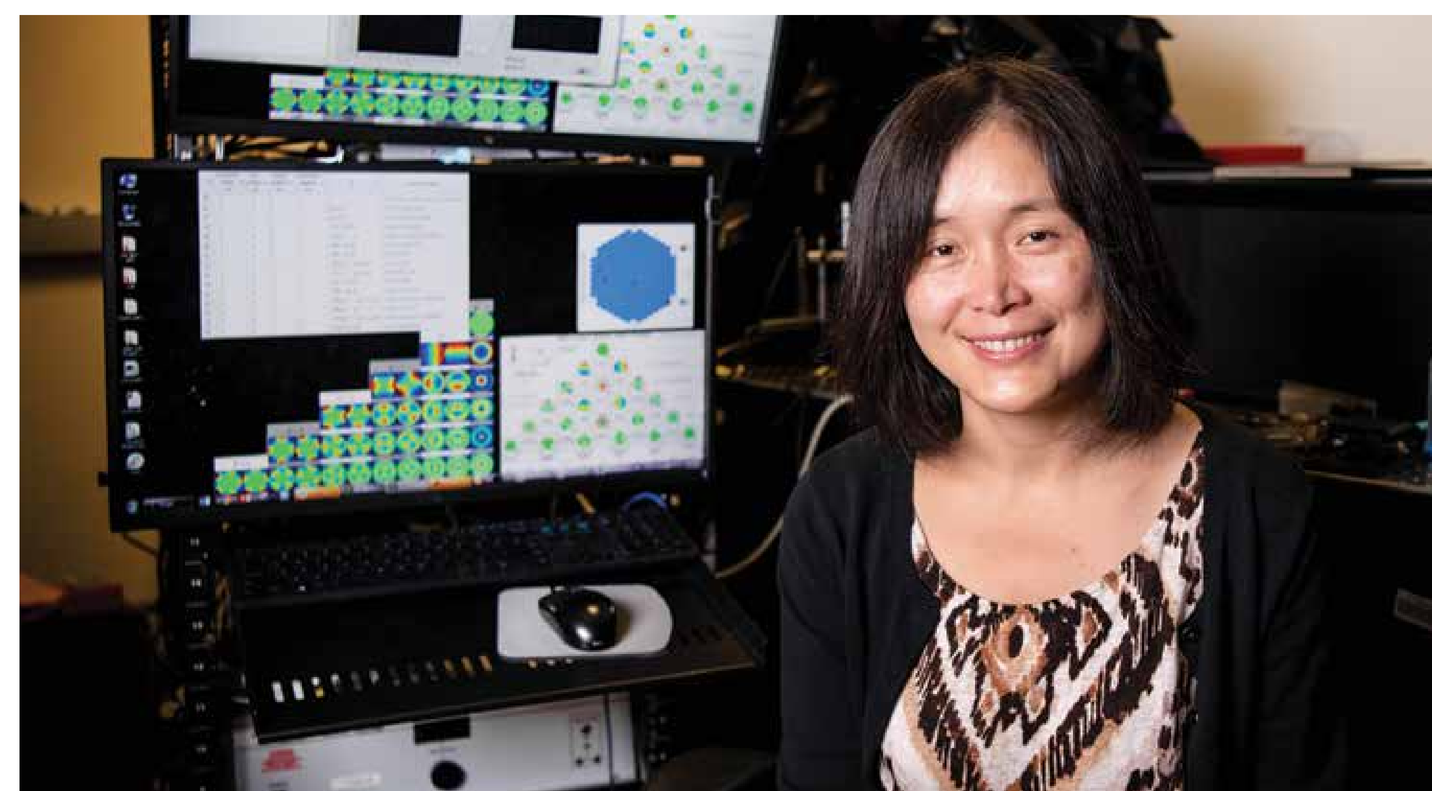
Inside the spinal cord of a zebrafish embryo, new neurons light up in different colors, enabling scientists to track nerve circuit development. Image compiled using combined lattice light-sheet microscopy and adaptive optics developed in Eric Betzig's Janelia laboratory.

He also emphasizes data science as a critical component of the ABC's activities. "Imaging cellular dynamics at high resolution across all four dimensions of space and time generates vast amounts of data," Betzig notes. "Few biologists are well equipped to mine the insights that can be unlocked through quantitative analysis of such data. There is an urgent and growing need for custom, computationally efficient, image analysis algorithms to address the needs of biologists who come to us with a wide variety of organisms and large lists of questions."

Betzig is looking to build collaborations with academic and corporate partners in basic bioscience, translational medicine, and high performance computing/machine learning to further develop, apply, and eventually commercialize the hardware and computational tools of the ABC. The goal is to make them easier for biologists to use and more widely accessible around the globe.

Housed in Barker Hall on campus, the ABC is already hosting visiting biologists. Its launch has been made possible by support from the Howard Hughes Medical Institute, Chan Zuckerberg Initiative, and Philomathia Foundation, and it welcomes additional philanthropic contributions to support ongoing operations and continued growth to fulfill its mission.

Berkeley biophysicist Na Ji, Luis Alvarez Chair in Physics, develops non-invasive microscopy techniques and uses them to image the activity of neural circuits in brain regions that process visual information.



From CHARM to STRINGS

Symposium Honors Mary K. Gaillard

"I have the good luck that my career spanned the entire period of the Standard Model from its inception to its verification with the discovery of the Higgs particle. And I had a lot of fun."

This September, colleagues, students, and friends gathered in downtown Berkeley for a two-day symposium celebrating **Mary K. Gaillard** and her brilliant career in theoretical particle physics. The Symposium – From Charm to Strings – was sponsored by the Heising-Simons Foundation and featured invited talks by scientists from around the world, including Beate Heinemann of the DESY accelerator center in Germany, Nima Arkani-Hamed of Princeton, and Lisa Randall of Harvard. A banquet in Gaillard's honor was held Saturday evening September 21.

Gaillard's distinguished career began in the 1960s. From 1964 to 1981 she was a research scientist at the French National Center for Scientific Research, and also a visiting scientist at CERN in Geneva. In 1981, she became the first woman to join the Berkeley physics faculty. At the same time she became a faculty senior staff member at Lawrence Berkeley National Lab (Berkeley Lab), serving as head of its Particle Theory Group from 1985-87. Retired since 2009, she is now a professor of the Graduate School at UC Berkeley and a visiting scientist at Berkeley Lab.

Gaillard has earned high regard not only for her scientific accomplishments but also for her courage and perseverance in the face of gender bias and her continuous efforts toward opening up opportunities for women in the sciences. She has written and spoken about the "determined antifeminism" she experienced while at CERN where, despite her accomplishments, she was never offered a staff position. She was the first person to address gender imbalance at that institution: in 1980, for International Women's Day, she published an essay about how women in scientific careers at CERN viewed their professional status. The essay became an important resource for eventual development of CERN's Equal Opportunities Program.

Colleague and fellow Berkeley physicist Lawrence Hall says of Gaillard's career, "In 1974, just as the pieces of the Standard Model were being put together, she made seminal discoveries connecting it to key puzzles in the experimental data. She showed that a variety of rare phenomena associated with kaon particles could be described by the proposed theory of weak interactions, but only if the hypothetical charm quark had a mass that was well within reach of planned experiments. Furthermore, other puzzles of kaon decays could be understood using the newly proposed theory of strong interactions. This greatly strengthened the evidence for the Standard Model, especially when later that year particles containing the charm quark were discovered."

Hall continues, "She made the first systematic studies of both charmed particles and the Higgs boson before they were discovered, with implications for key experimental searches. After a paper on gluon jets that led to experimental confirmation of the gluon, Mary K. turned her attention to schemes that unified the forces of nature, elucidating the properties of grand unified theories, speculating early on how the forces could be embedded in supergravity, and finally examining how they might arise from string theory. In a career spanning over half a century, Mary K. was on the forefront of new particle theories, keeping them anchored to experimental data."

In 2015, a memoir describing Gaillard's career, *A Singularly Unfeminine Profession: One Woman's Journey in Physics*, was published by World Scientific. Gaillard says she wrote the book "because I wanted to convey the difficulties I had as a woman in such a male-dominated field. And I wanted to convey the joy of doing physics. I have the good luck that my career spanned the entire period of the standard model from its inception to its verification with the discovery of the Higgs particle. And I had a lot of fun."

New Faculty

Heather Gray joined the Berkeley Physics faculty as assistant professor in January. She received her undergraduate education at the University of Cape Town, earned a PhD in physics from Caltech in 2011, worked at CERN as a research fellow and research scientist from 2011 to 2017, and has been a Lawrence Berkeley National Lab divisional fellow since 2017. She is an experimental particle physicist working on the ATLAS experiment at the Large Hadron Collider (LHC). She works with Berkeley physics professors Marjorie Shapiro and Haichen Wang on campus and with scientists in the ATLAS group at Berkeley Lab. "I study the properties of the Higgs boson," she says, "in particular how it interacts with different types of quarks, including top, bottom, and charm quarks." Gray's other research interests include the development of track reconstruction algorithms for the upcoming High-Luminosity LHC, as well as algorithms to tag charm quarks. "A theme throughout my research is applications of machine learning," she adds.

Haichen Wang joined the Berkeley Physics faculty as assistant professor in January. He received a BS in physics from Peking University in 2007, and a PhD in physics from the University of Wisconsin-Madison in 2013. He was an Owen Chamberlain fellow at Lawrence Berkeley National Lab from 2013 to 2018 and is currently a member of the ATLAS collaboration on campus and at Berkeley Lab. Wang's PhD thesis was about the discovery of the Higgs boson, using data collected by the ATLAS experiment at CERN. "My research is focused on discovering new physics phenomena at the LHC," he says. "To further exploit the physics potential of the LHC I am also contributing to the upgrade of the ATLAS detector for the upcoming HL-LHC. We live in an exciting time for particle physics. The long awaited discovery of Beyond the Standard Model (BSM) physics may well be right around the corner."

Littlejohn Receives Distinguished Teaching Award

At a public ceremony held on April 24, Berkeley physics professor emeritus **Robert Littlejohn** was presented with a 2019 Distinguished Teaching Award, Berkeley's most prestigious honor for teaching. The award recognizes teaching that incites intellectual curiosity in students, engages them thoroughly in the enterprise of learning, and has a lifelong impact.

"I am deeply moved by the beauty of physics," Littlejohn says. "When you first learn the subject and see how beautiful it is, you just want to share it. There are ways in which learning about physics, especially certain subjects such as quantum mechanics and general relativity, permanently transform the way one views the world and one's place in it."

Littlejohn's students express appreciation for the clarity of his presentations, and for his lecture notes, which he provides as a supplement to textbooks. "In his notes the math details are really explicit, so it's not too hard to follow," says one student. Another student adds, "He is uniquely aware of what students most often struggle with. He's able to find ways to help us understand it by connecting it to things we've learned previously."

Professor emeritus Robert Littlejohn, recipient of a 2019 Distinguished Teaching Award, currently teaches Quantum Mechanics, Physics 221.

Building New Global Partnerships

Berkeley Physics is broadening connections with scientists around the globe, establishing new partnerships that bring international students and researchers to campus and to Lawrence Berkeley National Lab (Berkeley Lab).

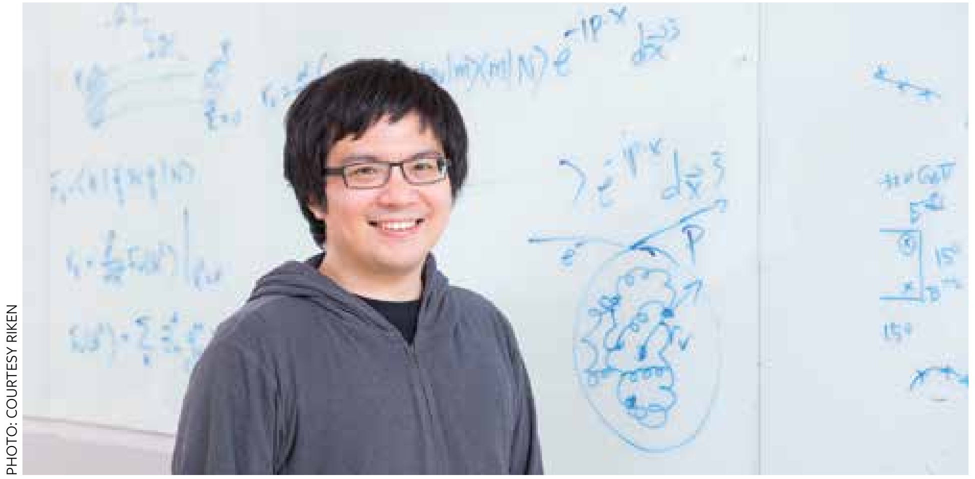


PHOTO: COURTESY RIKEN

Berkeley Physics postdoc Jason Chang is also a RIKEN researcher and member of the CalLat collaboration at Berkeley Lab. He headed the organizing committee for a highly successful RIKEN-Berkeley Quantum Information Workshop that took place in January.

PHOTO: KEEGAN HOUSER

Above: Students studying in the 7B Lab as part of the BPIE program.

Berkeley Physics International Education (BPIE)

The Berkeley Physics International Education (BPIE) program invites physics undergraduates from top-notch universities to spend a semester or two on campus. Launched in Fall 2018, BPIE gives upper division undergraduates from abroad a chance to take part in the outstanding academic experience Berkeley Physics has to offer, through Berkeley's concurrent enrollment program.

In part, BPIE is a response to a recent campus directive encouraging departments to create revenue generation programs that help sustain them in the face of budget challenges. "BPIE provides a new educational opportunity that would otherwise not be an option for international students," says **Claudia Trujillo**, Director of Student Services for Berkeley Physics. "The program contributes to student diversity on campus and, very importantly, allows us to continue to support programs and services for all of our physics students and our faculty."

During the 2018-2019 academic year, 42 students enrolled in the program, and a similar number is expected for 2019-2020. BPIE students complete 12 credits per semester of Berkeley Physics courses – credits that count toward a degree at their home university. Program participants also enjoy other benefits, from faculty-student lunches, career exploration panels, and tours of Berkeley research labs, to field trips and movie outings. Physics chair Wick Haxton notes, "The Department and our international partners owe Claudia great thanks for designing such a welcoming program."

"BPIE nominees are the top students at their home institutions," Trujillo notes. "All are majors in physics or physics-related fields." Nominees go through an application process to determine who will be invited to join the program.

"Current BPIE partner institutions include Shanghai Tech University, University of the Chinese Academy of Sciences, and Xi'an Jiaotong University," Trujillo adds, "and we look forward to launching additional partnerships around the world."

RIKEN and CNRS

Two research partnerships involve cooperative agreements with RIKEN in Japan and CNRS in France.

"RIKEN is analogous to Berkeley Lab," says physics chair Wick Haxton. "It's about the same size, the only lab of its stature in Japan, and has a mandate to invest a significant portion of its resources toward international projects."

The Berkeley-RIKEN effort was established by RIKEN's Interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS), which, after establishing partnerships with several leading Japanese universities, is now focusing on international opportunities.

The RIKEN partnership has brought several researchers to Berkeley, including postdoctoral fellow **Chia Cheng "Jason" Chang**, who arrived in May 2018. A nuclear physicist, he studies lattice quantum chromodynamics the fundamental theory of strong interactions. "My research centers around predicting properties of nuclei starting from modern quantum theory," Chang explains. "Such predictions play an important part in understanding and interpretation of particle and nuclear physics experiments aimed at, for example, discovering dark matter or uncovering the origin of matter."

"With the academic freedom granted to me by UC Berkeley and RIKEN," Chang continues, "I expanded my research and have made efforts to understand how quantum computing may play a role in the future of computationally intensive research fields such as nuclear physics." He has a long-term research fellowship with RIKEN that will allow him to spend an extended time at Berkeley, beyond what would be possible on a postdoctoral fellowship.

In August, an astrophysics delegation from RIKEN visited campus to discuss creation of a new Berkeley-based effort emphasizing supernovae, neutron star mergers, and other explosive astrophysical phenomena. These topics are of special interest to a number of Berkeley Physics faculty, including especially Dan Kasen and Elliot Quataert.

CNRS is the only large, multidisciplinary research institute in France. The Berkeley-CNRS partnership is expected to start up in 2020, with leadership from Berkeley Physics professor Saul Perlmutter and Robert Cahn of Berkeley Lab. "This initiative will establish a cosmology and astrophysics center," says Haxton, "with a scientific focus on dark matter, dark energy, gravitational waves, and similar topics."

Physics Innovators Initiative (Pi²): Going Strong

Berkeley Physics has embarked on a substantive effort to modernize laboratory equipment and classroom curricula for undergraduate physics courses. A new initiative, the Physics Innovators Initiative (Pi²), builds on the department's recent success in modernizing labs for Physics 5, the undergraduate course for advanced physics majors. The Physics 5 improvements include a new laboratory curriculum that emphasizes hands-on learning experiences.

Pi² will fund similar upgrades to our most popular undergraduate courses, including Physics 7, the main undergraduate course for physics and engineering majors. Pi² aims to prioritize experience with discovery, experimental design, and analysis, providing students with the technical skills they need to succeed in scientific research and innovation.

Major components of Pi² include construction of a new Tinkering Studio and a major upgrade of the Student Machine Shop. The Tinkering Studio offers a place where undergraduates can go beyond the format of a structured lab curriculum to explore independently and gain confidence in their ability to push boundaries and do something new. Revamping of the Student Machine Shop includes replacing decades-old equipment with the latest technologies in fabrication techniques and computer aided design – goals are not only to enhance educational impact but also to make sure students understand the importance of technologies like these for modern research.

PHOTO: SARAH WITTMER

Jesus (Jesse) Lopez (working at machine) is the new Student Shop Instructor and Principal Lab Mechanician. He is helping to identify what new equipment is needed for the shop, and changing the curriculum to better suit the needs of students in support of our research goals.

Associate Professor **James Analytis**, faculty lead for Pi², recently reported that work is well underway toward achieving these aims. "We've hired a new Shop Lead for the Student Machine Shop," he says, "and received some seed funding from campus towards a computer-controlled milling machine, SolidWorks™ software licenses, and computers for the Machine Shop, as well as a state-of-the art laser cutter for the Tinkering Studio."

Development of new lecture material that supports the laboratory experience is also underway. "We are in the process of refining the vision for the new curriculum and in the process of recruiting a new academic coordinator," Analytis adds, "who will be responsible for fine-tuning the new content of the lab course."

"We're off to a great start," says **Rachel Schafer**, Director of Development for Berkeley Physics. "We're still in the early phase of this initiative, and funding support from our alumni and friends will be crucial as we plan the scope of upcoming upgrades in more detail."

Milo Buitrago-Casas, a PhD student in Stuart Bale's research group at Space Sciences Laboratory, shows summer camp students in Colombia how rockets work.

Outreach in Colombia

In 2015 when graduate student **Milo Buitrago-Casas** first arrived on campus, he discovered he was only the third PhD physics student to come to Berkeley from Colombia, and the first ever from a non-private university. During that year he learned about teaching opportunities with Clubes de Ciencia, a series of non-profit summer camps that bring prominent scientists and high-quality research equipment to high school students living in disadvantaged and rural areas of Colombia. He quickly applied, and has taught there every summer since 2017.

Buitrago-Casas joined a chapter of the club in the small town of Bucaramanga, working with young people who have had little, if any exposure to science. He creates an environment in which students can identify with scientists who work in the field. Though extraordinarily rewarding, he acknowledges the experience also has its challenges. In one instance, a group of female students did not participate until he showed them that a female scientist was the "boss" of a major research project at a prominent university. Learning about a successful female scientist inspired the young women to join in camp activities, with great success.

Buitrago-Casas recently received a NASA research grant – Future Investigators in NASA Earth and Space Science and Technology – that will help fund his research at Berkeley, and with that, his work with Clubes de Ciencia. Also, the Center for Latin-American Studies on the Berkeley campus has helped him connect with other Spanish-speaking scientists who are teaming up to further develop the program in Colombia.

Buitrago-Casas stays in touch with his students through text messages and video calls. He looks forward to seeing some of them attend university and pursue a professional career, no matter what it is. His advice to all of them is, "Find your passion and follow it. It is possible."

STUDENT AWARDS

SURF/L&S Sciences Undergraduate Awards

Diego Pena
Dalila Robeldo
Peter Connick
Jinen (Timothy) Guo
Ryan Lee
Siyang Lee
Mingyu Li
Joshua Lin
Hunter Martin
Namrata Ramesh
Noah Stevenson
Zihang Wang
Zitong Yang
Jaime Zendejas
Huws Landsberger

2019 Physics Department Citation

Sijia Zhao

Lars Commins Memorial Award in Experimental Physics

Matthew Gilbert
Victoria Xu

Other Undergraduate Awards

Alexis Diaz: Livermore Lab Foundation Scholarship

2019 NSF Graduate Fellowships

Jonathan Cookmeyer
Dhruv Devulapalli (UG)
Spencer Doyle (UG)
Elizabeth Dresselhaus
Alexander Frenkel (UG)
Ankit Kumar
Vikram Nagarajan
Zachary Pagel
Hannah Weaver

Jackson C. Koo Award in Condensed Matter

Leigh Martin

Other Graduate Awards

Stephanie Mack: Winton-Kavli Exchange Fellowship to Cambridge, UK

Kyle Boone (PhD): The Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC), 1st place

Jennifer Barnes (former grad student): "Radiation Transport Modeling of Kilonovae and Broad-Lined Ic Supernovae" - 2019 HEAD Dissertation Prize

Brian Metzger (former grad student): the Rossi prize of the high energy astrophysics division of the American Astronomical Society

Marina Filip (postdoc): Speaker at the 2019 Rising Stars Physics Workshop, Stanford

Post Doc Awards

Ming Yi (postdoc and an assistant professor at Rice University): APS IUPAP 2019 Young Scientist Prize

Johannes Zehler (postdoc): Alexander Von Humboldt Postdoctoral Fellowship

DEPARTMENTNEWS

Invited Lectures

THE 2019 EMILIO SEGRÈ LECTURE

The Discovery of Pulsars: A Graduate Student's Tale was presented by **Jocelyn Bell Burnell** on November 1. Jocelyn Bell Burnell is a Visiting Professor at the University of Oxford and Chancellor of the University of Dundee. She has been President of the Royal Astronomical Society, in 2008 became the first female President of the Institute of Physics, and in 2014 the first female President of the Royal Society of Edinburgh. In this talk she described how pulsars were inadvertently discovered, described some instances where they were 'nearly' discovered, and outlined the properties of these amazing objects.

THE 2019 OPPENHEIMER LECTURE

Teaching for Learning - What I have Learned from Learning Research was presented by **Helen R. Quinn** on March 13. Dr. Quinn is a Professor Emerita of Particle Physics and Astrophysics at SLAC National Accelerator Laboratory and has taught physics at Harvard and Stanford. In her talk, Dr. Quinn addressed the importance of facilitating learning in the teaching process and explained the underlying research behind the "Framework for k-12 Science Education" with regard to new science standards.

Alumni Updates

Meng Luo (BA 2016, Physics and Astrophysics) graduated with a BA in astrophysics and with honors in physics, and is currently a third year PhD student in the Department of Physics and Astronomy at the University of Pennsylvania. Luo is working on SNO+ with Professor Joshua R. Klein to search for neutrinoless double beta decay, which could be used to probe the Majorana nature of neutrinos.

Elizabeth George (MA 2011, PhD 2013) is currently working as a Detector Engineer at the European Southern Observatory in Garching, Germany. Her main work is developing infrared detector systems for instruments on the Very and Extremely Large Telescopes, located in Chile. In addition to developing and delivering the detector systems, her group does detailed detector characterization and simulations to aid in predicting the impact of detector systematics on the data that will be acquired with these instruments.

Meng Luo

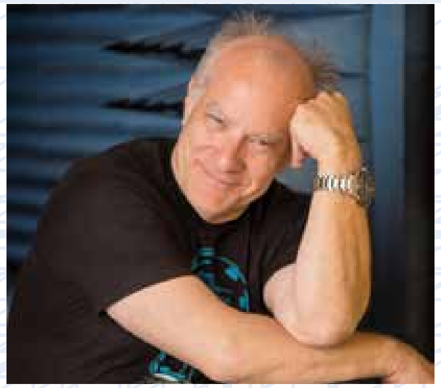
Elizabeth George

Alumni Updates (contd.)

Jason Chu (BA 2009, Physics and Astrophysics), after graduating with a physics and astronomy double major, went on to receive his Master's degree in 2011 and PhD in 2017 in astronomy from the University of Hawai'i at Manoa, Honolulu. His dissertation was titled "A Multi-Wavelength Study of Luminous Infrared Galaxies Across Cosmic Time." Chu is now a Science Fellow at the Gemini North Observatory on the Big Island of Hawai'i.

Hoover Wong (BA 1990) currently works as a Director of Design Assurance Engineering at BAE systems in San Jose. He recently took on the role as an Ethics Officer for his company, teaches a class at the Redwood City Community Center, and offers support to people in need of dissolving stress.

Jeffrey Hunt



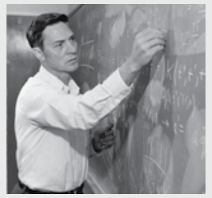
Jeffrey Hunt (MA 1981, PhD 1988) was promoted to Senior Technical Fellow at The Boeing Company, where he has worked since 1988. He is a Fellow of the American Physical Society and the Optical Society of America, and served on the executive leadership of the APS Forum on Industrial and Applied Physics from 2015 to 2019. Hunt holds 114 US patents, including some on quantum information technologies.

Bruce Cohen (BA 1972, PhD 1975) retired from the Lawrence Livermore National Laboratory after 40 years of service in 2017. In the spring of 2019, he completed "Theoretical Plasma Physics," a book with Professor Emeritus Allan N. Kaufman. This book will be published in the Lecture Notes Series in the Journal of Plasma Physics from Cambridge University Press.

Robert Dickinson (BA 1963) was CEO of California Micro Devices for 9 years before the company was sold to On Semiconductor in 2010. In 2011, he started Argos Analytics, whose mission is to help organizations prepare for climate change by focusing on future extreme weather events and climate-aware design tools. Most recently, the company is planning for the impact that changing climate conditions will have on winegrowers.

Thomas Schneck (BA 1961) served as an Air Force communications officer before starting a family and working as a patent engineer at the Lawrence Livermore National Laboratory. He received a law degree in 1971 and in 2017-2018, and was a pro-bono attorney representing immigrant mothers and children detained by the Department of Homeland Security in a detention center located in Dilley, Texas.

In Memory



Geoffrey Chew passed away on April 12, 2019. Chew was a student of Enrico Fermi. He joined the Berkeley Physics faculty in 1957, becoming emeritus professor in 1991. Over his career he mentored and graduated over 70 PhD students, including David Gross and John Schwarz. and led an influential theory group. He was a member of the National Academy of Sciences and the American Academy of Arts and Sciences.

Martin Halpern passed away on January 21, 2018. He joined the Berkeley Physics faculty in 1972, retiring in 2012. A theoretical physicist, Halpern contributed to several fields, perhaps most notably quantum field theory and string theory. His many honors included a NATO fellowship at the European Organization for Nuclear Research in Geneva and a Princeton University fellowship at the invitation of J. Robert Oppenheimer.

Charles Kittel passed away on May 15, 2019. He served on the Berkeley physics faculty from 1951 to 1978, becoming emeritus professor in 1978. His textbook *Introduction to Solid State Physics* remains a classic. Kittel is often credited with bringing the field of solid state physics to Berkeley. His honors include a Berkeley Distinguished Teaching Award and membership in the National Academy of Sciences and the American Academy of Arts and Sciences.

Suzanne Pierce passed away on April 29, 2019. Suzanne was Director of Administration for Physics from 1994 through 2004. She created a highly effective Management Team focused on the removal of campus obstacles to physics research. Suzanne came to Physics from Graduate Division and went on to serve as Senior Strategic Advisor to Vice Chancellor for Research.

Frederick Reif passed away on August 11, 2019. He taught for 29 years at Berkeley, and cofounded the interdisciplinary PhD program for science and mathematics education in 1969. His many accomplishments include the status of professor emeritus at Berkeley and Carnegie Mellon, the 1994 Robert A. Millikan Medal, 3 books on thermal and statistical physics.

Eyvind Wichman passed away on February 16, 2019. He joined the Berkeley Physics faculty in 1951, retiring in 1993. Wichman authored the widely-used textbook *Quantum Physics*. His honors include a UC Berkeley Distinguished Teaching Award, a Sloan Fellowship, and the 1999 Symposium on Mathematical Physics and Quantum Field Theory held in honor of his 70th birthday.

2019 Berkeley Physics AT A GLANCE

A look at the students and faculty who make up Berkeley Physics

Undergraduate Physics Majors

271 Total # of students

♂ 202 | 63 ♀ | 6 prefer not to say

131 BAs Awarded 2018-19

89 Transfer Students

Graduate Physics Majors

279 Total # of students

♂ 221 | 55 ♀ | 3 prefer not to say

46 PhDs Awarded 2018-19

22 Countries Students Are From

Physics Faculty

62 Active Faculty

35 Emeritus Faculty

3 Active Nobel Laureates

24 Members of the National Academy

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

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)

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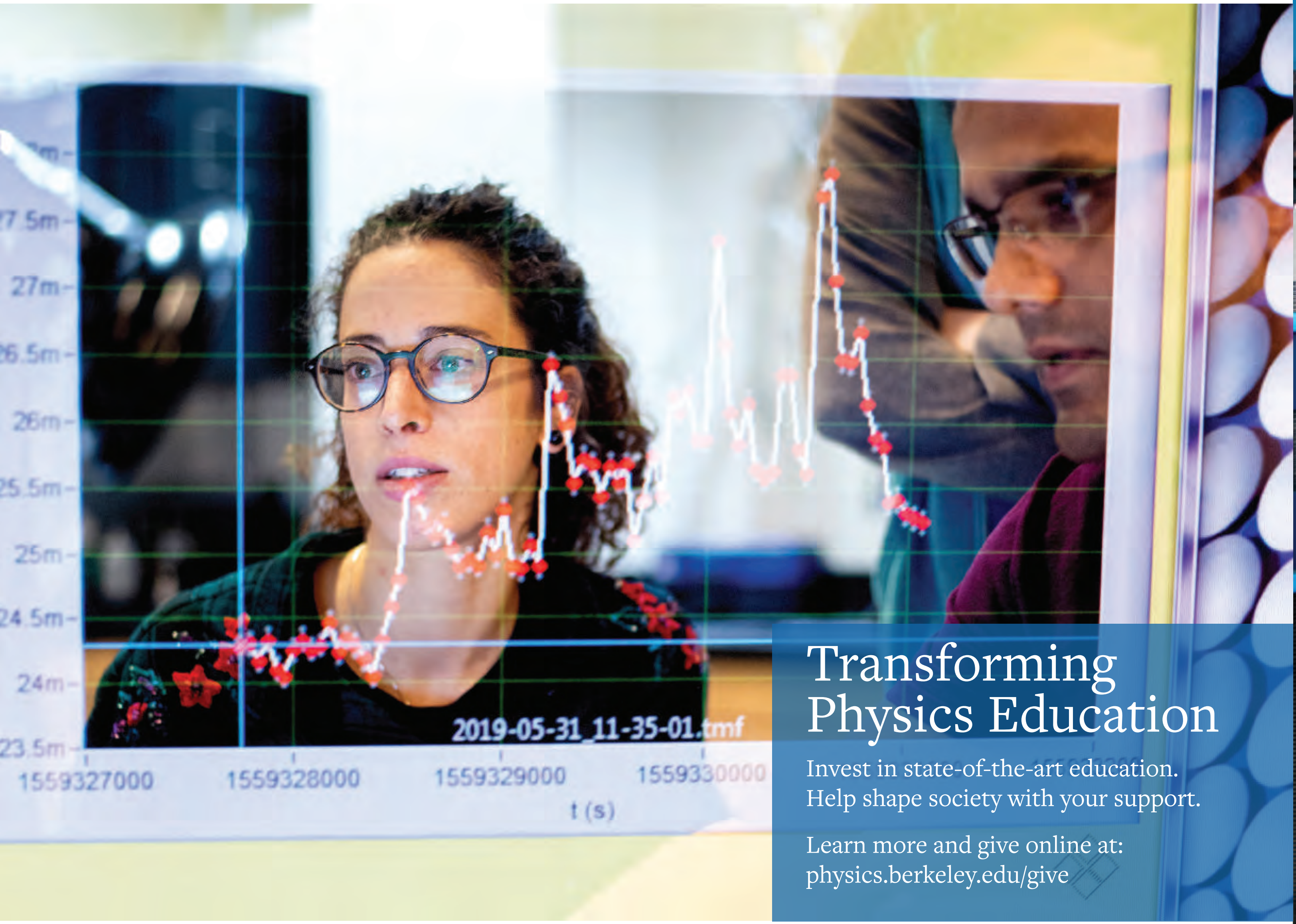

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