FALL 2016

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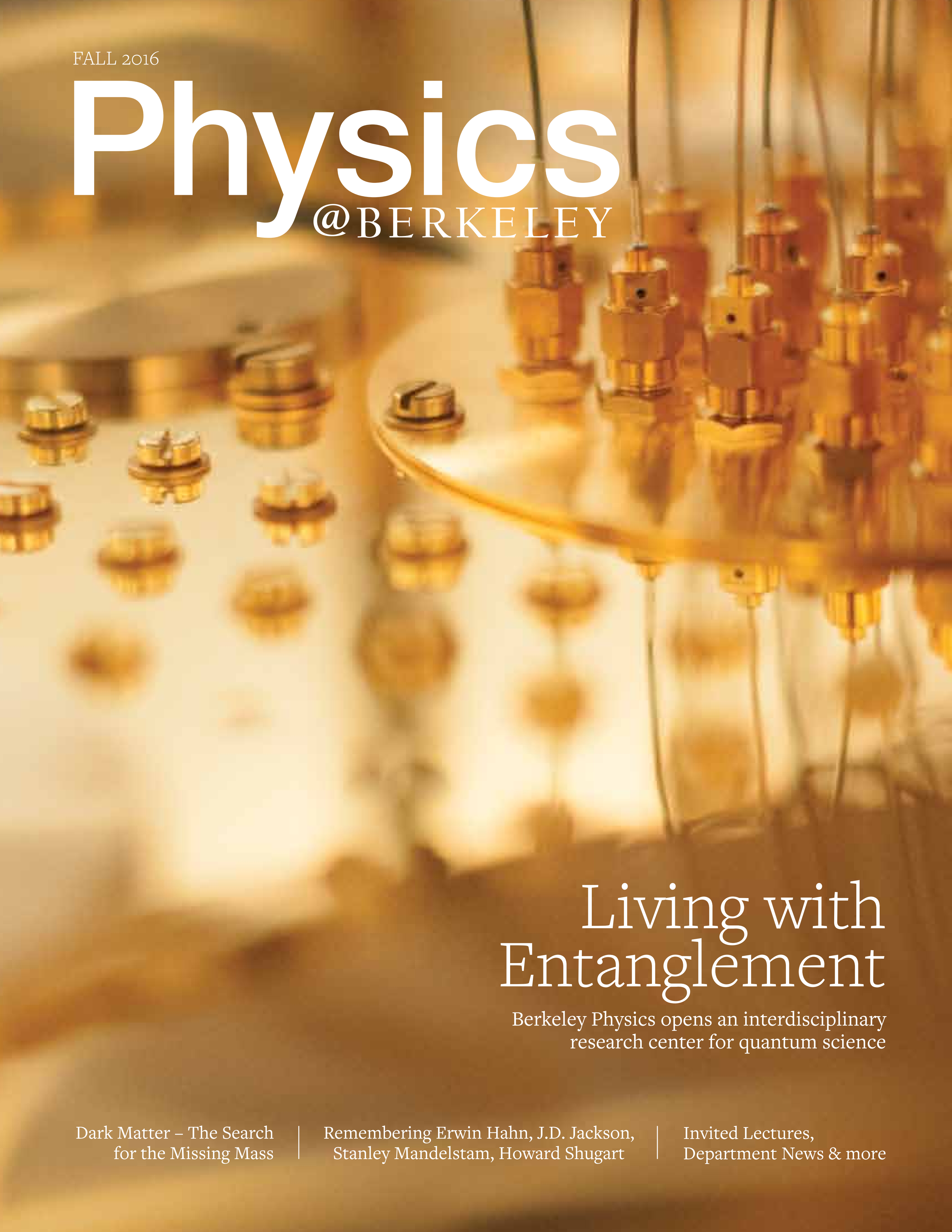


Living with Entanglement

Berkeley Physics opens an interdisciplinary research center for quantum science

Dark Matter – The Search for the Missing Mass | Remembering Erwin Hahn, J.D. Jackson, Stanley Mandelstam, Howard Shugart | Invited Lectures, Department News & more

Dear Alumni, Parents, Colleagues and Friends,

Greetings from Berkeley!

I am both thrilled and sad as I write this year's letter—my last as chair of this incredible department. In January 2017, I will join UC San Diego as Dean of Physical Sciences, overseeing the departments of Physics, Chemistry & Biochemistry, and Mathematics.

Chairing Berkeley Physics has been an incredible opportunity. I am grateful and humbled to have been entrusted with the challenge of leading the top physics department in the world and it was a pleasure to work with the very best faculty, staff and students. Hearing from alumni, donors and community supporters on the difference Berkeley Physics made in their lives also greatly enhanced my tenure. I am proud of all that's been accomplished.

What you may not be aware of is that Berkeley Physics has actually been my home since 1991, when I first came to this department as a graduate student. It's hard to believe it has been 25 years! I could never have imagined as a bright-eyed graduate student that I would one day be a professor, much less chair. But Berkeley gave me the opportunity to develop into a physicist and a scientific leader. I learned how to ask fundamental questions about our universe, and develop new ways to answer those questions. And in true Berkeley tradition, I have never stopped learning and growing—as a student, as a professor, and now, as chair.

That is true of the department as well. We continue to grow each year, pushing the boundaries of research, educating future leaders of science and industry, and continuing to build off the distinguished history of the department. Making a positive impact on society and forging great achievements is in the Berkeley Physics DNA. It's just what we do.

Professor Wick Haxton has been named the new Chair of Physics—and he will assume this position in July 2017. I know Wick comes with a number of new ideas that will take the department in exciting new directions. Until then, Professor Joel Moore, a trusted colleague and proven leader among the faculty, will be taking over the interim duties.

Physics Major Curriculum

Berkeley Physics is proud to be one of the largest departments for undergraduate physics majors in the country. The reputation of this department has been built through the success of our students! To better prepare them for success in today's world, we have been rolling out major revisions to our undergraduate physics major curriculum. These revisions will better prepare our students for research earlier in their studies, starting freshman year, to maximize their opportunities to participate in cutting-edge research at Berkeley. These revisions will also create more flexibility in the curriculum during their junior and senior years, allowing students to better specialize for careers in industry, teaching, or academic research. This past year we introduced two new courses. "Introduction to Mathematical Physics," designed to launch majors into their sophomore years with all the math tools they need to master higher-level physics subjects. In the Spring, we are offering "Introduction to Computational Techniques in Physics," a freshman-level course designed to introduce basic concepts of solving physics problems numerically, a powerful tool for succeeding in their classes and preparing them for research. Read more about our new physics courses on page 28.

New Reading Room

A huge thank you to all of our friends and alumni who helped create the new Reading Room and Collaboration Center on the first floor of Le Conte Hall. A fantastic grand opening celebration in February unveiled this new space for undergraduate majors! This center is well utilized by the students for study and collaboration, social interaction, and peer tutoring. I usually see the room quite packed with students, working together on the big black boards or else quietly studying alone or in small groups in the café-style Ron Shen Common Room. The overall space is dedicated to the late Professor Emeritus Harry S. Bingham and was made possible with the assistance of numerous supporters. It will have a lasting impact on physics majors for years and decades to come. Read more on page 25.

Fiat lux!

–Steve Boggs

On the Cover: Closed-cycle, 10 milliKelvin dilution refrigerator for operating dozens of entangled quantum circuits
Photo: Keegan Houser

Physics at Berkeley 2016

Published annually by the
Department of Physics
Steve Boggs, Chair

Devi Mathieu, Editor, Principal Writer

Meg Coughlin, Design

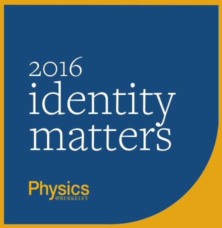
Cover and additional design assistance provided by Sarah Wittmer,
Visual Communications Specialist

Susan Houghton, Managing Editor

Rachel Schafer, Director of Development and Communications

Contributors: Corinne Lamata,
Sophia O'Brien

Department of Physics
366 LeConte Hall #7300
University of California, Berkeley
Berkeley, CA 94720-7300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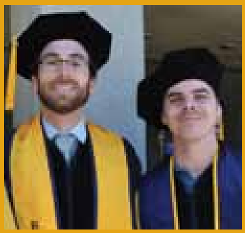


Search for the Missing Mass

Berkeley Physics Leads the Hunt for Dark Matter

Photo: Peg Skorpinski

WE CALL IT DARK because it neither emits nor absorbs electromagnetic radiation. We call it dark because we don't know what it's made of. Though we haven't yet glimpsed it directly, we know it's there.

We've seen its gravitational effects—it holds galaxies together, gathers them into clusters, bends light around them, and influences the speed of their rotation. We know it's responsible for the density fluctuations in the early universe as observed in the cosmic microwave background. Yet it travels through ordinary matter unhindered and undetected.

We hunt for dark matter because it makes up most of the matter in the universe. It's clearly a crucial piece of the cosmic puzzle. As Berkeley Physics Professor **Dan McKinsey** says, "It's one of the most important scientific questions of our age."

Dark matter is at least five times more abundant than ordinary matter—the protons, neutrons, and electrons that form stars, planets, people, and all the other objects we know about. It holds important clues to understanding the origin of all matter and the evolution of the cosmos. The ability to directly observe and study dark matter will reveal heretofore unknown laws of nature.

Berkeley Physics is a global leader in the quest for direct evidence of dark matter particles. No less than six of our physics faculty, along with collaborators within the department, at Lawrence Berkeley National Laboratory, and at other institutions around the world, are busy conducting experiments and devising new ones cunning enough to overcome the many challenges this hunt presents.

Experimental physicists at Berkeley have played central roles in the design, construction, and operation of two of the most sensitive dark matter searches ever conducted—the Large Underground Xenon Experiment (LUX) and the Cryogenic Dark Matter Search (CDMS). Both of these experiments made significant progress in narrowing the possibilities for what dark matter might be. Both experimental designs show so much promise that they've gained joint support from the Department of Energy and the National Science Foundation to move forward as Next Generation Dark Matter Experiments.

Theoretical physicists at Berkeley are hunting too, developing innovative new approaches to the search. They've already created analysis methods to help ensure that as much information as possible is extracted from experimental data. And they're working in tandem with experimentalists to extend the search for dark matter into unexplored territory.

Berkeley Physics Professor Dan McKinsey (L) and graduate student Kate Kamdin are members of the collaboration now developing the LZ dark matter experiment. They are shown with a device that measures electron extraction efficiency in liquid xenon detectors, developed by Principal Investigator Peter F. Sorensen, a Divisional Fellow at Berkeley Lab.

Searching for WIMPs

Direct detection of dark matter particles is tricky business. It requires identifying and measuring what happens when dark matter interacts with ordinary matter. Such events are exceedingly rare, and any evidence they produce is all too easily overwhelmed by ubiquitous background radiation coming from interactions among particles of ordinary matter.

"It's a little like looking for a single snowflake in a blizzard," says Physics Professor Dan McKinsey.

Rarity and background noise aren't the only challenges. Equally important is figuring out exactly what to look for. For the past few decades, the most promising candidates for dark matter particles have been WIMPs (weakly interacting massive particles). However, since WIMPs haven't yet been detected, other theories are beginning to gain ground.

Multiple WIMP theories have been proposed, and they encompass an enormous spectrum of possibilities. WIMPs are weakly interacting but heavy dark matter particles that were produced in the high temperature plasma of the Big Bang, but soon after ceased to interact with normal matter. Predictions of WIMP masses range anywhere from 10 to 10,000 GeV: one GeV is roughly the mass of the proton.

Searching for WIMPs has been the primary aim of the Large Underground Xenon (LUX) experiment and the Cryogenic Dark Matter Search (CDMS). Both experiments are now complete, and the design and construction of their successors is well underway.

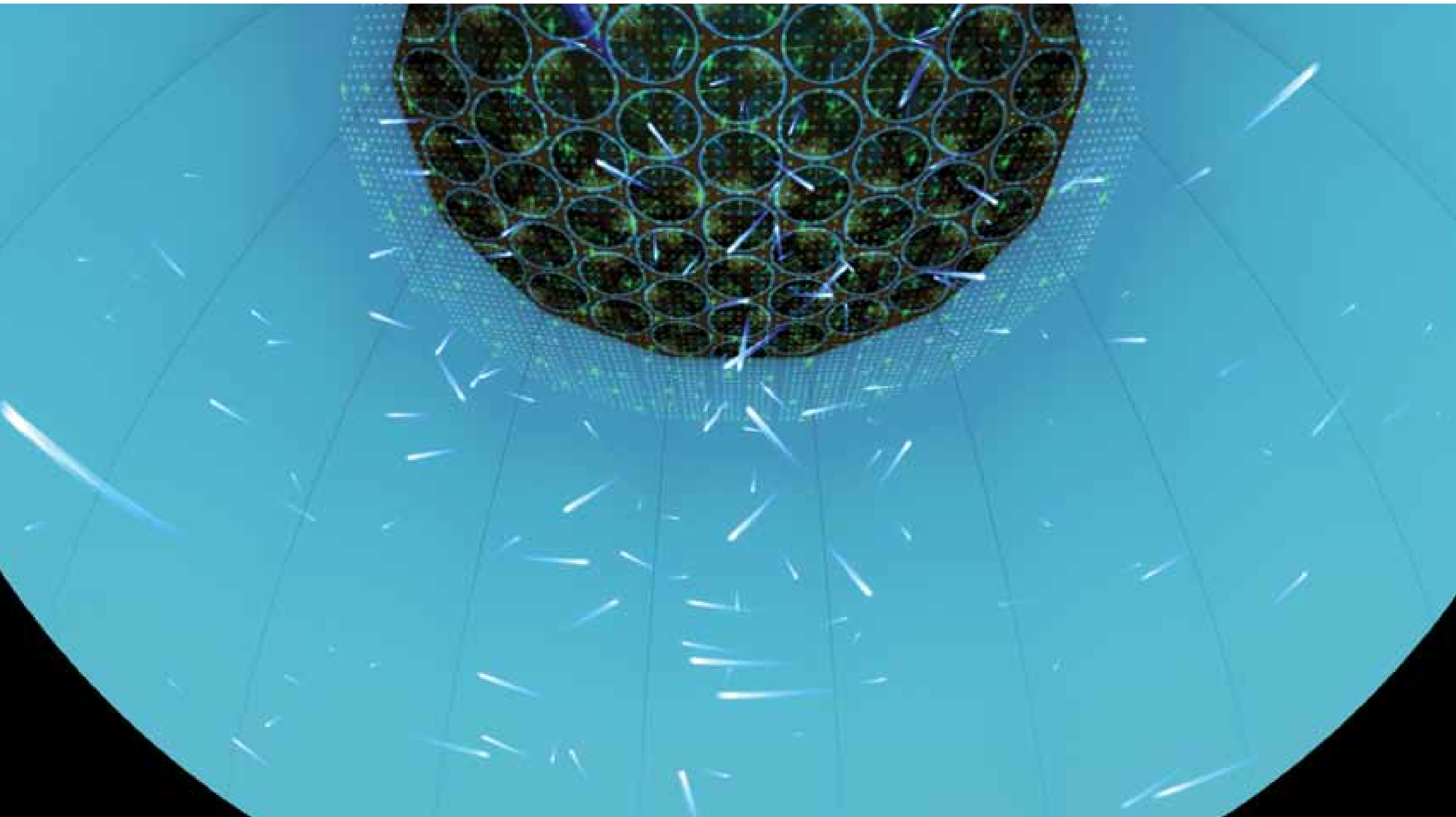
LUX-Zeplin (LZ), the successor to LUX, will search the entire spectrum of possible WIMP masses with much greater sensitivity than LUX. CDMS is becoming SuperCDMS, which will search for dark matter particles less massive than WIMPs, in the range of 0.1 to 10 GeV.

Large Underground Xenon (LUX) Experiment

LUX has been a central research focus of Physics Professor Dan McKinsey for the past decade. A world-renowned expert in the field of dark matter detection, McKinsey joined the Berkeley Physics faculty in July 2015, coming to campus from a post as Physics Professor at Yale University. Co-leader of LUX, he also is a collaborator in its successor experiment, LZ.

Top deck of the LUX dark matter search, 4850 feet underground in the former Homestake Mine in North Dakota. Dan McKinsey (L), and Richard Gaitskell of Brown University serve as co-spokespersons for LUX. Gaitskell was a postdoc in Berkeley physicist Bernard Sadoulet's research group during the 1990s, working on the Cryogenic Dark Matter Search (CDMS).

A simulation of particles interacting with liquid xenon inside the LUX experiment. Credit: "Phantom of the Universe"



Housed almost a mile underground at Sanford Lab in North Dakota, LUX—shown here under construction—sat in the same cavern in which neutrinos were first detected by Nobel laureate Ray Davis in the 1950s. LZ will be installed in the same location.

In addition to being a Berkeley Physics Professor, McKinsey is a Senior Scientist at Lawrence Berkeley National Laboratory (Berkeley Lab), where much of the design, construction, and analysis of LUX took place and where many LZ components are being developed. Among the many scientists at Berkeley Lab with important roles in the LUX and LZ collaborations are physicist **Mike Witherell**, who became a Berkeley Physics Professor and Director of Berkeley Lab in January this year (see his profile on p 31).

LUX completed its experimental runs this May, and final results were announced in July. Although the experiment did not see a dark matter signal, it set the most detailed constraints yet on what dark matter might be. "There are many dark matter theories," McKinsey notes, "and LUX eliminated a large number of those possibilities. We made great progress."

The experiment's superb sensitivity was due in large part to innovative calibration measures developed by the collaborators to confidently distinguish dark matter signals from conventional radiation. "The charge and light signal response of the LUX experiment varied slightly over the dark matter search period," McKinsey explained in a media release. "Our calibrations allowed us to consistently reject radioactive backgrounds, maintain a well-defined dark matter signature for which to search, and compensate for a small static charge buildup on the Teflon inner detector walls."

The LUX collaboration involved 18 research institutions in the US, UK, and Europe. Berkeley Physics became involved early in the project, when Professor **Bob Jacobsen** and his group joined to help with detector construction. Jacobsen and his students provided micro-fabrication of several components, assisted with assembly, and contributed to data analysis.

LUX-Zeplin (LZ)

McKinsey now focuses increasing attention on LZ, a detector with many similarities to LUX, but 25 times larger and 70 times more sensitive. "We'll have a lot more xenon atoms," he points out, "so we'll have a much better chance of encountering an interaction."

LZ is being designed to make the most sensitive search possible through the entire range of WIMP masses and possible coupling energies. If LZ doesn't see WIMPs, many more dark matter theories will be ruled out. "In particular," McKinsey says, "theories in which the WIMPs interact with ordinary matter by exchanging a Higgs boson—the same particle discovered recently at the Large Hadron Collider—will be exhaustively probed."

The LZ collaboration includes Berkeley Physics, Berkeley Lab, and Brown University, plus dozens more research institutions worldwide. Design and construction of LZ system components is now underway, with underground installation set for 2018 and startup expected by 2020.

How LUX and LZ Work

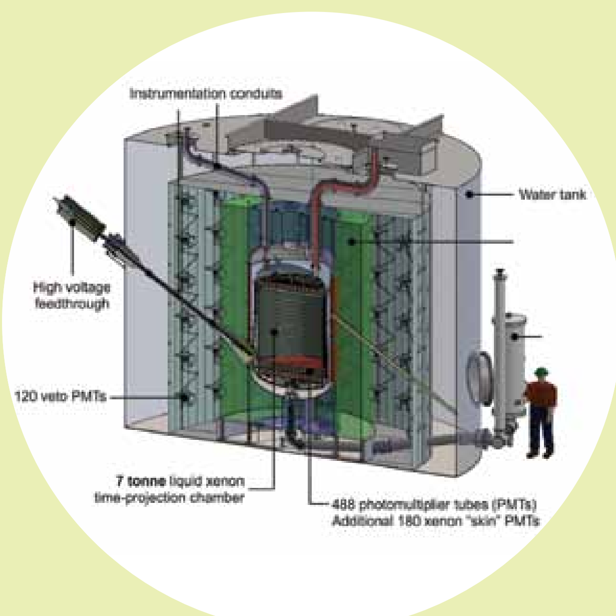
Both the LUX and LZ dark matter searches use highly purified liquid xenon (Xe) as the target for dark matter collisions. The detector looks for photons given off when a dark matter particle strikes the nucleus of a Xe atom. “We use an array of photomultiplier tubes immersed in the liquid Xe to look for these bits of light,” Berkeley physicist **Dan McKinsey** explains. “Our threshold for the amount of light needed to identify a potential dark matter interaction is very low, only two photons.”

“Detection is actually a two-step process,” he continues. “When a xenon nucleus recoils from an impact, photons are fired in an initial flash of light, and an electric charge is produced. A strong electric field in the detector extracts this charge, pulling it to the top of the tank and creating a second, delayed flash that is much larger than the first.”

The pattern and timing of the two flashes pinpoints each event’s location within the detector, as well as its energy. This information is used to reconstruct the interaction and determine whether or not it’s a dark matter signal.

LUX was an 815-pound vat of liquid Xe held at -100 degrees Centigrade, instrumented with 122 photomultiplier tubes and an array of charge detectors. It was installed almost a mile underground and immersed in a 72,000-gallon tank of purified water for shielding from cosmic rays and other background radiation.

LZ will be much larger, containing ten tons of liquid Xe and instrumented with 488 photomultiplier tubes for signal detection. LZ will be immersed in the same underground cavern and the same tank of purified water as LUX.



Cryogenic Dark Matter Search (CDMS)

Berkeley Physics Professor **Bernard Sadoulet** has been a world leader in the search for dark matter for more than three decades. He pioneered the first experiment to use low-temperature solid-state detectors to look for dark matter particles scattering off from collisions with the nuclei of ordinary atoms. Research performed by Sadoulet’s Particle Physics Group has been central to development and operation of CDMS technology.

From 1995 until about 2011, CDMS dominated the hunt for dark matter. It was the world’s most sensitive experiment in the search for WIMPs during that time period, setting the most stringent limits on possible WIMP interactions at masses above 7 GeV. When xenon technology, like that used in LUX, became mature, Sadoulet says, “CDMS shifted focus to lighter mass ranges, where its high signal to noise and sensitivity is unique.”

Sadoulet joined the dark matter search soon after he arrived at Berkeley, in 1985. “I got involved very close to the beginning,” Sadoulet remembers. “I had just been appointed to the physics department when theorists began to realize that if dark matter is made of particles, they could be detected in the lab. Colleagues and I began to look at the possibility of using phonons.” Phonons are vibrations generated when atoms of a crystal are struck under conditions of very low temperature.

Sadoulet credits a conversation with Berkeley Physicist **Marvin Cohen** as critically important to the inspiration for CDMS. Cohen, now Emeritus Professor, pointed out that if the nucleus of an ordinary atom in a crystal was struck by a dark matter particle, the nuclear recoil would produce not only phonons but also a tiny amount of ionizing radiation.

That insight prompted Sadoulet and his collaborator, Blas Cabrera of Stanford, to conceptualize an instrument capable of not only detecting a dark matter event but also distinguishing it from background radiation, and with very high precision. Their ideas evolved into a design philosophy that resulted in CDMS and was adopted later on by the developers of LUX.

“The phonons give a measure of the total energy of the event,” explains Sadoulet. “We also measure the ionization. If the ionization energy is high compared to total energy, that’s an electron recoil, a normal radioactive background event. But if the ionization energy is depressed by a factor of about three, that’s a nuclear recoil, from a dark matter collision. That’s basically the calculation we made here at Berkeley.”

Another important contribution to development of CDMS technology came from Berkeley Physics Professor Emeritus **John Clarke**, who pioneered the development of SQUIDs—Superconducting Quantum Interference Devices. Sadoulet notes that SQUIDs are among the most sensitive detection technologies available today. And he points out that their contributions to dark matter searches like CDMS is just one of myriad ways in which SQUIDS are used in modern physics.

CDMS was conducted in a series of three increasingly sensitive experiments. Sadoulet led the CDMS experimental collaboration from its inception and now leads SuperCDMS.

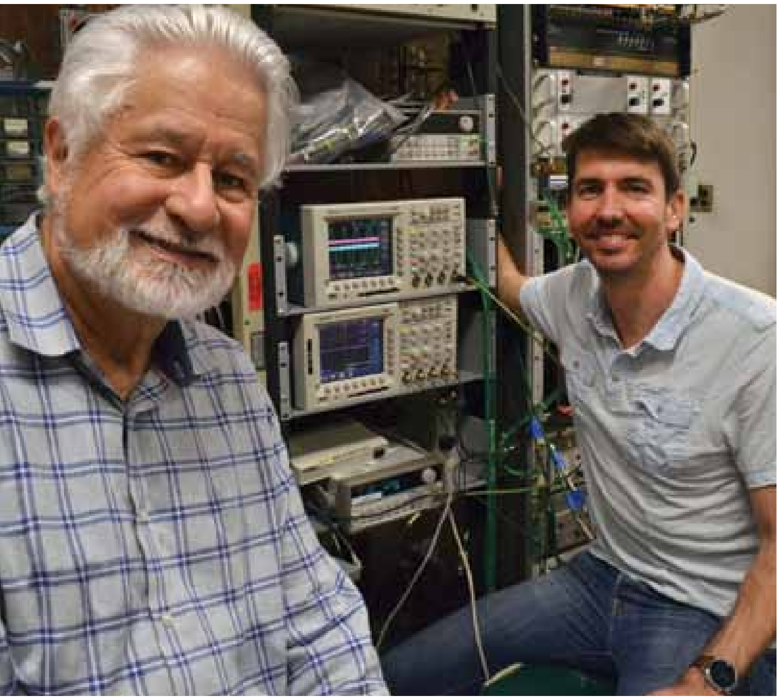


Photo: Sarah Wittmer

Berkeley Physics Professor Bernard Sadoulet (L), a member of the Berkeley Physics faculty since 1985, leads the CDMS and SuperCDMS experiments. Sadoulet also serves as Director of the Institute for Nuclear and Particle Astrophysics and Cosmology at Berkeley Lab. Matt Pyle joined Berkeley Physics in 2015, after spending two years as a postdoc in Sadoulet's lab. He develops innovative, high-precision detectors.

SuperCDMS and Asymmetric Dark Matter

SuperCDMS, the successor to CDMS, will complement the LZ search. A mass of 10 GeV is about the lightest dark matter particle LZ can expect to detect, and that's where SuperCDMS takes over. It's being designed to search for dark matter particles with masses ranging from 10 GeV to as light as 0.1 GeV.

"This moves us out of the range of WIMPs," says Berkeley Physicist **Matt Pyle**, "into asymmetric dark matter." Asymmetric dark theory posits that dark matter particles carry a matter-antimatter asymmetry just like ordinary matter does. The mass of asymmetric dark matter is expected to be similar to, or perhaps somewhat heavier than, the mass of a proton or neutron.

Detecting particles with these comparatively light masses requires "amazing sensitivity that has not yet been achieved," Pyle notes. He calls himself a "detector physicist" who develops new, high-precision instruments not only for SuperCDMS and other dark matter searches, but also for advanced explorations of other fundamental physics questions.

Many technologies detect phonons by measuring the heat their vibrations produce. "Instead," Pyle says, "our detectors collect and concentrate these vibrations before they thermalize, which will hopefully allow us to be hundreds of times more sensitive."

Design of SuperCDMS will continue until the end of 2017 and, following construction, the experiment is expected to begin operating by 2020.

Effective Field Theory

Berkeley Physics Professor **Wick Haxton,** a theorist, and his research group contributed an important enhancement to the scope and precision of the LUX and CDMS experiments. They did so by applying a template known as Effective Field Theory to the data analysis. "What sparked this research was concern that our experimentalists get everything they could from their data," Haxton says.

"The framework that LUX and CDMS had been using for data analysis was limited to one or two possible ways a dark matter particle might scatter from ordinary matter," he explains. "In theory, there are all kinds of ways dark matter could be incorporated into some extension of our Standard Model. My colleagues and I began to think of ways to make the experimental analysis more general, but not too complicated."

"A tool used throughout theoretical physics, known as Effective Field Theory, can be applied to such problems," Haxton continues. "We formulated the elastic scattering of a dark matter particle off a nucleus within this theoretical framework."

Instead of the one or two scattering responses experimentalists had been using, Haxton's group found there were in fact six. "Basically," Haxton says, "we found that experimentalists are able to see a whole class of theories they previously thought they were blind to."

McKinsey adds, "Wick and his group systematically went down the list of possibilities and gave us a full list of the interactions we could look for with various nuclear targets. It's a sort of 'completeness theorem'." And it's now been adopted by other dark searches around the world.

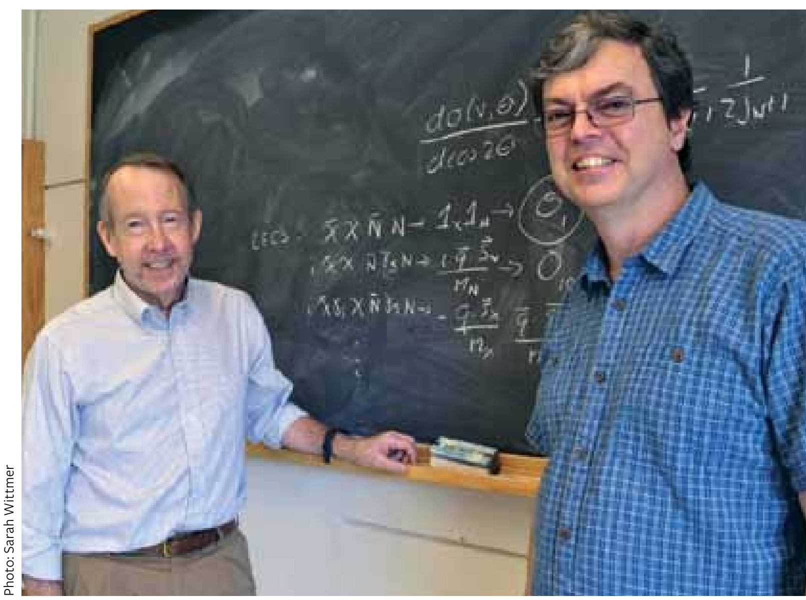


Photo: Sarah Wittmer

Berkeley Physics Professor Wick Haxton (L) and graduate student Ken McElvain (R), along with colleagues at Stanford, developed a data analysis approach that maximizes information obtained from dark matter searches like LUX, LZ, CDMS, and SuperCDMS.

How CDMS Works

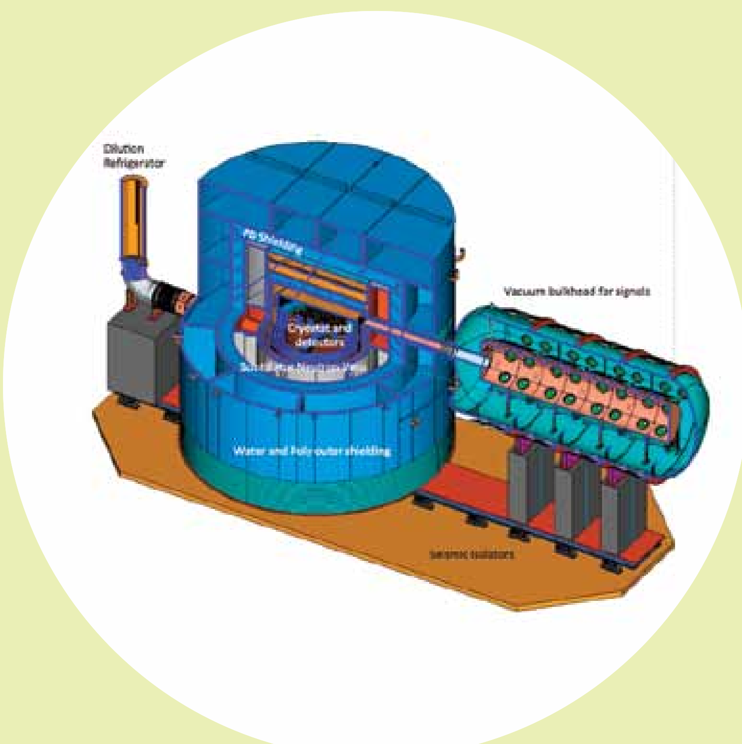
At the heart of CDMS dark matter detectors are advanced germanium semiconductors capable of distinguishing dark matter signals from normal background radiation with very high precision.

CDMS technology uses super-cooled Germanium (Ge) crystals as the dark matter target. The experiment's extreme sensitivity stems from the precision with which it can distinguish potential dark matter signals from conventional radioactive background. Like other earth-based dark matter searches, CDMS is housed underground for shielding from cosmic ray radiation. It's also immersed in purified water and surrounded with special materials to further exclude background signals.

When a Ge nucleus is struck by a dark matter particle, it recoils, creating vibrations called phonons and a tiny amount of ionizing radiation. The ratio between the total energy of an event, as measured by the number of phonons produced, and the ionization energy determines whether the event involves dark matter and is used to reconstruct the location of the event within the detector.

CDMS was conducted as a series of three experiments located a half-mile underground in an abandoned iron mine in Minnesota, the Soudan Underground Laboratory. SuperCDMS, designed to search for lower mass, asymmetric dark matter, will be installed more than one mile underground, at SNOLAB in Ontario, Canada.

Compared with LUX and LZ, solid-state CDMS technology is more sensitive to the very small recoils produced from interactions of dark matter particles with masses less than 10 GeV. Its smaller size, though, means it covers less area and so has a proportionally smaller chance of encountering a dark matter interaction. The two technologies complement one another very well. SuperCDMS is being designed to detect asymmetric dark matter particles, which are lighter than WIMPs, while the design of LZ will favor detection of WIMPs.



"Berkeley Physics is a department where so much is happening that good people want to come and be a part of it."

Teaming Up to Lead the Way

Having so much interest in dark matter among so many Berkeley Physics researchers working in such close proximity increases in-person interactions, leading to new ideas and attracting yet more researchers. "Berkeley Physics is a department where so much is happening that good people want to come and be a part of it," says Bob Jacobsen.

Haxton's work with Effective Field Theory is just one example of new ideas sparked by the critical mass of interest in dark matter among Berkeley Physics faculty. Here's another: Berkeley theoretical physicist **Surjeet Rajendran** has teamed up with Berkeley Physics Professor **Dima Budker,** an experimentalist, and other colleagues to look for axions, dark matter particles with very light mass. This effort, called the CASPEr experiment, makes use of precision nuclear magnetic resolution techniques pioneered by Budker's research group.

CASPEr stands for 'Cosmic Axion Spin Precession Experiment'. Rajendran says, "It will look for a time-varying electric dipole moment of protons and neutrons caused by a type of axion called the QCD axion—we call this the axion electric effect. CASPEr will also look for the rotation of nuclear spins induced by the velocity of the axion—we call this the axion wind effect."

LUX is the subject of an award-winning documentary produced in 2015 by the radio program *Science Friday*. The video, *4850 Feet Below: The Hunt for Dark Matter*, can be viewed at ScienceFriday.com.

Dan McKinsey recently joined forces with Berkeley Lab theoretical physicist Kathryn Zurek to pioneer a new approach that uses superfluid helium as a dark matter target. "We have some ideas about new experimental signatures for extremely low-mass dark matter," McKinsey explains. "Superfluid helium is sensitive to extremely low-mass dark matter, while also being able to reject natural radioactivity and instrumental backgrounds." Matt Pyle is on board as well, designing supersensitive instruments capable of detecting very low-energy events.

"This superfluid helium collaboration is just one more new idea that's arisen from us being in the same place at the same time," McKinsey notes.

Bernard Sadoulet puts it this way: "That we are all in the same place, that we so effectively join theory and experiment, that we tend to speak together quite a bit, that we are discovering how we can combine our technologies... All this makes us probably the leading dark matter institution worldwide."

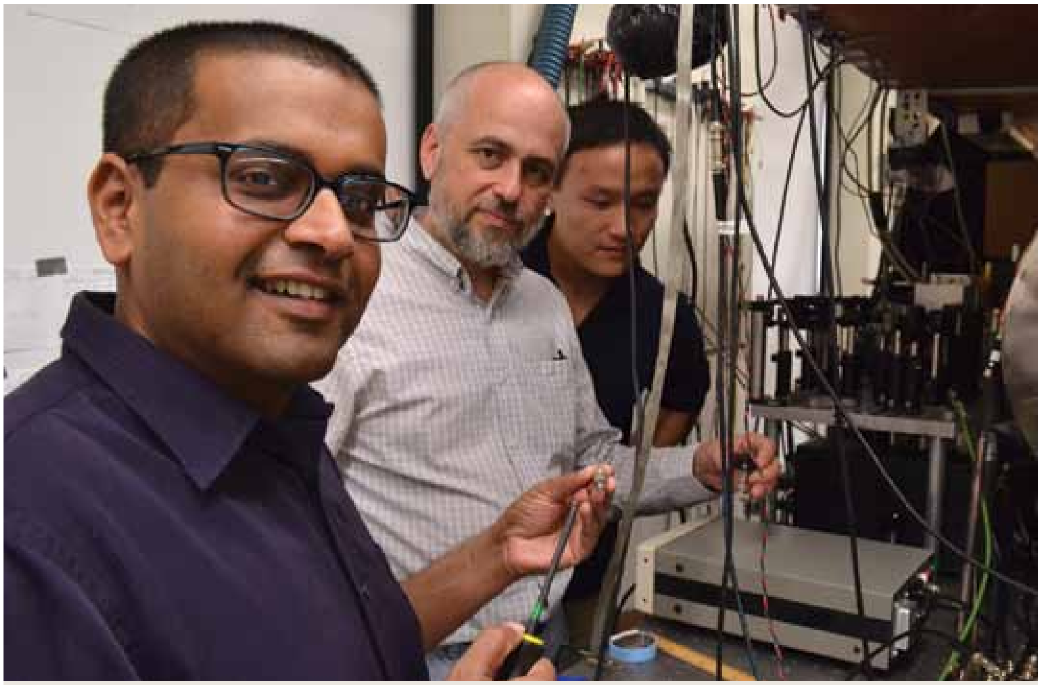


Photo: Sarah Wittmer

Berkeley theoretical physicist Surjeet Rajendran (L) works with Berkeley experimental physicist Dima Budker (C) and visiting graduate student from China Wenhao Li on the CASPEr experiment, searching for axions.

Tantalizing New Ideas

Theorist **Surjeet Rajendran** began developing unique approaches to the dark matter search even before joining the Berkeley Physics faculty in 2014. One of his special interests is the notion that dark matter consists of extremely light particles, with masses on the order of 10^{-22}eV to 10^{-6}eV. "There are about seven ways in which these particles can couple to ordinary matter," he reports. "We are developing experimental techniques to look for all of them."

One of those techniques is the CASPEr experiment he and Berkeley Physics Professor **Dima Budker** are developing. It uses highly sensitive magnetometry to measure spin rotation.

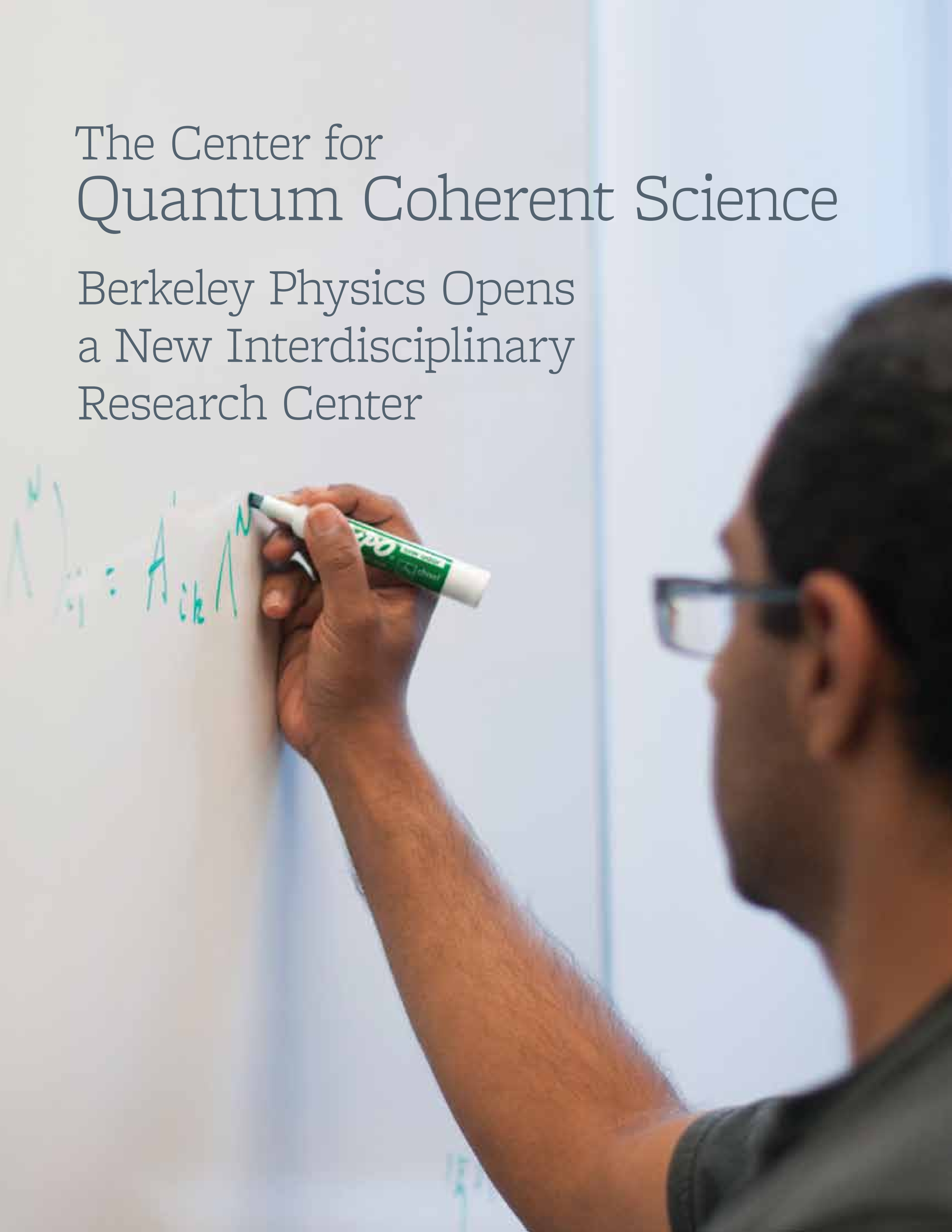
Another technique Rajendran proposes is a Dark Matter Radio, now under development with colleagues at Stanford. In essence, a Dark Matter Radio is a resonant electromagnetic circuit surrounded by a shield that blocks out all electromagnetic radiation. "Dark matter can exert tiny forces on the electron," Rajendran explains, "causing them to run in a circuit. If your radio is tuned to the mass, or frequency, of the dark matter, it would excite the circuit inside."

"Yet another way dark matter could couple with ordinary matter is if it exerts a force directly on atoms," he adds. "If so, you would be able to measure that force through an extremely sensitive accelerometer, a device that measures very small accelerations."

Rajendran's ideas don't stop with very light particles. He's also thinking about what a search for very heavy dark matter might look like. "If dark matter particles interact strongly with each other," he surmises, "they would not be spread evenly through the universe. Instead, they would coalesce into lumps." And that lumpiness might seriously reduce the likelihood of dark matter encountering the kinds of detectors envisioned so far. "You would want to build a very big detector that is looking for a very loud event," he concludes. He and his graduate students are working on ways to accomplish that.

The Center for Quantum Coherent Science

Berkeley Physics Opens a New Interdisciplinary Research Center



QUANTUM MECHANICS was conceived to describe the behavior of matter and energy at the size scale of atoms and subatomic particles. Exploration of the quantum world has produced many technologies that form the foundation of modern life—transistors, lasers, computers, light emitting diodes, superconductors, photovoltaics, and magnetic resonance imaging, to name a few.

Revolutionary as these developments have been, our understanding of the seemingly implausible features of quantum mechanics remains far from complete. "We are still working to understand the implications of living in a world governed by the counterintuitive predictions of quantum science," says Berkeley Physics Professor Irfan Siddiqi.

A New Center

The new Berkeley Physics Center for Quantum Coherent Science (CQCS) provides an expansive new forum for investigating the complexities of quantum science and its practical applications. The potential for new scientific discoveries and technological advances is immense. They range from quantum computers and simulators capable of solving classically intractable problems—including the description and synthesis of complex materials—to secure communications hardware and new types of coherent sensors with unparalleled resolution.

"Such advancements would resolve outstanding questions related to the control and measurement of quantum systems while also giving rise to the next generation of thought experiments," says **Irfan Siddiqi**, who serves as Founding Director of CQCS. "This new center aims to create novel quantum machines for investigating and manipulating fundamental properties of quantum coherence. CQCS pulls together under one roof scientists from many fields, all of whom speak the language of quantum mechanics—researchers from atomic and optical physics, condensed matter physics, quantum information science, high-energy physics, string theory, computer science, and chemistry."

Broad Participation

"We also welcome participation from researchers in biology, neuroscience, and other scientific disciplines that attempt to describe complex systems," Siddiqi adds. "The biological world is robust in the presence of disorder. For example, if tissues are damaged, cellular activity makes repairs. We seek to bring the same robustness, the same complexity of architecture, into our engineered quantum systems."

Managed by an Executive Board made up of award-winning Berkeley faculty, membership in CQCS is open to all faculty, students, and interested scientists across campus and around the world. "CQCS is owned and managed by Berkeley Physics, but it's a worldwide center in terms of operation," Siddiqi notes.

CQCS features a multimedia conference center situated next door to guest offices that provide welcoming workspaces for visiting researchers. "We will be able to bring to Berkeley an ongoing collection of visitors to enrich our intellectual environment," reports Berkeley Physics Emeritus Professor **John Clarke**. "And we now have a single space for faculty, postdocs, students, and visitors to meet—to listen to seminars or simply to hang out and exchange ideas."

"Scientists will be able to spend time with us, share knowledge, and help promote productive, synergistic activity," Siddiqi says.

Student participation is an important facet of CQCS. "We want our students and postdocs to be connected at the same breadth that we are as professors," says Berkeley Physics Professor **Dan Stamper-Kurn**. "I want my students to hear about all of these topics, become familiar with research in all these areas, know the practitioners, hear the talks, and be part of the conversation."

Siddiqi adds, "One of the most exciting things for me as a physicist is to think the debate we're having with graduate students today might become the next page in the quantum textbook."

Construction of CQCS facilities, located in Campbell Hall, was completed this summer, and official opening ceremonies are planned for January 9, 2017. The center is already active though, and held its its first public scientific forum on November 7, 2016. Entitled "Our Quantum Society: Living with Entanglement," the event featured distinguished panelists discussing the broad impact of quantum theory through the lenses of cognitive science, history, policy, cosmology, and computing.

Graduate student Vinay Ramasesh explains continuous quantum measurement of a qubit.

Photos: Keegan Houser

Housed in Campbell Hall, CQCS offers a vibrant environment for collaboration and the creation of new ideas and experiments. Facilities on the first floor feature a state-of-the art multimedia center designed for local and remote participation, where cross-disciplinary seminars, focused workshops, and international conferences can take place. Facilities also feature fully furnished guest offices for visiting scholars.

Bill Huggins, Birgitta Whaley, and Leigh Martin (L-R) discuss protocols for continuous measurement-based quantum control.

Graduate student John Mark Kreikebaum (L) and postdoctoral researcher Allison Dove at work in the newly constructed CQCS experimental labs. Housed in the basement of Campbell Hall, the labs offer state-of-the-art facilities for exploring new frontiers of quantum research.

Coherence and Decoherence

The science of quantum mechanics arose from the discovery that electromagnetic radiation is not continuous, but exists only in discrete packets, or quanta. “In other words,” Siddiqi notes, “if you look closely enough the world is a staircase, not a ramp. Life is grainy.”

That concept isn’t especially difficult to comprehend, but its consequences have proved to be provocative. Of particular importance is the quantum phenomenon called superposition, in which an individual particle has the potential to possess multiple values of a single property. At the quantum scale, a particle can have several locations, travel at several different speeds, or have more than one spin, at least until the moment a measurement is attempted. At that instant, the superposition collapses and multiple values are reduced to one. A familiar analogy is Schrödinger’s famous thought experiment, in which a cat sealed in a box is in a superposition—both alive and dead—until the box is opened.

“This has always been discussed in the literature as collapse of the wave function,” Siddiqi explains. “It means you have a wave function which describes a quantum superposition. When you make a measurement of the system, this wave function collapses into a classical state.”

A related quantum phenomenon is entanglement, the condition Einstein called ‘spooky action at a distance’ in early critiques of quantum theory. “Entanglement is like a superposition involving disparate particles,” Siddiqi explains. In this case, the properties of two or more particles are so closely associated that a change made to one of them causes a simultaneous change in the others—even if the particles are separated by distances that would require communication between them to exceed the speed of light.

Quantum coherence—the length of time a superposition or entanglement can be maintained—is of major significance in quantum science. Harnessing quantum coherence is a key enabling step toward the successful development of quantum information processing hardware and other quantum devices.

“Until recently, quantum coherence has been frustratingly short-lived,” Siddiqi reports. “Now we can actually interact with a quantum system and keep it alive forever in a quantum state.”

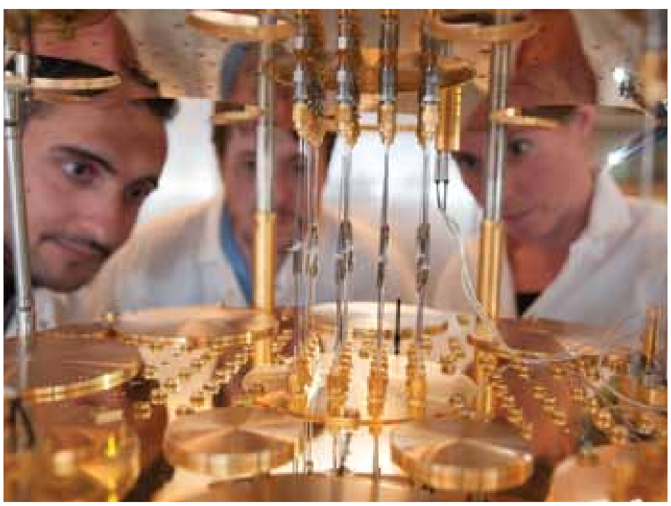
Quantum Feedback and Weak Measurement

Siddiqi’s campus research group, the Quantum Nanoelectronics Laboratory, is one of the first research groups in the world to successfully prolong quantum coherence. And it’s the very first group to accomplish this with a solid-state, superconducting circuit that emulates the behavior of a single atom.

Siddiqi and his colleagues have developed sensitive measurement tools capable of probing this type of quantum system, tracking the pathways by which it collapses into decoherence and identifying the most likely path by which it changes from one quantum state to another.

“It gives us a handle on quantum control,” Siddiqi says. “We can also run the process in reverse and steer the quantum system through a desired path.”

Berkeley Physics Professor Irfan Siddiqi, Founding Director of CQCS, received a 2016 Distinguished Teaching Award as an outstanding, dedicated, and committed instructor.



Berkeley Physics Professor Irfan Siddiqi's research group was the first in the world to successfully control and stabilize the quantum properties of a tiny, solid-state superconducting circuit that models the behavior of a single atom. Pictured here (L-R) are postdoctoral researchers James Colless, Kevin O'Brien, and Sydney Schreppler.

"To do this," he explains, "we take a very small amount of information from the system. We never really measure the system completely. We use the principle of quantum feedback, which for us is accomplished by way of weak measurement, to infer the system's trajectory. Then, based on that inference, we correct the system to maintain its quantum properties." Weak measurement refers to an experimental method that extracts only tiny amounts of information from a quantum system.

For their experiments, the group fabricates integrated chips, measuring about five millimeters on a side. Each chip contains a series of Josephson junctions—the core of the quantum circuit—about 100 nanometers across. The chip sits in a cavity, somewhat analogous to the box containing Schrödinger's cat. The entire assembly is placed in a dilution refrigerator that lowers the temperature to within a fraction of absolute zero—10 millidegrees Kelvin.

"We send microwave light through the cavity to probe the state of the circuit," Siddiqi explains. "Based on the phase shift of the light that comes out, we input a control pulse to measure and stabilize the state. It's a feedback controller. With a little bit of information we can steer the system, stabilize it."

These developments were discussed in several *Nature* articles, one of which was featured on the cover of the July 31, 2014 issue. The headline reads 'The Road Most Taken—Defining the optimal path through quantum space'.

Today, Siddiqi works with more complex systems, developing ways to apply quantum feedback and weak measurement to several atom-like superconducting circuits at a time. "We can already do this with two circuits, showing how entanglement is generated in real time," he reports.

Ultimately, the goal is to achieve simultaneous control of larger and larger numbers of superconducting circuits. Each circuit can be considered as a single qubit—the quantum counterpart of a classical bit in conventional computing. A methodology for constructing and controlling multiple qubits will go a long way toward designing a quantum computer. "It will elucidate how quantum coherent phenomena are exhibited in systems with many independent parts," Siddiqi says, "which is a currently unexplored frontier."

The Second Quantum Revolution

The Quantum Revolution in physics took place during the 1920s, as Albert Einstein, Neils Bohr, and others debated the non-Newtonian nature of quantum phenomena. Many of today's physicists suggest a Second Quantum Revolution is now underway, as research worldwide brings us closer to the reality of manipulating quantum phenomena and creating new technologies.

Part of Siddiqi's inspiration for establishing the Center for Quantum Coherent Science is to reignite dialog and debate, to revive the kinds of scientific discussions that were going on in the 1920s. "It's a culture we'd like to inculcate in the Center," he says, "having open, cross-disciplinary conversations. We plan to beam a lot of these discussions into the cloud, so anyone, anywhere, can participate."

"Understanding and controlling quantum coherent matter is essential to meeting the many scientific and technological challenges of the 21st century," Siddiqi emphasizes. CQCS will foster opportunities for open dialog and in-person encounters that can accelerate the process.

Berkeley Physics: the Perfect Home for CQCS

The great strides Berkeley Physics has already made in resolving some of the mysteries of quantum mechanics make the department a perfect home for the Center for Quantum Coherent Science. The CQCS Executive Board is made up of award-winning Berkeley faculty with world-renowned expertise in this arena.

In addition to **Irfan Siddiqi**, board members include three more experimentalists—**John Clarke**, **Dan Stamper-Kurn**, and **Michael Crommie**—plus theorists **Petr Hořava** and **Joel Moore**, and Berkeley Chemistry Professor **Birgitta Whaley**.

John Clarke

For almost 50 years, John Clarke has been a guiding light in harnessing features of quantum mechanics for practical use. He is the world's leading authority on the design, understanding, and application of SQUIDs (Superconducting QUantum Interference Devices). SQUIDS are exquisitely sensitive magnetometers that serve as central components in a wide range of important technologies and scientific endeavors, from nuclear magnetic resonance imaging to searching for cold dark matter to investigating fundamental quantum properties.

A member of the Berkeley Physics faculty since 1969, Clarke is now Professor of the Graduate School. He is a Fellow of the Royal Society, from which he received the Hughes Medal, and a Foreign Associate of the National Academy of Sciences, from which he received the Comstock Prize in Physics.

One of Clarke's hallmark contributions, accomplished with postdoc Michel Devoret and graduate student John Martins, was the first demonstration of quantized energy in a mesoscopic system. Their experiment demonstrated that the energy of a single Josephson junction is quantized, just as for atoms. "We showed that our junction really did behave as a quantum mechanical object," Clarke notes.

More recent research conducted with Will Oliver and others at MIT and MIT-Lincoln Laboratory studied a modified version of the superconducting flux qubit. "We demonstrated an order-of-magnitude enhancement in its relaxation and decoherence times," Clarke explains, "making it a strong candidate for the putative quantum computer. One of my current interests is trying to gain a better understanding of the fundamental physical processes that lead to relaxation and decoherence in superconducting qubits."

"The greatest strength of the CQCS Executive Board," Clarke asserts, "is that it brings together seven individuals who have a remarkably broad range of interests united by a single motivation—to develop a deeper understanding of the implications and applications of quantum mechanics. I have enjoyed highly productive collaborations with Birgitta Whaley and Irfan Siddiqi, and I look forward to continuing these interactions as well as developing new ways of thinking with other members of CQCS."

Michael Crommie

Condensed matter physicist Michael Crommie uses advanced scanned probe technologies to explore the quantum properties of atomic and molecular structures at surfaces, and to investigate wavelike behavior of electrons in one- and two-dimensional (2D) nanostructures. He is a leading expert in scanning tunneling microscopy and other advanced probe techniques.

Crommie joined the Berkeley Physics faculty in 1999. Research currently underway in his laboratory includes efforts to directly visualize the effects of quantum coherence in 2D materials and molecular systems. Crommie's research group is known for the ability to manipulate individual atoms and molecules on surfaces to directly access the quantum realm.

His group has shown that it is possible to sculpt the energy landscape of graphene using techniques that allow the quantum mechanical wave properties of electrons to be imaged with startling clarity. This provides a new view into the quantum interference properties of ultra-relativistic electrons whose behavior is determined by a different set of quantum rules than electrons in more conventional systems.

Crommie feels that a tight-knit, interdisciplinary community is the best possible environment for making exciting scientific breakthroughs. "CQCS will be a place where researchers from very different backgrounds can find common ground. It will be a place where new collaborations are formed that allow investigators to chase after goals that would otherwise be out of reach."

Petr Hořava

Theoretical physicist Petr Hořava joined the Berkeley Physics faculty in 2001 and directed the Berkeley Center for Theoretical Physics from 2010-2015. He works at the confluence of string theory, high-energy physics, and condensed matter physics to explore quantum science and the search for a theory of quantum gravity.

Hořava is a highly respected authority in the field of string theory. In the 1980s he pioneered the study of 'open strings', which led him to the discovery of objects later named 'D-branes' by Polchinski and collaborators. In the 1990s he collaborated with Edward Witten to introduce 'M theory', which he describes as "a unifying yet somewhat mysterious theory behind all string theories." That work inspired particle physicists to study scenarios with large extra dimensions of space, an attractive scenario for physics beyond the standard model.

In the past decade, Hořava has pioneered a novel approach to the problem of unifying gravity with quantum mechanics. "Deeply rooted in concepts from many-body physics and condensed matter," he explains, "this is a theory of quantum gravity which is deeply non-relativistic at short distances, but can mimic observed properties of Einstein gravity at observable energies. This theory has become known as "Hořava-Lifshitz gravity."

Hořava is excited about the interdisciplinary nature of the CQCS. "The concepts we develop in one field are universally applicable across all fields of physics," he notes. "A lot of excitement comes from people talking about their own puzzling problems within their own field and realizing that their colleagues may face similar questions and may have already provided interesting answers."

Joel Moore

Condensed matter theorist Joel Moore, a member of the Berkeley Physics faculty since 2002, focuses on "strongly correlated" materials and devices—systems in which electron-electron interactions yield new states of matter. These range from superconductors and magnets to recently discovered "topological" states of matter, which may themselves be useful for quantum computing.

Moore's work also uses concepts from quantum information theory to analyze problems in condensed matter physics. "We are at an exciting time," he notes, "where some of the most challenging questions about materials should start to become answerable by quantum computers. Already, the way we think about many classes of quantum materials is heavily influenced by the concepts that are the focus of CQCS."

He is excited about the scope of connected problems CQCS addresses, from engineering aspects of building a quantum computer to fundamental questions about the behavior of quantum systems ranging from materials to spacetime.

Dan Stamper-Kurn

A member of the Berkeley Physics faculty since 2000, Dan Stamper-Kurn uses ultra-cold atomic gases as a resource for studying quantum phenomena. "We bring atoms and molecules to temperatures that are the lowest we know in the universe," he explains. "When you make things very cold, you get rid of noise, stray motion, stray vibration, stray signals, and that allows you to make measurements of very subtle effects without all that noise being in the way."

Stamper-Kurn's Ultracold Atomic Physics Group recently developed methods for making the most precise measurements yet of very tiny forces. In research published in 2014, the group designed a novel optical trapping regime that detected the smallest force ever measured—only a factor of four above the Standard Quantum Limit, the most sensitive measure possible.

Stamper-Kurn's group also studies ultracold gases that are simultaneously superfluid and ferromagnetic, atomic gases trapped within light fields that act similar to electrons within crystalline solids, and gases of polar molecules for use in quantum simulation and computation. "In all these research areas," he remarks, "the extremely low temperatures—measured as low as one billionth of a degree above absolute zero—and the simple and deliberate construction of the systems under study allow subtle quantum mechanical effects to emerge in clear view."

CQCS reinforces the ongoing collaborations and conversations Stamper-Kurn says he has always enjoyed with colleagues at Berkeley. One example: "Theorists bring forward abstract concepts that can be useful in understanding the systems my group is working with," he reports. "And we can provide an experimental platform for the study of concepts that so far have been only theoretical. CQCS will make these interactions more visible, more thorough."

Birgitta Whaley

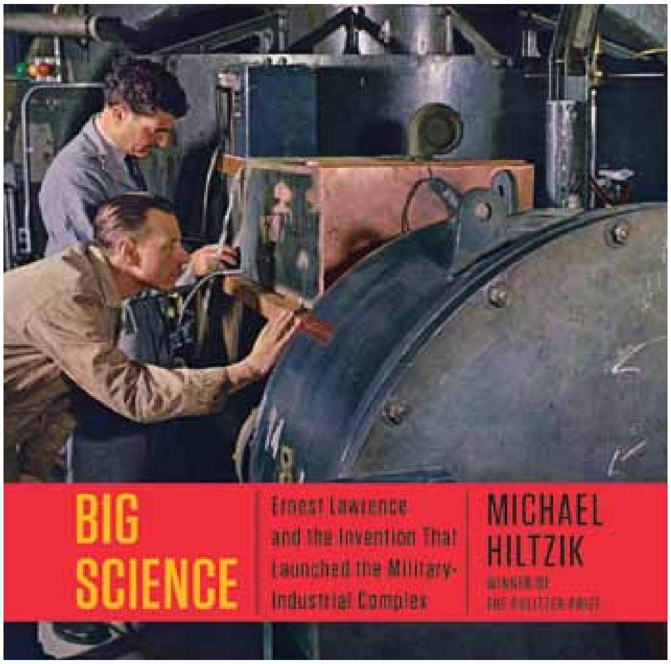
Berkeley Chemistry Professor Birgitta Whaley works at the interface of physics, chemistry, and biology. Her research is broadly focused on quantum information and on quantum computation, control and simulation of complex quantum systems, as well as quantum effects in biological systems.

Specific topics include quantum measurement and feedback control, topological quantum computation, and analysis of macroscopic quantum superpositions in many-body systems—all of which offer unprecedented opportunities for precision measurements as well as key benefits for quantum information processing.

"The rise of quantum information science over the last years has led to new ways of both analyzing quantum behaviors and controlling quantum systems, and thereby to hitherto unexplored regimes of quantum materials and dynamics," Whaley remarks. "There's a new interface between experiments and theory, and it's only in the context of an interdisciplinary quantum-focused center like this where we can really make progress and move forward."

Invited Lectures for 2015-2016

Six exceptional speakers presented lectures at Berkeley Physics this past year. View online at physics.berkeley.edu.



BIG SCIENCE was presented by **Michael Hiltzik** on October 30, 2015. Hiltzikis a Pulitzer Prize-winning journalist and author of *Big Science: Ernest Lawrence and the Invention That Launched the Military-Industrial Complex*. Hiltzik spoke about Ernest Lawrence, UC Berkeley's first Nobel Prize Laureate, and how history was shaped by his influence. The lecture was preceded by a reception and followed by a question and answer session and book signing.

Hiltzik visited Berkeley as the Warren William Chupp Distinguished Lecturer and presented three talks while he was here. Audiences included not only UC Berkeley students, but also staff members of Lawrence Berkeley National Lab (Berkeley Lab) and Lawrence Livermore National Lab (LLNL) as well as community leaders. The Chupp Lecture is sponsored annually by Berkeley Physics and the Lawrence Hall of Science, promoting both excellence in science education and the broad public understanding of science.

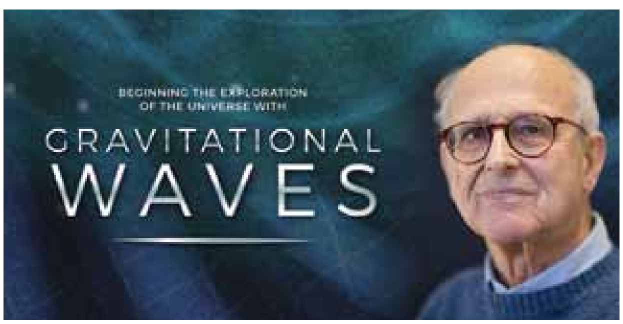
LHC RUN 2–WHY IT MATTERS was presented on November 5, 2015, by Berkeley Physics Professors **Beate Heinemann** and **Hitoshi Murayama**. Heinemann,an experimentalist, is Deputy Spokesperson for the ATLAS experiment at CERN. Murayama, a theorist, directs the Kavli Institute for Physics and Mathematics of the Universe at University of Tokyo.

In Heinemann's presentation, "What we have done at the LHC," she described work accomplished so far at the Large Hadron Collider, including discovery of the Higgs boson in 2012 and the recent improvements made to increase its collision energy by 60 percent. She discussed final results from the first LHC run (2010-2012) and initial results from the second run, which began in June 2015.

In Murayama's presentation, "What we expect from the LHC" he described how the experiment's discovery in 2012 changed our view of 'empty space,' which is actually stuffed with the Higgs boson. The LHC is now gearing up, he said, "to look for 'dark matter', which is actually our mother who got separated at our birth and whom we never met." He discussed what might come out of the upcoming run.

THE INTERSECTION OF ART AND SCIENCE was a special lecture presented January 7, 2016 by Professor Frank Wilczek, theoretical physicist, mathematician, and 2004 Nobel Laureate. "There are profound reasons, rooted in the nature of human cognition and perception," Wilczek said, "why art and science have a lot to offer one another." He offered important historical examples of the synergy between art and science, some emerging opportunities, and several striking images.

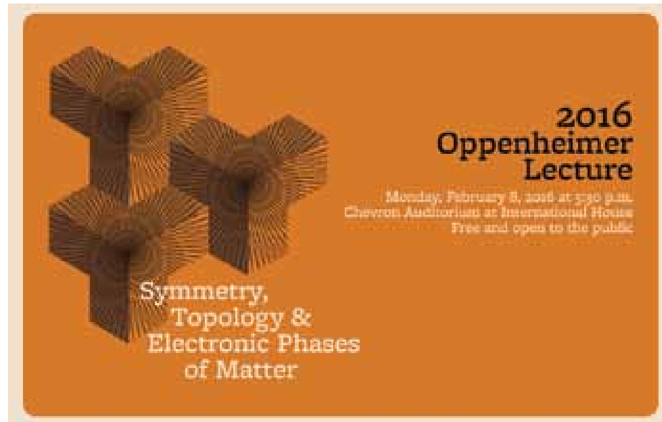
The lecture was co-sponsored by Berkeley Physics, the Division of Arts & Humanities in the College of Letters & Science, and Berkeley Lab.



THE 2016 EMILIO SEGRÈ LECTURE, "Beginning the Exploration of the Universe with Gravitational Waves," was presented by Rainer Weiss on October 3. Weiss, Professor of Physics Emeritus at MIT, spoke on behalf of LIGO—the Laser Interferometer Gravity Wave Observatory.

Earlier this year, LIGO reported the first direct detections of gravity waves from the merger of binary black holes. These observations open a new way to learn about the universe as well as to test General Relativity in the limit of strong gravitational interactions—the dynamics of massive bodies traveling at relativistic speeds in a highly curved space-time.

In his lecture, Weiss described some of the difficult history of gravitational waves. He presented concepts used in the instruments and the methods for data analysis that enable the measurement of gravitational wave strains of 10^{-21} and smaller. Also discussed were results derived from the measured waveforms, their relation to the Einstein field equations, and astrophysical implications. The talk ended with his vision for the future of gravitational wave astronomy.

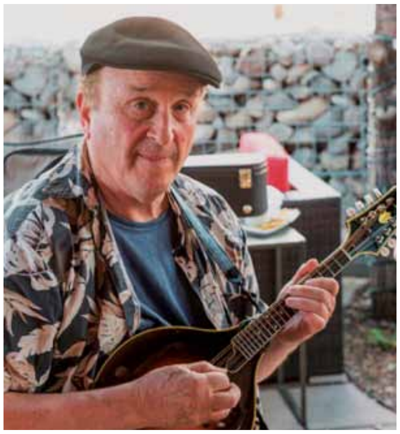


THE 2016 OPPENHEIMER LECTURE, "SYMMETRY, TOPOLOGY & ELECTRONIC PHASES OF MATTER" was presented by Charles Kane on February 8. Kane is Christopher H. Browne Distinguished Professor of Physics at University of Pennsylvania. His research focuses on the theory of quantum electronic phenomena in solids. Kane's many honors include the 2015 Benjamin Franklin Medal, the 2014 Physics Frontier Prize, and the 2012 Dirac Medal.

In his talk, Kane focused on topological electronic phases of matter, particularly interfaces between different topological phases that exhibit gapless conducting states that are protected and impossible to get rid of. He discussed the application of this idea to the quantum Hall effect, topological insulators, topological semimetals, and topological superconductors. The latter case has led to the quest for observing Majorana fermions in condensed matter, which opens the door to proposals for topological quantum computation. Kane concluded his remarks with a survey of the frontier of topological phases in the presence of strong interactions.

Alumnus Profile

Robert A. Fisher—from Physics to Chess to Bluegrass



Alumnus Bob Fisher, an accomplished bluegrass musician, is well known for the innovative and highly effective methods he has developed for teaching technique and music theory to guitar and mandolin players.

Bob Fisher (BS '65, MS '67, PhD '71) credits his Berkeley education for success in a fascinating variety of professional pursuits: conducting research in nonlinear optics, discovering how to create femtosecond laser pulses, teaching professional advancement courses, providing expert-witness testimony, serving on federal government technical panels, editing books and journals, and authoring more than 60 scientific publications. Not to mention playing and teaching bluegrass music, teaching college algebra to elementary students, and coaching an elementary school chess team to a national championship.

After earning his PhD, Fisher worked in the Laser Fusion Group at Lawrence Livermore National Laboratory and taught graduate courses at UC Davis. In 1974 he joined Los Alamos National Laboratory, working in the laser fusion and laser isotope separation groups until 1986, when he formed his own consulting business, RA Fisher Associates LLC.

Fisher recently renewed ties with Berkeley Physics, reflecting on how his Berkeley education launched his career and continues to support his professional pursuits. He remembers receiving instruction and encouragement from a number of Berkeley faculty giants, ranging from his thesis advisor Erwin Hahn (see p 20) to Charles Townes, Leo Falicov, Linn Mollenauer, Y. Ron Shen, Gerson Goldhaber, Owen Chamberlain, and many others.

Appreciating Ray Chiao's Teaching Excellence

Fisher's fondest memories are reserved for physicist Raymond Chiao, now Professor Emeritus at UC Merced. "Ray Chiao was the best teacher I ever had," Fisher remembers. "His course was valuable to me not only for learning nonlinear optics, but also for seeing that certain styles of teaching can be more motivating, more fulfilling, more memorable."

"I prepare for my own courses," Fisher notes, "by asking myself, 'How would Ray Chiao do this?'"

Fisher points to a number of instructional coincidences that gave him a head start on his career path. As a graduate student in Berkeley Physics, he wrote a term paper for a course in electronics and magnetism taught by Professor Donald Miller. The paper explored the phenomenon of atmospheric whistlers—low frequency electromagnetic waves generated by lightning. "The paper introduced me to how delta function pulses change their shape as they go through a dispersive item," Fisher relates. As it happens, whistlers exhibit similar properties to the dispersive fibers used today in lasers and other nonlinear optics applications.

"The following year," he continues, "Ray Chiao asked me to write a paper for his nonlinear optics class involving another aspect of the same problem. Between those two special assignments, I learned how laser pulses would reshape in dispersive fibers, long before fibers were invented that allowed laser pulses to go through them. I was set up perfectly to understand things not yet seen that were about to be discovered. And it put me in the magical position of being in a field that I found fascinating."

Fisher also credits his PhD advisor Erwin Hahn with inspiring him to approach nonlinear optics in the time domain—a development that significantly enhanced Fisher's insight.

Becoming a Pioneer in Nonlinear Optics

In 1969, while still a graduate student, Fisher helped pioneer methods for making femtosecond laser pulses. The research was accomplished with two colleagues, Paul Kelly and Ken Gustafson, both of whom he met because Charles Townes had drawn them to Berkeley.

"Nonlinear optics started out as an orphan," Fisher remembers. "No one was sure whether it belonged in physics, chemistry, or engineering. So there was a little going on in each of those departments. That's why I spent so much time hanging around Electrical Engineering on campus, helping people do experiments there. And listening."

Another critical turning point came as a direct result of Fisher's interdisciplinary involvement. During his graduate studies, he and Professor T. K. Gustafson walked past the office of Electrical Engineering Professor Charles Birdsall. "Birdsall stopped us," Fisher remembers, "handed us a deck of punched IBM cards, and said 'This is the first time the Fast Fourier Transform has crossed the Mississippi River, and I'm handing it to you.' Gustafson and I took it, digested it, and immediately started using it."

"I've used that algorithm all my life," Fisher continues. "I can't imagine the difference in my career if Birdsall hadn't handed me those cards."

"Throughout my career," he continues, "when faced with tough problems, I've always drawn on my Berkeley training. There were so many influences at Berkeley, and for so long I didn't know what to be grateful for. Now, looking back, I do."

Faculty Q&A

Alessandra Lanzara, Materials Scientist and Inventor

Alessandra Lanzara explores the electronic properties of quantum materials such as high temperature superconductors, graphene, and topological insulators. Her research group uses experimental tools—some of which Lanzara helped invent—that use high-intensity light to probe the behavior of electrons in these materials.

After receiving a PhD from Universita' di Roma La Sapienza, Italy in 1999, Lanzara spent two years as a postdoc at Stanford. In 2002 she joined the Berkeley Physics faculty and also became a Faculty Scientist at Lawrence Berkeley National Laboratory (Berkeley Lab).

What scientific topics are you interested in?

My interests lie on the frontier of condensed matter physics, specifically the study of emergent properties in quantum materials. We are interested in uncovering the secrets of high-temperature superconductivity and of novel metallic and insulating materials. Our goal is to understand, manipulate, and control novel properties using ultrashort and intense light pulses, on the order of femtoseconds—one millionth of a billionth of a second. My group is a world leader in taking advantage of this nascent field's tremendous unexplored opportunities.

You helped invent a new technology that measures electron spin. How did this invention come about? What new capabilities does it provide?

Technologies of the future will exploit electron spin in addition to electron charge to build devices that use much smaller batteries and operate much faster with much less power. Keys to achieving these aims are instruments that can directly probe electron spin polarization, which is fundamentally difficult. A number of complex approaches have been developed, each with its own strengths and weaknesses.

In collaboration with Dr. Zahid Hussain at Berkeley Lab, we developed a microscope that allows us to directly measure electrons and spin in the space where they live, the momentum space. The working principle is the same as photoemission spectroscopy: we use photons to eject photoelectrons out of the sample in a vacuum. Our group's unique approach combines time-of-flight energy technology to measure the photoelectron energy, together with exchange scattering out of a magnetized target to measure spin polarization. Today we can perform experiments with efficiencies up to 100 times higher than other devices, allowing us to conduct experiments that would otherwise be impossible.

It is thanks to the immense resources at Berkeley Lab that realizing this unique and complex instrument has been possible. It's a beautiful example of why national laboratories need to exist.

What excites you most about the experiments you conduct?

Passion for discovery, the mystery of the unknown, the unique feeling that follows from the discovery of a new material property, even if it is just a tiny piece of a huge and still unsolved puzzle.

Photo: LBNL

You serve on the Committee for Diversity, Equity, and Campus Climate at UC Berkeley, the Diversity and Inclusion Committee at Berkeley Lab, and as an advisor for Society of Women in Physical Science and other diversity programs. What inspires you to devote so much time to this effort?

Scientific discoveries are enabled by approaching a problem in a variety of creative ways—by combining diverse perspectives, not simply by being smart. Innovations in STEM fields touch nearly every aspect of human life and are often driven by societal needs. To address these needs, it is imperative that diverse pools of individuals get involved in the STEM fields.

My early education was in Italy, where the percentage of women in STEM is pretty high. I had many role models of women being successful while still having beautiful families and raising children.

When I arrived in the US as a post-doc at Stanford, I was surprised to find a totally different reality. There were barely any women in the physics department and there was a misconception that being a scientist and raising a family cannot go together. Here in Berkeley I've seen so many girls turn away from science because of this damaging message. The way society is structured does not provide the right support and often paints the wrong portrait of what a scientist is, leading to prejudices that end up affecting women.

So many of my Berkeley students have told me that seeing a woman with kids being also a successful scientist has changed their perspective. They felt they could also follow their dream and purse a scientific career. It is because of this that I am a strong promoter and volunteer for diversity in science.

What do you see coming up in the next decade?

Research into quantum materials is in an era of extraordinary promise. The quantum spin Hall effect, topological insulators, and high-temperature superconductors are just the tip of an iceberg. Many more novel states with unexpected properties are expected to appear.

These states can be achieved in bulk materials,and by engineering novel two-dimensional (2D) heterostructures, obtained by stacking different 2D layers in new ways. This is in my opinion the next revolution in condensed matter physics, where scientists can play Lego bricks with 2D materials, leading to almost infinite possibilities of novel and unexpected properties.

In Memory

ERWIN HAHN (1921-2016)

Berkeley Physics Professor Emeritus Erwin Hahn, a dedicated educator for more than 70 years, passed away in September at the age of 95. He enjoyed a long and accomplished career as a researcher in condensed matter physics and materials science.

A Professor of Physics at UC Berkeley since 1955 and Professor Emeritus since 1991, Hahn is best known for his work on nuclear magnetic resonance and is credited with discovering the spin echo.

He created pulsed nuclear magnetic resonance (NMR) sequences, which enabled him to discover the spin echo and make the first recording of nuclear free-induction decay due to free precession. All of these accomplishments are of monumental significance to many areas of science. The prominent use of spin echoes and gradient echoes in Magnetic Resonance Imaging (MRI) is one of the most significant developments in medical diagnostics history.

David Feinberg, Professor of Neuroscience at UC Berkeley and president of Advanced MRI Technologies said, "The transformative changes made by Erwin Hahn to NMR instrumentation, his discovery of spin echo, gradient echo refocusing, diffusion and velocity phase encoding are the foundation of modern day MRI. The world has lost a genius physicist."

In a recent cover story for Magnetic Resonance in Medicine Highlights, Feinberg wrote about the significance of Hahn's early research:

> *...I first saw in a slide his 1949 experiment to measure T1 by incrementally changing the timing between RF pulses. I came to the realization that this was the very first pulse sequence! Erwin Hahn invented pulse sequences! Of course, I knew he discovered the spin echo, but I thought pulse sequences somehow came from the spectroscopy era, like babies from storks.*
>
> *Pulse sequences are a specific time-dependent series of radio-frequency pulses and magnetic fields that produce echo signals and are used to create essentially all imaging methods of MRI. Erwin Hahn is well known for the discovery of the spin echo, but a fact often ignored by the MR community is that he was also the first to perform pulsed NMR (the first Free Induction Decay (FID)) and to describe the gradient echo. The FID was published in a brief Physical Review paper in 1949, but was quickly overshadowed by the spin echo paper.*

In May of this year, just a few weeks before his 95th birthday, Hahn was presented with the 2016 Gold Medal from the International Society for Magnetic Resonance in Medicine (ISMRM) and named an honorary member of that organization. The award, ISMRM's highest honor, was given to acknowledge Hahn's creation of pulsed magnetic resonance and other processes essential to MRI and magnetic resonance in general.

Hahn received the medal at a reception in his honor, held on campus and attended by family members, a number of accomplished physicists, community leaders, and physics students eager to meet Hahn in person. The reception was co-sponsored by Berkeley Physics, the ISMRM, and the Helen Wills Neuroscience Institute (HWNI).

In addition to the ISMRM Gold Medal, Hahn's many awards include the Buckley Prize from the American Physical Society, the Comstock Prize from the National Academy of Sciences, and the Wolf Foundation Prize in Physics.

Alexander Pines, Professor of Chemistry at UC Berkeley said, "The contributions of my mentor and dear friend Erwin to science are phenomenal. He did so many creative and beautiful things, a fraction of any one of which could serve each of us for a lifetime. The Hahn Echo changed the very foundations of spectroscopy and diagnostic imaging. We have lost a giant and our world will never be the same."

Born in Sharon, Pennsylvania on June 9, 1921, Hahn was the seventh child of Hungarian/German Jewish immigrants. He received his BS in Chemistry in 1943 from Juniata College and completed a year of graduate studies in physics at Purdue University. He continued studying physics at University of Illinois, earning his MS in 1947 and PhD in 1949.

Though presented with several interesting possibilities for a career, among them the US Navy, movies, and music, Hahn chose to pursue the science of magnetic resonance and optics. He joined the Department of Physics at UC Berkeley as an Assistant Professor in 1955, becoming full professor in 1961 and emeritus in 1991. From 1982-1983 he chaired a special ad hoc committee to improve the physics preliminary examination. From 1985 to 1986, he was a Research Professor of the Miller Institute for Basic Research at UC Berkeley.

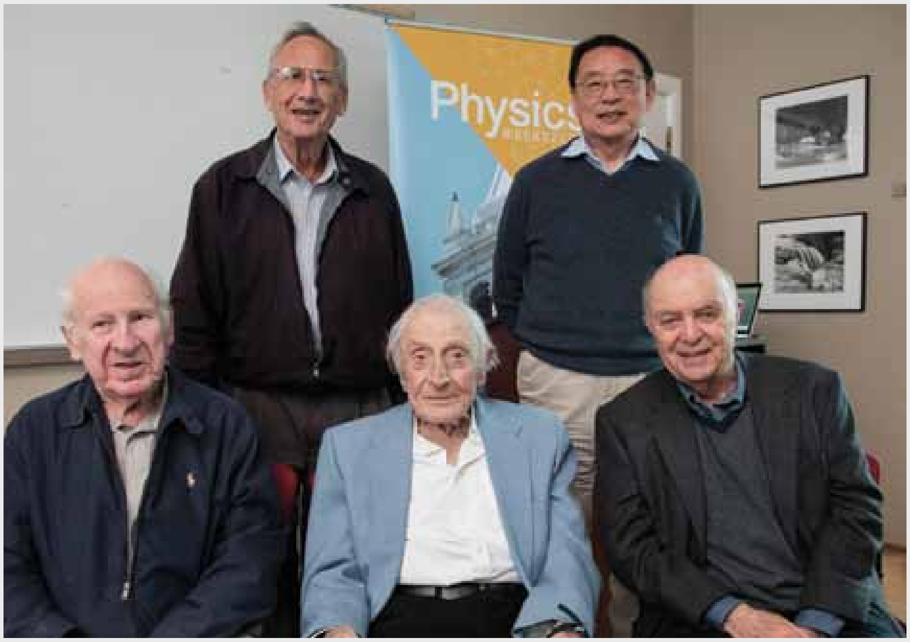
In 1991, Hahn received the Berkeley Citation for his dedication to the department and the University, as well as his contributions to magnetic resonance and optics.

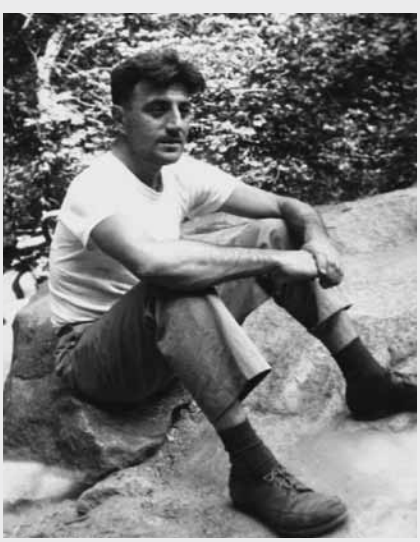
Beyond Hahn's famous published works, his colleagues and friends have always admired him as a brilliant, provocative, and entertaining lecturer, raconteur, and teacher.

Hahn received incalculable support from his spouses during his two long marriages. He married Marian Ethel Failing in 1944 and, after her death in 1978, married Natalie Woodford Hodgson in 1980. Hahn is survived by his widow Natalie, three children, two stepchildren, three grandchildren, and three great-grandchildren.

Donations in his honor can be made to the Hahn Graduate Fellowship in Physics.

Top: At the 2016 ISMRM Gold Medal ceremony, with Richard Marrus, Herbert Steiner, Y. Ron Shen, and Marvin Cohen (from L-R)
Middle: Erwin Hahn was presented with the 2016 ISMRM Gold Medal for his work on MRI and magnetic resonance in general.
Bottom left: Young Erwin Hahn sitting on Lambert Dome rock in Yosemite Park, from Erwin Hahn's scrapbook
Bottom right: Erwin and Natalie Hahn





Remembering Betty Helmholz (1915-2015)

Elizabeth (Betty) Helmholz, widow of Berkeley Physics Professor Carl Helmholz and longtime supporter of Berkeley Physics, passed away on December 15, 2015 at the age of 100.

"Carl and Betty Helmholz were generous donors to the UC campus, in particular to the Department of Physics, and also to the Botanical Garden, the University Library, and International House," recalls Maria Hjelm, Senior Development Director for the College of Letters and Science. "Carl and Betty will always be remembered for their warmth, kindness and hospitality."

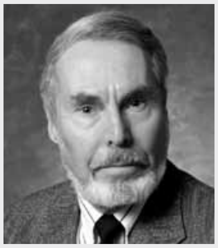
The couple's support for Physics included contributions to the Berkeley Center for Theoretical Physics, the Donald A. Glaser Advanced Lab, the Helmholz Graduate Student Aid Fund, and the Carl and Betty Helmholz Gateway Fellowship at International House. Their seed gift to the 'Integrated Physical Science Complex' was very important, as it ultimately funded the replacement for Campbell Hall.

"Betty also funded the renovation of 375 LeConte Hall, which is now called the A. Carl Helmholz Room," Hjelm adds. "This gift was typical of Betty because she wanted to foster collegiality in the department by providing a pleasant room for social functions and gatherings."

Elizabeth Jane Little was born on September 15, 1915 in Duluth, Minnesota. In 1938, soon after earning a degree in Social Sciences at Stanford, she married Carl Helmholz. The couple had four children, Chalan, Edith, George, and Fred, who are continuing the family tradition of support for Berkeley Physics.

Betty Helmholz was an appreciator of opera and symphony and an avid tennis player. She was known for hosting dinners for Berkeley physicists and their scientific counterparts. "She would go to some length to prepare a special dinner for members of the physics department," remembers her son George. "She always had a twinkle in her eye and ready smile."

JOHN DAVID JACKSON (1925-2016)



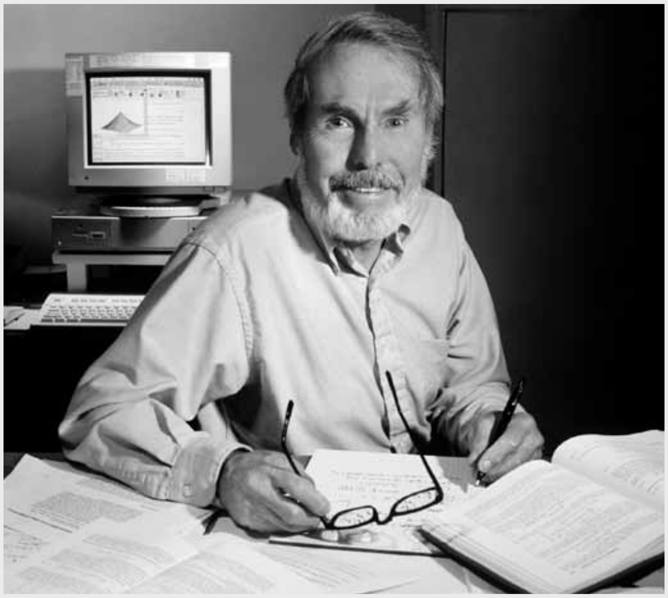
Theoretical physicist J. D. Jackson died in May at the age of 90. A Canadian-American, he was internationally known for his scientific publications and his work as a teacher in high energy physics. He received a BSc in Honors Physics and Mathematics at University of Western Ontario and a PhD in Physics at MIT under Victor Frederick Weisskopf. While living in Boston, Jackson met Marilyn Barbara Cook and the two were married in 1949.

Jackson taught at McGill University for seven years and at the University of Illinois for ten before coming to UC Berkeley and Lawrence Berkeley National Laboratory (Berkeley Lab) in 1967. He also held appointments at Fermilab, CERN, and numerous physics summer schools. Although he retired from teaching in 1993, Jackson remained active at Berkeley Lab as a Participating Retiree and on campus as Professor Emeritus in Berkeley Physics.

Among his three books, *Classical Electrodynamics* is known worldwide as the seminal graduate text on the subject. Jackson served as Editor of the *Annual Review of Nuclear and Particle Physics* for 17 years and was active in the Superconducting Super Collider Project during the 1980s, serving as Deputy Director for Operations for two years.

Jackson was a fellow of the American Physical Society and American Association for the Advancement of Science, and a member of the American Academy of Arts and Sciences and the National Academy of Sciences.

Jackson received the Distinguished Teaching Award from UC Berkeley in 1986. The American Association of Physics Teachers continues to recognize his outstanding teaching career through the JD Jackson Award for Excellence in Graduate Education. The McGill University Physics Department also continues to honor him through the JD Jackson Award for Excellence in Teaching.



J.D. Jackson

Physicists John T. Donohue, Gordon L. Kane, Robert Cahn, Richard Field, and Chris Quigg are among his doctoral students. “A short philosophy of teaching might be love your subject and convey that love,” Jackson once said. “All else is secondary.”

A staunch advocate for human rights and academic freedom, Jackson was actively involved in Scientists for Sakharov, Orlov and Sharansky (SOS), created in the mid-1970s. A lifelong major donor to the ACLU, American Friends Service Committee, and the Unitarian Universalist Service Committee, he also enjoyed listening to jazz and hiking in the mountains.

Jackson is survived by his four children and three grandchildren. His much loved wife of 65 years, Barbara, died in 2014. A memorial gathering took place in Michigan on June 2 and in California in September.

JEREMY LYS (1938-2016)

Jeremy Lys, a longtime physicist on the UC Berkeley campus and at Lawrence Berkeley National Lab, passed away in May from complications of Parkinson’s Disease. He retired from UC in 1993 but continued particle physics research at Berkeley Lab until 2013.

Born in New Zealand, Lys grew up on a sheep farm. He completed bachelors and masters degrees in physics at the University of Canterbury in Christchurch, and received a doctorate in particle physics at Oxford in 1964. He continued working in high energy physics for almost 50 years, beginning with postdoc appointments at the University of Liverpool (where he witnessed the Beatles on parade) and at the University of Michigan. In Ann Arbor he met his future wife, Annette.

The couple lived in Australia from 1972-1975, where Jeremy taught high school physics, then moved to Illinois, where he returned to research at Fermilab. In 1977 he became a research scientist in the Department of Physics at UC Berkeley, joining the late Professor Harry Bingham to work on a neutrino oscillations experiment at Fermilab.

In 1993 Lys retired from UC but continued particle physics research at Berkeley Lab, joining Lina Galtieri’s group to work on the CDF experiment at Fermilab. He later contributed to preparation of the ATLAS experiment at the Large Hadron Collider.

His talents as a physicist were demonstrated by the fact that he moved through many experiments, contributing ideas and delivering results. Very competent in analyzing data, and particularly strong in statistics, he was often called on to review the ideas of others. Graduate students sought his approval of their work and looked for his counsel when they encountered difficulties. At CDF he participated in the search for the top quark and was very much involved in measuring its properties. Modest and unassuming, he was always ready to help with any physics endeavor.

Lys excelled in athletics, from rugby and cricket in his early years to long distance running in later life. He ran in the Berkeley Lab Runaround race many times. His records for the 50-60 and 60-70 year old categories, established in 1998 and 2008, are not yet broken. He was active for many years with the Lake Merritt Joggers and Striders running club. He volunteered as a math and physics tutor for local students and in the 1980s helped turn Berkeley's Jefferson School playground into an oasis of greenery.

Lys is survived by his wife, two children, two brothers, and extended family, friends, and colleagues around the world.

Contributed by Lina Galtieri of Berkeley Lab

STANLEY MANDELSTAM (1928-2016)

Berkeley Physics Professor Emeritus Stanley Mandelstam passed away in June at the age of 87. Born in Johannesburg, South Africa, Mandelstam earned his BA from Cambridge in 1954 and his PhD from Birmingham University in 1956. He joined UC Berkeley in 1963 as a Professor of Physics and became Professor Emeritus in 1994. He was also an emeritus faculty member of the Berkeley Center for Theoretical Physics (BCTP).

Mandelstam's field of research was particle theory, specifically string theory. His most recent research interests included finding an explicit expression for the n-loop superstring amplitude and proving that it is finite; he was also interested in the results of Seiberg and Witten in supersymmetric field theories.

In 1991, Mandelstam received the esteemed Dirac Medal for Theoretical Physics—an award conferred to only a few of the most outstanding living theoretical physicists by the International Centre of Theoretical Physics in Trieste, Italy. Berkeley Physics Emeritus Professor Bruno Zumino, who won the Dirac Medal in 1987, wrote of Mandelstam: "He has resolved the problem of ambiguities in superstring theory and has shown the finiteness of the perturbation expansion. These are extremely important results, as demonstrated by the prestigious meetings where Stanley was invited to describe them."

"Stanley Mandelstam was simply a giant in theoretical physics." says Professor Yasunori Nomura, Director of the BCTP. "He made a tremendous amount of fundamental contributions to the development of quantum field theory and string theory. There are famous objects called Mandelstam variables, which every student learning theoretical physics knows. He made crucial contributions throughout virtually all aspects of quantum field theory and string theory, including the early bootstrap program, the Regge theory, and supersymmetric field theories. But it took some time for me to realize this, even after I joined the Berkeley theory group as a postdoc, because he never banged his own drum."

During his tenure at UC Berkeley, Mandelstam was one of the few particle physics theorists who regularly taught undergraduate courses. He was known as a brilliant, patient, and humble instructor who found joy in making physics "come alive" for his students. As one student put it at the time: "He is undoubtedly in that small category of theorists who have built our current knowledge base. ... In spite of Professor Mandelstam's accomplished grasp of physics and patience as a teacher, his most prominent characteristic is his humility. He is the only person I know who does not refer to the Mandelstam Variables by their so-designated name."

Stanley Mandelstam as an undergrad at Cambridge in 1953.

Berkeley Physics Professor Emeritus Mary K. Gaillard, also a member of the BCTP, wrote that Mandelstam proved an important theory, but was so modest that nobody in her research group knew about it."It is just a beautiful example of Stanley's modesty in the face of his remarkable contributions to physics," she says.

Mandelstam is survived by his sister Gerta and her husband, and their two sons.

HOWARD A. SHUGART (1931-2016)

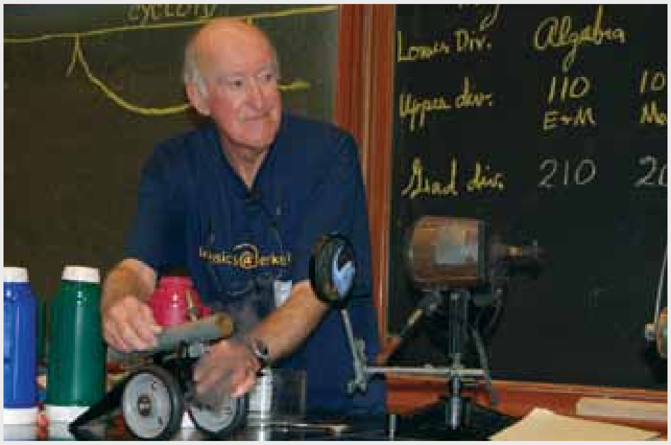
Howard A. Shugart, Berkeley Physics Professor Emeritus and dedicated educator for more than 60 years, passed away on March 21. He was 84.

Born in Orange, California in 1931, Shugart received his BS in Physics in 1953 from the California Institute of Technology. He continued his studies in Physics at UC Berkeley, earning his MA in 1955 and his PhD in 1957.

He joined the department as a lecturer in 1957, becoming a full Professor in 1959 and Emeritus Professor in 1993. From 1980-1987 he served as vice-chair of the department and was responsible for a complete reorganization of the advanced laboratory courses for physics majors. Colleagues cite him as among the first to recognize the valuable role computers could have within physics. He was dedicated to improving lower division and upper division laboratories through the introduction of computers, new experiments, and computer simulation modules to demonstrate physics principles.

In 1965, Shugart became group leader of Lawrence Berkeley National Laboratory's Atomic Beams Group. Research interests included atomic and molecular beams, low energy nuclear physics, and the experimental determination of the mechanical and electromagnetic properties of nuclei and atoms.

In 1988 Shugart became the second recipient of the Donald Sterling Noyce Prize for Excellence in Undergraduate Teaching. In 1993, he was awarded the Berkeley Citation for his dedication to the department and the University. The nomination letter read, in part, "...his outstanding achievements can be attributed to his great efficiency and energy and even more to his impeccable integrity, courtesy and modesty, which is universally recognized and respected."



For many years, Professor Shugart presented “Fun with Physics” on Cal Day.

Professors Shugart (R) and Mel Pomerantz (L) talk with a student at the 2014 Student Fellowship event.

Shugart was a member of Tau Kappa Epsilon Fraternity, and resident and member of International House from 1953-62. A fellow of the American Physical Society and the National Speleological Society, he authored more than 130 scientific papers.

His passion for teaching extended to the greater Berkeley community as well as through regular Cal Day offerings, including ‘Fun with Physics’ lectures and a demo lab entitled ‘Why Should Students Have All the Fun?’

During one Cal Day presentation, asked when he knew he wanted to be a physicist, Shugart replied that the pivotal moment came at the age of five when his father gave him a train set powered by a car battery. Cables ran from the train through a window to the outside where they connected to the battery. He learned about electricity by expanding his train set, finally leading to a model railroad complete with town and countryside.

His curiosity about electric power grew, and he began talking with the lineman who worked in his neighborhood. By the time he was seven he knew and understood how the power grid for his entire city worked.

Shugart remained actively involved with Berkeley Physics and Berkeley Lab until his death. He is survived by his wife of 44 years, Elizabeth (Betty) A. Shugart, who is retired from the nursing profession.

Department News

New Physics Reading Room

The new Physics Reading Room and Collaboration Center, designed especially for Berkeley Physics students, was unveiled in a special ceremony on February 25, 2016. The dedication event, hosted by Department Chair **Steve Boggs**, brought together alumni, students, faculty, staff, and many community supporters to celebrate this important new study space. Located on the first floor of LeConte Hall, the new facility replaces the iconic Reading Room on the second floor that had not changed in more than 50 years.

“This new Reading Room now provides a welcoming space to new students as soon as they walk through the front door,” said Boggs, who also called it “a home for undergraduate students to better their education.” He went on to acknowledge the collaborative effort that made the space possible, with special recognition of **Frances Hellman**, Dean of Math and Physical Sciences and former Chair of the Physics Department, for understanding the value of community space for students and for creating the vision for the new reading room. Hellman spoke briefly to the guests, praising Boggs for turning her vision into a reality.

Honoring Harry Bingham

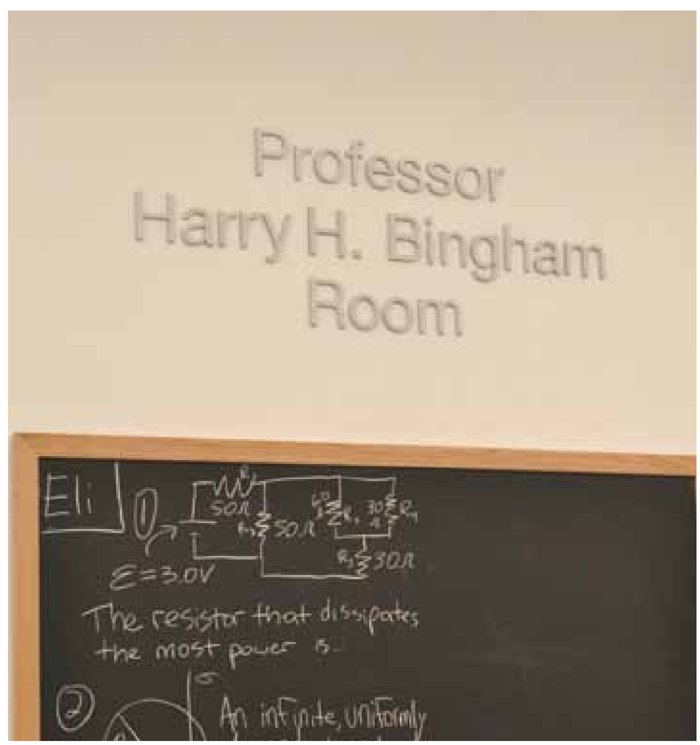
Among the speakers at this event was Dr. Caroline Gee (’75), an integral supporter of the Department and the Reading Room, along with her husband Dr. Hank Blauvelt. When Dr. Gee first arrived at Berkeley as an undergraduate, she was a chemistry major following the pre-med path. However, because chemistry majors were required to take the Physics 4 series course, she met and made an important and lasting relationship with the late Professor Harry Bingham. Not only did he help guide her new path as a physics major, but he was a vital mentor in her future endeavors at MIT and later working in industry. Because of this strong bond between Professor Bingham and Dr. Gee, she and Dr. Blauvelt provided generous funding to support the new Reading Room space renovation in honor of Harry Bingham.

At the south end of the new space is the Y. Ron Shen Common Room, named in honor of Berkeley Physics Professor Emeritus Y. Ron Shen. A faculty member since 1964, Shen told the guests how, years earlier, he was passing the old Reading Room where a group of his students were having an energetic discussion. When he offered his help, they said they were working on his problem set. “So I came in and gave some hints and approach and, of course, enough so they could easily work out the problem set. And they were so happy!”

Top left: Major Donors Caroline Gee (R) and Hank Blauvelt. Top right: The Bingham Family—Sanford Bingham, his wife Diana, and children Aidan and Daphne—with Caroline Gee, Hank Blauvelt, Grace Fretter, and Alison Mankin and her son Riley. Middle right: Y. Ron Shen with Alex Shen, Wei Chen, Lydia Chen, and Hsiaolin Shen, (L-R). Bottom left: The event ended with guests happily tossing their own hand-folded paper airplanes in synchronized flight toward the ceiling. The symbolic gesture was in tribute to a decades-long tradition: over the years, 119 origami aircraft had become stuck in the ceiling of the old Reading Room.


The Physics Reading Room
and Collaboration Center


Common Room


Professor
Harry H. Bingham
Room
Eli
The resistor that dissipates
the most power is
An infinite, uniformly

DEDICATION OF TOWNES BENCH

On May 15, the Berkeley Physics Class of 2016 dedicated a new bench in Le Conte Courtyard in honor of the late Professor Emeritus and Nobel Laureate Charles Townes, who passed away in January 2015. Le Conte Courtyard lies between Le Conte and Birge Halls.

Students raised about $5,000 for the installation, which pays tribute to the epiphany Townes had in 1951 while sitting on a park bench in Washington DC. Years later he recalled that moment, when he was struck with a solution to the problem of how to create a pure beam of short-wavelength, high frequency light. This moment of realization led to development of the laser and his 1964 Nobel Prize. Visitors are encouraged to sit and have their own memorable moment, and perhaps change the world.

This was the first class gift for the department. "Our goal was to honor everything that Charles Townes has done for the field of physics as a whole and Berkeley as a university," said Kelly Backes, Senior Class President. Frances Townes, the widow of the late Professor Emeritus Charles Townes, attended the dedication event.

Photo: Ben Ailes

Frances Townes, widow of Charles Townes, at the dedication for the new Townes Bench donated by the Berkeley Physics Class of 2016. Mrs. Townes is joined by class officers (l-r) Isabella Urdinaran, Kelly Backes, Ivan Aguilar, and Kathryn Chu.

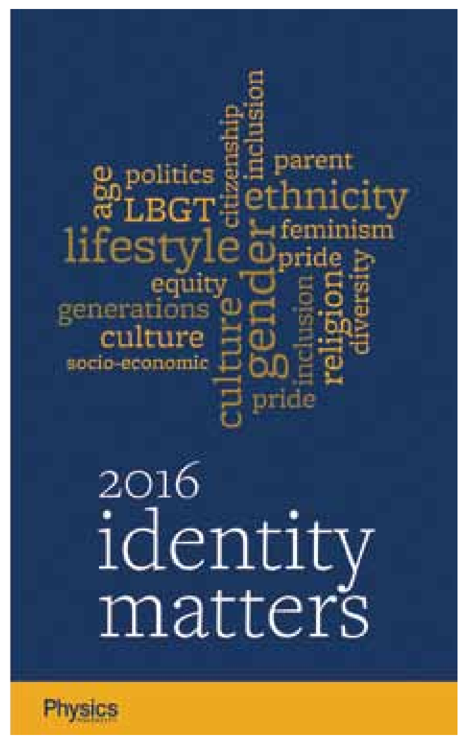
Two New Berkeley Physics Videos

This past spring the Department of Physics released two exciting new videos, one that gives an overview of the student experience in Berkeley Physics and one that introduces the department's new Center for Quantum Coherent Science.

Viewers of the Berkeley Physics video meet a cross-section of students and faculty and see how they collaborate to gain knowledge, advance research, and achieve discoveries. The CQCS video introduces viewers to the goals of the new center and profiles a number of Berkeley researchers who are not only responsible for groundbreaking research in quantum science but also have taken on leadership roles in CQCS.

Both videos were shown at the March meeting of the American Physical Society (APS). Each video is about six minutes long and can be viewed at physics.berkeley.edu.

Identity Matters



This May, Berkeley Physics launched "Identity Matters," a campaign to highlight the department's Strategic Plan for Equity, Inclusion, and Diversity among students, faculty, and staff.

Steve Boggs, Physics Department Chair, spearheaded the program by convening groups of faculty, students, and staff for a series of discussions over a number of months. Working with members of his leadership team, Boggs used input from those meetings to develop the new plan, aimed at enhancing and sustaining diversity, building an inclusive climate, and promoting equitable career opportunities within the department.

"Anybody can do physics, regardless of race, ethnicity, gender, sexual orientation," Boggs asserts. "We know, when we talk to the students, that their perceptions of the department are different depending on their personal identity. So Identity Matters is a chance for us to welcome and celebrate identities that the students bring to the department, to let them know that all identities are welcome here and they play a crucial role in not only being a person, but being a physicist."

The campaign was rolled out with a complete communications plan that represents the department's open culture of encouragement and equal opportunity. For more information on the Department of Physics Strategic Plan for Equity, Inclusion, and Diversity, visit physics.berkeley.edu and click on the "Equity & Inclusion" tab at the top.

Annual BCTP Tahoe Summit

Berkeley Center for Theoretical Physics (BCTP) faculty, researchers, post docs, students and their families gathered in September at the Lake Tahoe home of Doug Tuttle ('71) and his wife Lynn Brantley.

Cal Day 2016

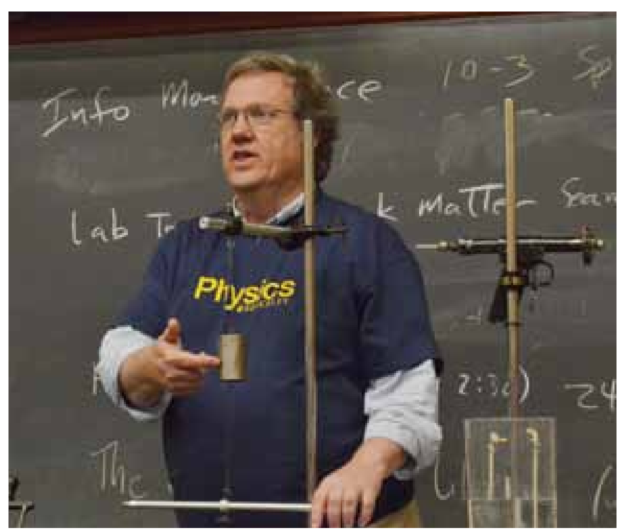
On Saturday, April 16, UC Berkeley opened its doors for Cal Day. This annual open house offers prospective students, alumni, and the general community an opportunity to explore the campus and enjoy a fun-filled day of activities. This year, Berkeley Physics offered a full schedule of events that drew hundreds of visitors to LeConte Hall.

Professor **Matt Pyle** and graduate student **Todd Doughty** led guided tours of the Dark Matter Search Lab where Professor **Bernard Sadoulet** and his research team probe the fundamental physics of the universe. Professor **Irfan Siddiqi** and members of his research group welcomed guests to the Quantum Nanoelectronics Lab, where researchers investigate the quantum coherence of condensed matter systems.

Staff members **Dr. Amin Jazaeri** and **Terry Buehler**, along with 15 undergraduate and graduate students, led Hands-On Physics—interactive exhibits that provided fun and amazement for visitors of all ages.

Professor **Bob Jacobsen** and his popular lecture, Fun with Physics, drew standing-room-only crowds.

Cal Day 2017 is scheduled for Saturday, April 22.



(L) Grad Student Milo Buitrago-Casas demonstrates physics for young visitors on Cal Day. (R) Bob Jacobsen presents his ever-popular "Fun With Physics" demonstrations on Cal Day.

New Berkeley Physics 5 Series

This year Berkeley Physics is introducing new introductory physics courses tailored for physics majors, the Physics 5 series. This series is designed to better prepare students for the rigors of upper division course work. Accompanying the 5 series is a set of two new freshman-level laboratory courses—"Introduction to Experimental Physics I & II"—designed specifically for physics majors.

These courses are more challenging and quantitative than current undergraduate laboratory classes, and will provide freshman physics majors more opportunity to explore hands-on physics from the start of their arrival at Cal. The new series will also better prepare students for their upper-division laboratory work in the Donald A. Glaser Advanced Lab.

These new laboratory courses require the support of our Berkeley Physics friends and family to become a reality. Contact new development director, Rachel Schafer to learn more about how you can help this important project.

Machine Shop Gets New Equipment

The Physics Machine Shop Crew in front of the VM3 Machine: (L-R) Gordon Long, Tommy Gutierrez, Abel Gonzalez, Student Shop Supervisor Joseph Kant, and Machine Shop Manager Warner Carlisle.

Two new and highly anticipated computer numerical control (CNC) machine tools arrived in the Berkeley Physics Machine Shop in March.

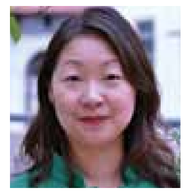
The new Haas VM3 Mold Milling Machine increased the shop's part machining capacity by 60 percent. It is fully automated—it can run unassisted, which reduces operational costs. The VM3 is also extremely accurate, and has a wireless probing system that automates the setup of workpieces and provides quality assurance for machined components.

The Haas TL2 CNC Tool Room Lathe has automated tool changes, can run unassisted, and provides a more useful computer interface for the machinists who program and operate it.

"Both the VM3 and the TL2 can be programmed at the machine or by using our modern CAD/CAM software," said **Warner Carlisle**, Mechanical Shop Manager. "They both produce difficult-to-machine components effortlessly and with increased accuracy and efficiency." Carlisle added that the addition of the two state-of-the-art machine tools has allowed his team to increase the shop's workload.

In addition to supporting Berkeley Physics, the Machine Shop assists other departments on campus as well as universities and research groups around the country and around the world.

Rachel Schafer, Director of Development & Communications

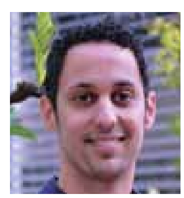


Rachel Schafer, new Director of Development & Communications for Berkeley Physics, joined the department just after Labor Day.

Schafer has been with UC Berkeley since 2007, most recently as Director of Business Development for Tsinghua-Berkeley Shenzhen Institute and before that as Associate Director, Corporate and Foundation Relations for the College of Engineering.

In her new position, Schafer will oversee fundraising, communications, and events to support the needs of Berkeley Physics. She'll also work closely with Sarah Wittmer, Graphics & Communications Specialist, to keep the Berkeley Physics community—students, faculty, staff, emeriti faculty, alumni, and donors—apprised of the department's latest news and upcoming events.

Joel Cruz, Financial and Business Services Manager



In January, Berkeley Physics welcomed Joel Cruz to the post of Financial and Business Services Manager. Joel came to the Physics Department from UC Berkeley Economics, where he held the position of Budget Officer. Before arriving on campus, Joel worked as a financial services consultant for Arvato Financial Solutions, spending most of his time in Mountain View at the headquarters of his primary client, Google.

Faculty Honors and Awards

Mina Aganagic was awarded a Miller Professorship for 2016-2017 from the UC Berkeley Miller Institute for Basic Research in Science. She also won a 2016 Simons Investigator Award in Physics from the Simons Foundation.

Robert J. Birgeneau (R) was presented with the 2016 Vannevar Bush Award from Vinton Cerf (L) of the National Science Board, "For exceptional public service and scientific leadership."

Birgeneau also received the 2015 Darius and Susan Anderson Distinguished Service Award from the UC Berkeley Institute of Governmental Studies. The award recognizes those who contribute to advancing the spirit of good government and improving the quality of public affairs for California and the nation.

Roger Falcone won the 2015 American Physical Society's Dawson Award for Excellence in Plasma Physics Research.

Hernan Garcia received a three-year Searle Scholarship, granted to universities and research centers to support the independent research of exceptional young faculty in the biomedical sciences and chemistry. He was also named a 2016 Sloan Research Fellow by the Alfred P. Sloan Foundation.

Naomi Ginsberg won the 2016 Camille Dreyfus Teacher-Scholar Award for "Elucidating Dynamic Processes in Heterogeneous Condensed Phases at the Nanoscale."

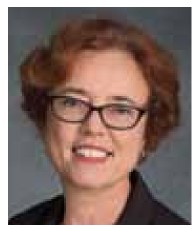
Hartmut Häffner was named Associate Professor in Berkeley Physics.

Erwin Hahn won a Gold Medal from the International Society for Magnetic Resonance in Medicine (ISMRM). The award, ISMRM's highest honor, acknowledged his creation of pulsed magnetic resonance and processes of signal refocusing which are essential to, and the foundation of, modern day MRI and magnetic resonance. (See related story, p 20)

Lawrence Hall was named a 2016-2017 Simons Fellow in Theoretical Physics, Math & Physical Sciences Program, by the Simons Foundation.

Wick Haxton was named a 2016-2017 Simons Fellow in Theoretical Physics, Math & Physical Sciences Program, by the Simons Foundation.

Petr Hořava was awarded the 2015 Neuron Award for Lifetime Achievement in Physics. He was also named a 2016-2017 Simons Fellow in Theoretical Physics, Math & Physical Sciences Program, by the Simons Foundation.



Barbara Jacak has been elected to the American Academy of Arts and Sciences.

Robert Jacobsen was named Dean of Undergraduate Studies. He is also a co-recipient of the 2016 Berkeley Faculty Service Award.

Edgar Knobloch was named London Mathematical Society Invited Lecturer, University of Loughborough, UK and became Nelder Fellow, Imperial College, London, for May-June 2016.

Alessandra Lanzara won the 2016 Fibonacci Prize and the Women at the Lawrence Berkeley Laboratory Award in 2015, and was included among the Leading Scientists of the World 2015 by the International Biographical Center, Cambridge, England.

Steven Leone received an honorary doctorate from University of Warwick, UK.

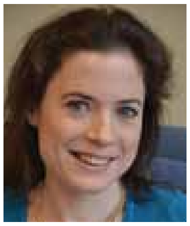
Steve Louie won the 2015 Materials Theory Award from the Materials Research Society and the 2017 Jubilee Professorship at Chalmers University of Technology in Gothenberg, Sweden.

Kam-Biu Luk received a 2016 Breakthrough Prize in Fundamental Physics for his leadership of the Daya Bay reactor neutrino experiment, which in 2012 discovered the third kind of neutrino oscillation. The 2016 Prize was shared among five experiments investigating neutrino oscillation.

Chris McKee was awarded the 2016 Henry Norris Russell Lectureship from the American Astronomical Society for lifetime preeminence in astronomical research.

Holger Müller was named Associate Professor in Berkeley Physics and received a UC Research Catalyst Award from the Office of UC President Janet Napolitano.

Hitoshi Murayama won a 2016 Breakthrough Prize in Fundamental Physics as team member of the KamLAND collaboration.



Gabriel Orebi Gann won a 2016 Breakthrough Prize in Fundamental Physics as team member of the Sudbury Neutrino Observatory Experiment (SNO).

Saul Perlmutter was named leader of the WFIRST space telescope project.

Surjeet Rajendran was named a 2016 Sloan Research Fellow by the Alfred P. Sloan Foundation.

Arthur Rosenfeld won the 2016 Tang Prize in Sustainable Development. The prize—Taiwan's top science award—was announced in Taipei by Nobel laureate Y. T. Lee, who is a UC Berkeley professor emeritus of chemistry and former head of Taiwan's Academia Sinica. Lee hailed Rosenfeld "for his lifelong and pioneering innovations in energy efficiency resulting in immense reductions in energy consumption and greenhouse gas emissions around the world."

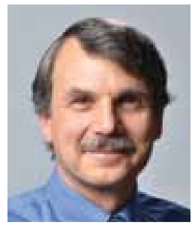
Rosenfeld, a particle physicist, founded the Center for Building Science at Berkeley Lab, which has had a lasting effect on the nation's energy use. The group developed the high-frequency electronic ballasts that made compact fluorescent light bulbs possible, coated windows to block heat from the sun, and developed computer programs for building energy analysis and design.

Rosenfeld helped pass energy standards for "energy vampires," which are appliances, such as TVs and computer monitors, that use energy even when they are in "sleep" mode. In recent years, he has promoted the widespread use of "white roofs" and "white pavement," which reflect thermal radiation back into the atmosphere rather than absorbing it. He is currently a professor emeritus of physics and a distinguished scientist emeritus at Lawrence Berkeley National Laboratory.

Irfan Siddiqi received a Distinguished Teaching Award from the UC Berkeley Center for Teaching & Learning and a 2015 Fellowship from the American Physical Society. He has been named a full Professor in Berkeley Physics.

Dan Stamper-Kurn was elected a 2016 Fellow of the Optical Society of America.

Ahmet Yildiz was awarded a Miller Professorship for 2016-2017 from the UC Berkeley Miller Institute for Basic Research in Science.



Alex Zettl received an R&D 100 award from *R&D Magazine* for his research group's Extended Pressure Inductive Coupled Plasma System, which enables continuous production of boron nitride nanotubes.

New Faculty

Ehud Altman joined the Berkeley faculty as Professor this summer. After receiving his PhD from the Technion, Haifa in 2002, he was a postdoctoral fellow at Harvard University for three years, then joined the faculty of the Weizmann Institute of Science as a Yigal Alon fellow in 2005. He was promoted to the rank of Associate Professor there in 2011. In 2010 he was awarded the young investigator prize from the Israel Physical Society and the Krill prize of the Wolf foundation. He was a Miller visiting professor at UC Berkeley in 2012-2013.

Altman's interests involve condensed matter theory and many-body aspects of ultra-cold atomic systems and quantum information theory. "Broadly speaking," he says, "I investigate quantum matter, in which interactions and quantum entanglement between the particles can give rise to unexpected emergent properties. A recent focus of our research is how such emergent behavior unfolds in non equilibrium systems."

Research aims include trying to understand the phenomenon of many-body localization, and thermalization in quantum systems. To address these problems, his group uses a variety of theoretical and numerical tools including field theory, strong disorder renormalization, tensor networks, and quantum Monte Carlo calculations, as well as close collaboration with experimental groups.

Photo: Michaela Rehle, Reuters

Eric Betzig, Nobel laureate, will join the UC Berkeley faculty next summer as a Professor in the Departments of Physics and Molecular and Cell Biology and as a member of the Helen Wills Neuroscience Institute. He will also maintain an appointment as a Howard Hughes Medical Investigator and as a senior fellow at the Howard Hughes Medical Institute's Janelia Research Campus.

Betzig received a 2014 Nobel Prize in Chemistry for his work in developing super-resolution fluorescence microscopy, which allows scientists to look inside cells and visualize the pathways of individual molecules, including those involved in disease.

He received the Nobel prize, along with Stefan Hell of the Max Planck Institute for Biophysical Chemistry and William Moerner of Stanford University, for bypassing the presumed scientific limitation that an optical microscope can never yield a resolution better than half the wavelength of light, or 0.2 micrometers. Super-resolution microscopy gets around this limitation by actively controlling the fluorescence of subcellular structures to reveal their morphology and dynamics at a resolution up to ten-fold better than this limit.

Betzig first demonstrated his technique, widely known as PALM, or photoactivated localization microscopy, in 2006. It relies upon turning the fluorescence of individual molecules on and off. The same area is imaged thousands of times, with different subsets of widely dispersed molecules glowing each time. Superimposing the positions of all molecules across all images yields a dense super-image resolved at the nanolevel. In more recent work, Betzig's technology has allowed scientists to look inside the cells of living organisms with the same precision.

Today, the PALM technique is used worldwide in biomedical research, such as in observations of how disease-related proteins aggregate and trigger Parkinson's, Alzheimer's and Huntington's diseases. More recently, Betzig has invented other new microscopes, including one that produces 3D images of the inner dynamics of cells with unprecedented speed and sensitivity.

Betzig earned a BS in physics from Caltech and MS and PhD in applied and engineering physics from Cornell University. He will spend his first year at UC Berkeley on sabbatical, exploring ways to take advantage of multiple recent breakthroughs in the field of microscopy in collaborations with his new colleagues, as well as talking with faculty across campus to identify new research opportunities.

Na Ji will join Berkeley Physics in 2017 as Associate Professor of Biophysics, with a joint appointment as faculty scientist at Lawrence Berkeley National Laboratory (Berkeley Lab) in the Molecular Biophysics and Integrated Bioimaging Division of the Biosciences Area.

Ji is a world-class biophysicist and Howard Hughes Medical Investigator. She studied chemistry and physics at the University of Science & Technology in China, earning a BS in Chemical Physics there. She subsequently received a PhD in Chemistry from UC Berkeley. Ji is married to Nobel laureate Eric Betzig, who also joins the Berkeley Physics faculty next year.

Ji describes her goal in life as trying to understanding "as much about this beautiful world around me as possible." After studying chemistry and physics, she says, "I had an in-depth understanding of the inanimate world but knew little about how life works. Particularly attracted to the problems of the brain, the organ that defines me as a person but whose inner workings still evade us, I moved to Janelia and worked with Eric Betzig on improving the speed and resolution of in vivo brain imaging."

In 2011 Ji started her own group at Janelia where, in addition to imaging technology development, her lab applies the resulting techniques to outstanding problems in neurobiology. The Ji Lab develops optical methods for in vivo imaging and applies these methods to structural and functional studies of neural circuits.

Jacob Willig-Onwuachi came to Berkeley this summer to take up a position as Teaching Professor. He arrived from Grinell College in Iowa, where he chaired the Physics Department. "Using physics to solve applied problems is an exciting and rewarding challenge for me," he says. "In pursuing this challenge over the years, I have conducted experimental and computational physics research projects in a broad range of areas, including plasma physics, industrial physics, radiofrequency (RF) engineering, and imaging physics."

"Magnetic resonance imaging (MRI) is a particularly interesting and exciting field that is a great example of physics in action," he continues. "Physics serves as a foundation for MRI—from the basic principles to the newest technical design challenges."

His research is based on using the physics behind MRI to improve medicine through technological advancements or the development of new imaging techniques, such as acquiring images more quickly, increasing image accuracy, or designing shorter scanners for increased patient access and reduced claustrophobia. Recent work has focused on parallel MRI, which exploits redundancy in data acquired from multiple detector coils, as well as image reconstruction and RF coils and detection.

Mike Witherell joined the Berkeley Physics faculty in January as a Professor and became the new Director of Lawrence Berkeley National Laboratory. He came to Berkeley from UC Santa Barbara, where he served as Vice Chancellor for Research and held the UCSB Presidential Chair in Physics. He formerly served as Director of Fermilab.

Witherell received his BS from the University of Michigan and his PhD in experimental particle physics from the University of Wisconsin. He won the W. K. H. Panofsky Prize in Experimental Particle Physics from the American Physical Society in 1990 and was elected to the National Academy of Sciences in 1998.

He has conducted particle physics research at accelerators and in underground laboratories. His current research is part of the campaign to observe interactions of dark matter particles with ordinary matter. He worked on the LUX (Large Underground Xenon) experiment in the Sanford Underground Research Facility (SURF) in the Black Hills of South Dakota. He is a member of the LUX-ZEPLIN (LZ) collaboration, which is building a much more sensitive experiment to start operating at SURF in 2019.

Witherell's interests extend to the search for neutrinoless double beta decay using LZ, in addition to the dark matter search for which it is principally designed.

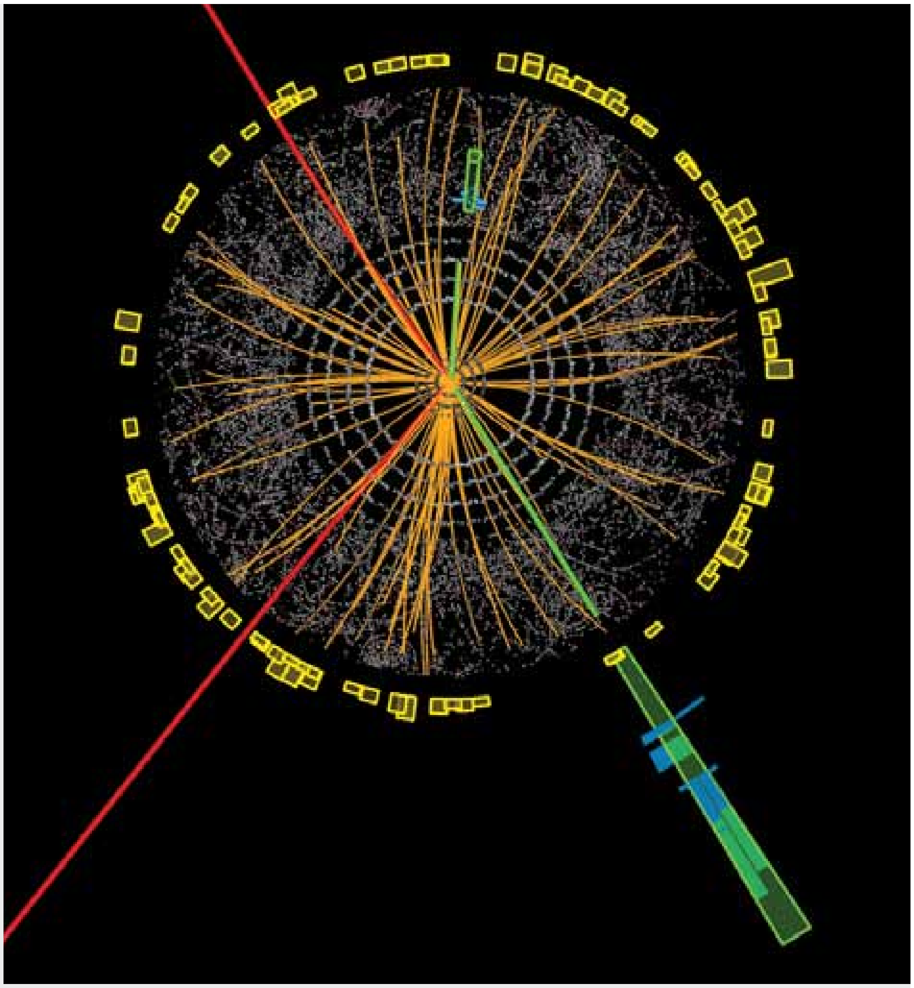


Photo: ATLAS

Physics Beyond the Higgs Boson

Tim Folger, *Discover*, October 2015

The leading candidate for succession [to the Large Hadron Collider] is a project called the International Linear Collider. The ILC would hurl electrons and their antimatter counterparts, positrons, from opposite ends of a straight, 19-mile-long tunnel, generating collisions at the machine's center. By using electron and positron beams instead of heavier protons, the ILC will allow physicists to probe particle properties with much greater precision than they can at the LHC.

"The LHC is a like a collider of cherry pies," says Berkeley's [theoretical physicist] **Hitoshi Murayama**. "Cherry pies are easy to throw, and they smash together rather easily, but they produce a huge splash, and all the goo comes out of the pie." In the case of the LHC's collisions, the "goo" consists of the protons' components—quarks and gluons. The sheer messiness of proton-proton collisions makes it difficult to detect new particles, or to make accurate measurements of known particles.

Electrons and positrons, on the other hand, don't have any components, so the collisions are cleaner. At the LHC, maybe one in a billion proton-proton collisions yields a Higgs boson. Physicists estimate that a Higgs should pop up roughly every hundred electron-positron collisions at the ILC. The challenge then will be aiming the electron beams accurately enough to ensure enough collisions occur.

Blind analysis: Hide results to seek the truth

Robert Macoun and Saul Perlmutter, *Nature*, 8 October 2015

Decades ago, physicists including Richard Feynman noticed something worrying. New estimates of basic physical constants were often closer to published values than would be expected given standard errors of measurement. They realized that researchers were more likely to 'confirm' past results than refute them—results that did not conform to their expectation were more often systematically discarded or revised.

To minimize this problem, teams of particle physicists and cosmologists developed methods of blind analysis: temporarily and judiciously removing data labels and altering data values to fight bias and error. By the early 2000s, the technique had become widespread in areas of particle and nuclear physics. Since 2003, one of us (**Saul Perlmutter**) has, with colleagues, been using blind analysis for measurements of supernovae that serve as a 'cosmic yardstick' in studies of the unexpected acceleration of the Universe's expansion. ▼

… We argue that blind analysis should be used more broadly in empirical research. Working blind while selecting data and developing and debugging analyses offers an important way to keep scientists from fooling themselves.

THE CREATURE WITH THE KEY TO IMMORTALITY?

Mary Colwell, BBC News, 9 October 2015

Sea anemones are a common sight on many coastlines ... As far as we know, these are immortal animals," says **Dan Rokhsar**, professor of genetics at the University of California, Berkeley. "... They don't have old age."

... "If I look at a sea anemone today and compare it to a week later the same structure will be there but many of the cells will have been replaced."How it does this isn't clear. "We would love to be able to find a gene or pathway that allows it to avoid ageing," says Rokhsar. But he and his team are still searching for that Holy Grail.

"Sea anemones share a lot with us. ... There are parallels in the way the genomes are organised and the way the genes are structured, revealing a link that "goes back at least 700 million years".

But there are philosophical questions too. "To what extent is immortality for a sea anemone and immortality for a human the same kind of thing?" asks Rokhsar. A sea anemone simply lives in the moment. People, however have thoughts, memories and consciousness that they want to retain. Keeping these bright and present in our regenerating bodies may not be something the anemone can help with. "That," says Rokhsar, "is a much taller order."

DOES TIME RUN BACKWARD IN BLACK HOLES

Cathaleen Chen, *Christian Science Monitor*, 1 November 2015

A supermassive black hole in the nearby spiral galaxy NGC 1365. A study published in the journal Nature found it's rotating close to the speed of light. NASA image

Time, at least defined thermodynamically, might not always run forward, at least not inside black holes. Recent research published in *Physical Review Letters* may have discovered a new area law in general relativity that describes the geometry of black holes as curved "holographic screens."

In their study, **Raphael Bousso**, a professor at the University of California, Berkeley and Lawrence Berkeley National Laboratory, and Netta Engelhardt, a graduate student at the University of California, Santa Barbara, developed an alternative explanation of a black hole's event horizon, the point-of-no-return that separates a black hole from its observers.

Berkeley Physics Professor and Nobel laureate Saul Perlmutter has been named leader of the WFIRST telescope project.

Bringing Dark Energy to Light

Gabriela Quirós, *KQED Science*, 25 November 2015

...dark energy... is believed to be causing galaxies to move away from each other faster and faster. Now, researchers who have been trying to figure it out for more than 20 years by studying supernovae—stars that exploded billions of years ago—are hoping to send a telescope into space, where they'll be able to get a better look.

"You can see hundreds of times more sky at a time," said **Saul Perlmutter**, a professor of physics at the University of California, Berkeley. "And it's also designed for just the wavelength range, just the colors, where we need to study the supernovae and the other galaxies in order to study dark energy."

The new NASA telescope is known as WFIRST, which stands for wide-field infrared survey telescope. If Congress approves initial development funds of $50 million to $100 million by the end of the year, WFIRST could launch sometime between 2022 and 2025.

Teatime at Kavli Institute in Japan

Opening Borders and Barriers

Nature, 12 November 2015

…lately, governments have begun paying heed to evidence that suggests international, multidisciplinary collaborations … will yield high-impact results.

Tea time is a custom that Kavli IPMU director and particle physicist, **Hitoshi Murayama**, brought back to Japan from the United States after witnessing its benefits in labs he had worked in. He was so convinced of its value in promoting collaboration among researchers that he put it in the initial proposal for the institute and battled with the funders to have it included. “I don’t think taxpayers anywhere like to pay for tea, but I knew that it was worth fighting for,” he says.

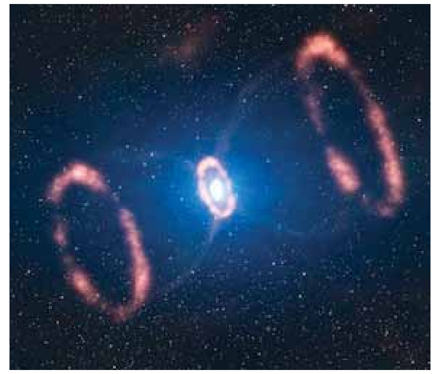
Researchers re-calibrate world’s most sensitive dark matter detector

Brooks Hays, UPI, 14 December 2015

The LUX detector is giant tank of liquid xenon surrounded by ultra-sensitive photon detectors. The device is designed to measure weakly interacting massive particles, or WIMPs, a leading dark matter candidate.

“We look for WIMPs produced in the Big Bang that are still around, up to very high masses—we have the best sensitivity of any experiment to date for WIMP masses above four times that of a proton,” explained **Daniel McKinsey**, a LUX researcher and a professor of physics at the University of California, Berkeley, said in a press release. “We haven’t yet observed dark matter interactions, but the search goes on.”

The new sensitivity was made possible by a re-calibration of the device’s detectors, which rule out bogus interactions and collisions among cosmic and gamma rays.



An artist’s impression of the rings around SN 1987A. Image: ESO/L Calçada.

Deciphering a Famous Supernova

Liz Kreusi, *Astronomy*, January 2016

Each year, ***Astronomy*** magazine ranks the top 10 astronomic discoveries and space stories. Here’s where 2015’s biggest ones fall.

#7. When a star at least ten times the Sun’s mass explodes at the end of its life, the energies, temperatures, and pressures are so high that the supernova produces a range of heavy chemical elements, one of those is titanium 44 (Ti-44), which is an unstable radioactive isotope. “The isotope is produced deep in the core of the explosion, and its properties—mass, ejection speeds, and distribution—directly reflect the physics in the core,” says **Steve Boggs** of the University of California, Berkeley.” … none of Ti-44’s colors had been visible to astronomers until a recent X-ray telescope, the Nuclear Spectroscopic Telescope Array (NuSTAR), opened its eyes and began collecting data.

Boggs and colleagues described in the May 8 issue of *Science* their study using NuSTAR to map Ti-44 in SN 1987a. The element’s distribution is clumpy and uneven, implying that the explosion was off-center. …Most computer models have assumed a symmetrical blast, but the new studies prove something more complex is happening.

It's Elementary: Berkeley Can Bask in the Glow as More Elements Hit Periodic Table

Glen Martin, California magazine, 7 January 20116

Speaking to Berkeley's place in the annals of element hunting, [Berkeley Physics Professor] **Barbara Jacak**—director of the Nuclear Science Division at Berkeley Lab, the faculty senior scientist at Berkeley Lab and the discoverer of quark gluon plasma (a variant of matter thought to exist at extremely high densities and temperatures)—says the university's preeminence is due to a happy convergence.

"It was a combination of the fact that this is where the cyclotron was invented, and we had the best and the brightest people," she says. "Back when it all started, Berkeley was really the only place where you could do this kind of work. Now other labs are involved in super heavy element research, of course, but Berkeley [Physics] and LBNL have been able to maintain their momentum."

GIANT ATOM-SMASHER GEARS UP TO CHASE WHIFF OF NEW PHYSICS

Adrian Cho, *Science*, March 16

CERN's ATLAS detector may have glimpsed a partner of the Higgs boson.

Later this month, physicists will rev up the world's biggest atom-smasher—the Large Hadron Collider (LHC) at the European Particle Physics Laboratory, CERN, in Switzerland—for this year's run. They are eagerly awaiting the first new data, due in May, as last year's run ended with a cliff-hanger. The LHC blasted out hints of a new fundamental particle—potentially the first in decades to come as a surprise—and thousands of physicists now want to see whether those signs will pay out.

Many urge caution. "If it's real, it's like opening a window on a new world," says **Beate Heinemann**, an experimentalist at the University of California, Berkeley, who works on ATLAS, one of four particle detectors fed by the LHC. But, she adds, "by far the most likely explanation is that it's a statistical fluctuation."

The Calculated Value of a President with a STEM Degree

Paul Voosen, *Chronicle of Higher Education,* 3 April 2016

At the country's most influential universities, scientific dominance in the presidency is growing: At the 115 doctoral institutions with the highest research activity, nearly half are led by STEM researchers. More than 40 percent of the members of the Association of American Universities, an elite club of research universities, are led by scientists, engineers, and mathematicians—and that's excluding technical-focused members like the Massachusetts Institute of Technology.

... The sciences, at their best, value failure and share an openness to ignorance. For the scientists who do end up as university presidents, nearly all of them see their leadership as a continued form of experimentation.

Most STEM presidents seem to share one point: They never planned to be administrators, particularly at liberal-arts universities. It "was never one of my ambitions," says **Robert J. Birgeneau**, a physicist and former chancellor of the University of California at Berkeley. His dream was to win a Nobel Prize, he says.

Improved Path to Cassava Production

Cindy Ha, *Technology Networks,* 19 April 2016

A new analysis of the genetic diversity of cassava will help improve strategies for breeding disease resistance and climate tolerance into the root crop, a staple and major source of calories for a billion people worldwide.

… the team, led by **Daniel Rokhsar**, a UC Berkeley professor of molecular and cell biology and of physics, compared the cassava reference genome to the genomes of its relatives: the castor bean, rubber tree, Ceara rubber and 53 cultivated and wild cassava varieties from around the world.

They found that the genetic diversity of cassava used in current breeding efforts has been greatly reduced in Africa, where viruses such as the cassava mosaic disease and the cassava brown streak disease have affected crop yields in many countries. They were able to detect the genetic signature of past cassava improvement programs going back to the 1930s, which interbred cassava and Ceara rubber, and the persistence of these Ceara rubber regions in elite cassava varieties suggests they confer desirable traits.

…Cassava root is easy to grow and has a high starch content—between 20 and 40 percent by weight—which makes it an ideal source of calories. …The root crop also represents a strategic source of renewable energy—as biomass from which ethanol is being produced for transportation fuels. With the help of genomics, researchers hope to apply advanced breeding strategies that can improve cassava's resistance to diseases and improve crop yields, Rokhsar said.

Billionaire Facebook backer puts up $100M to send nanobot spacecraft to find alien life

Cromwell Schubarth, *Silicon Valley Business Journal*, 12 April 2016

Yuri Milner, the Russian billionaire who backed online hits including Facebook and Twitter, is putting up $100 million in a new effort to find life on other planets.

The Breakthrough Starshot project announced Tuesday by Milner and famed physicist Stephen Hawking plans to find a way to send a tiny robot spacecraft weighing a little more than a piece of paper to the Alpha Centauri star system, which is 25 trillion miles away. To do this they plan to use a 100 billion-watt laser-powered light beam to accelerate their "nanocraft" to a speed of about 37,000 miles a second.

Other Bay Area scientists involved in the Breakthrough Starshot program include … Nobel Prize winning astrophysicist **Saul Perlmutter** of UC Berkeley and the Lawrence Berkeley National Laboratory.…

Bigger than the Higgs, bigger even than gravitational waves…

Matthew Chalmers, *New Scientist*, 27 April 2016

It looks like the LHC may have found a surprise massive particle that gives a glimpse into a better—and entirely unexpected—theory of reality.

…The hope springs from two "bumps" that have appeared independently, in the same place, in the latest data from the LHC's two big detectors, ATLAS and CMS. They point to the existence of a particle that dwarfs even the Higgs boson, the giver-of-mass particle discovered at CERN in July 2012.

…Barely a week after the ATLAS and CMS bumps were made public, theorists had posted more than 100 possible explanations to the arXiv server, a repository where physicists post data before formal publication, and the number has been skyrocketing ever since.

Yasunori Nomura of the University of California, Berkeley, was one of the first. "I don't normally jump in on anomalies such as these because most of them are just too crappy, but this one is relatively clean," he says. "We're desperate to some degree because we have lots of problems to solve and no data."

… Nomura thinks it must be a composite particle similar to the protons and neutrons within the atomic nucleus. These are made up of quarks bound together by the strong nuclear force. The mystery particle, on the other hand, would be the first in a family bound by an entirely new fifth force that only kicks in at high energy.

NASA image

Balloons. NASA Is Using *Balloons* to Study Space

Emma Grey Ellis, *Wired*, 19 May 2016

Earlier this week, the US space agency sent a high-pressure balloon skyward from Wanaka, New Zealand, with inflated hopes that it will stay up there and circumnavigate the globe for 100 days or more—a flight time that's about twice the current record. Along for the ride is the Compton Spectrometer and Imager (COSI), a gamma-ray telescope developed by scientists at UC Berkeley.

Steven Boggs of UC Berkeley calls this a super pressurized inflatable guinea pig. If it works, it will give scientists like himself deeper insights into nuclear physics. For instance, COSI detects gamma radiation emitted when new elements are created—something that happens when a star Hulks out, goes supernova, and puts the stuff at its center under incredible pressure and high temperatures. "You can never recreate these conditions on Earth," Boggs says. "So we're using the cosmos as our laboratory to test our understanding of nuclear physics."

"This is a great training ground for the next generation," says Debbie Fairchild, NASA's Balloon Program Office chief. "They can design, build, and fly their project in the time period of their PhD. We have grad students actually down there babysitting their payload before launch, which is something they wouldn't get to see for many years if we had to send them up on satellites."

THE MYSTERY OF DARK ENERGY

BBC Horizon documentary, broadcast 30 March 2016

The quest to understand dark energy is one of Physics leading problems and may take another pioneering mind such as Einstein or Newton to crack the issue. This documentary offers an insight into what little we know about Dark Energy as well as some of the forunning theories to explain it. [Featured scientists include Berkeley Physics Professors **Saul Perlmutter** and **Holger Müller** and one of Müller's graduate students, **Matthew Jaffe**.]

A mathematician has built a machine that can beat the odds in roulette

Fiona Macdonald, *Science Alert*, 6 June 2016

Richard Muller, a professor of physics at the University of California, Berkeley, … admitted that a colleague of his once built a device that allowed him to beat the roulette table.

"It worked as follows: to encourage people to bet at roulette, it has been traditional to allow bets to be made after the wheel is spun and the ball is flung, but only before it begins to drop. In that second or two, there is enough information to allow a measurement and computation that will, for example, double your odds of winning.

If the computation simply rules out half of the wheel as unlikely, then the odds jump up highly in your favour. Whereas before, your odds of winning might be 98:100 (so you lose), if you exclude half of the numbers, your odds become 196:100; you win big!

You don't have to predict the number where it will fall. You only have to increase your odds by 3 percent to go from losing on average to winning on average."

With that in mind, Muller explains that the machine worked by attaching a switch to the player's toes. The player would tap one switch each time the ball completed a full spin, and the other switch each time the wheel spun.

From that data, a small pocket computer could calculate the odds and let him know, via a tap on the leg, where he should place his bet. All in the small window of time before the ball stops spinning.

Phantom Particles that Should Have Redefined Physics Probably "Aren't Real" Scientists Conclude

Daniela Hernandez, The *Wall Street Journal*, 8 August 2016

For two decades, physicists hunted for a ghostly theoretical particle that held the promise of redefining our understanding of the universe.Now an international group of scientists has concluded, with 99% certainty, that the light sterile neutrino doesn't exist, according to findings published Monday in the journal *Physical Review Letters.*

…One neutrino type can morph into others, a process the IceCube researchers can observe using light detectors. If some neutrinos were to transform into sterile ones, fewer neutrinos would produce flashes of light in the ice. That ghosting is what IceCube researchers tried—but failed—to detect for one type of neutrino, the muon.

…"It's too important to give up," said **Kam-Biu Luk**, a particle physicist at the University of California, Berkeley, also not involved with IceCube. "We haven't covered a lot of ground yet. We need…to explore more hiding places."

Voices of the Manhattan Project—J. Robert Oppenheimer's Interview

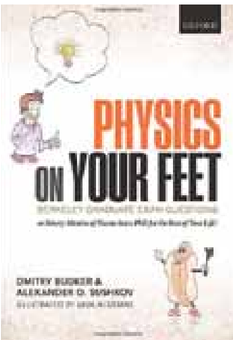
Cindy Kelly, Atomic Heritage Foundation and Los Alamos History Foundation, posted online at manhattanprojectvoices.org

In this rare interview, [former Berkeley Physics Professor] **J. Robert Oppenheimer** talks about the organization of the Manhattan Project and some of the scientists that he helped to recruit during the earliest days of the project. Oppenheimer discusses some of the biggest challenges that scientists faced during the project, including developing a sound method for implosion and purifying plutonium, which he declares was the most difficult aspect of the project. He discusses the chronology of the project and his first conversation with General Leslie Groves.Oppenheimer recalls his daily routine at Los Alamos, including taking his son Peter to nursery school.

[Voices of the Manhattan Project includes an interview with Emilio Segre and will eventually include Berkeley Physics Professor Emeritus **Geoffrey Chew.**]

Physics on Your Feet: Berkeley Graduate Exam Questions: or Ninety Minutes of Shame but a PhD for the Rest of Your Life!

BY DMITRY BUDKER AND ALEXANDER SUSHKOV, OXFORD UNIVERSITY PRESS, 2015.
ISBN-10: 019968166X. ISBN-13: 978-0199681662



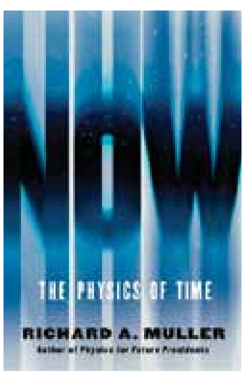
Physics on Your Feet was named a 2015 Top 10 Book by Physics World: "The inventive and challenging puzzles in this book are guaranteed to make you think—and they will probably also make you glad you're not encountering them "on your feet" in an exam."

Physics on Your Feet gives a collection of physics problems covering the broad range of topics in classical and modern physics that were, or could have been, asked at oral PhD exams at Berkeley. The questions are easy to formulate, but some of them can only be answered using an out-of-the-box approach. Detailed solutions are provided, from which the reader is guaranteed to learn a lot about the physicists' way of thinking.

The book is also packed full of cartoons and dry humor to help take the edge off the stress and anxiety surrounding exams. This is a helpful guide to students preparing for their exams, as well as to University lecturers looking for good instructive problems. No exams are necessary to enjoy the book!

Now: The Physics of Time

BY RICHARD MULLER, WW NORTON & COMPANY, 2016
ISBN-10: 0393285235; ISBN-13: 978-0393285239



Now: The Physics of Time delves into the history of philosophers' and scientists' concepts of time, uncovers a tendency physicists have to be vague about time's passage, demolishes the popular explanation for the arrow of time and proposes a totally new theory.

Some physicists have given up trying to understand, and call the flow of time an illusion, but the eminent experimentalist physicist **Richard A. Muller** protests. He says physics should explain reality, not deny it.

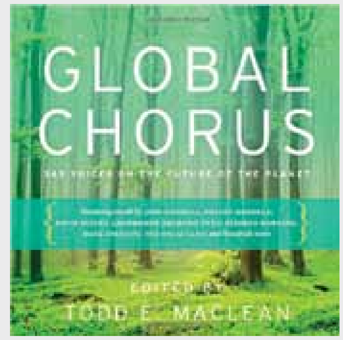
In *Now,* Muller does more than poke holes in past ideas; he crafts his own revolutionary theory, one that makes testable predictions. He begins by laying out with the refreshing clarity that made Physics for Future Presidents so successful a firm and remarkably clear explanation of the physics building blocks of his theory: relativity, entropy, entanglement, antimatter, and the Big Bang. With the stage then set, he reveals a startling way forward.

Muller points out that the standard Big Bang theory explains the ongoing expansion of the universe as the continuous creation of new space. He argues that time is also expanding and that the leading edge of the new time is what we experience as "now." This thought-provoking vision has remarkable implications for some of our biggest questions, not only in physics but also in philosophy including the ongoing debate about the reality of free will. Moreover, his theory is testable. Muller's monumental work will spark major debate about the most fundamental assumptions of our universe, and may crack one of physic's longest-standing enigmas.

[A short video of Muller explaining his theory of time and space can be viewed on the Berkeley Physics web site.]

GLOBAL CHORUS: 365 VOICES ON THE FUTURE OF THE PLANET

BY TODD MACLEAN, ROCKY MOUNTAIN BOOKS, 2015.
ISBN-10: 1771601035.
ISBN-13: 978-1771601030



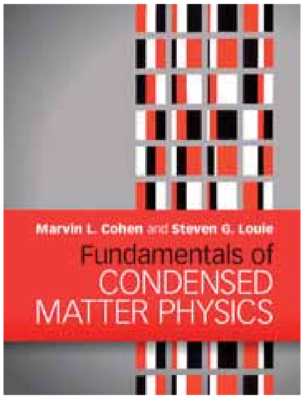
Global Chorus is an illustrated collection of 365 daily meditations around some very large and crucial questions: "Do you think that humanity can find a way past the current global environmental and social crises? Will we be able to create the conditions necessary for our own survival as well as that of other species on the planet? What would these conditions look like? In summary, then, and in the plainest of terms, do we have hope, and can we do it?"

Contributors include Berkeley Physics Professors **Robert J. Birgeneau** and **Richard Muller**, along with many others: writers, environmentalists, spiritual leaders, politicians, professors, doctors, athletes, business people, farmers, chefs, yogis, painters, architects, musicians, TV personalities, humanitarians, children, concerned students and senior citizens, carpenters, factory workers, activists, CEOs, and scientists—people who have something passionate and insightful to say about humanity's place on Earth.

Proceeds from the sales of *Global Chorus* will be distributed to a select group of organizations helping to recover, protect, and sustain life on Earth.

Fundamentals of Condensed Matter Physics

by Marvin Cohen and Steven Louie, Cambridge University Press, 2016.
ISBN: 9780521513319



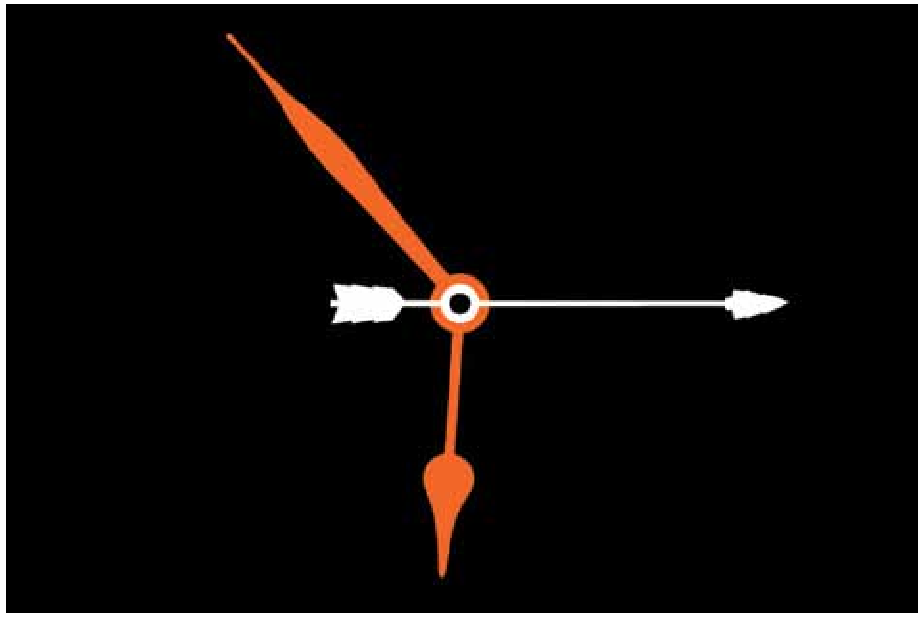
Fundamentals of Condensed Matter Physics is a textbook for graduate students, based on an established course and covering the fundamentals, central areas, and contemporary topics of this diverse field.

The book begins with an introduction to the modern conceptual models of a solid from the points of view of interacting atoms and elementary excitations. It then provides students with a thorough grounding in electronic structure and many-body interactions as a starting point to understand many properties of condensed matter systems—electronic, structural, vibrational, thermal, optical, transport, magnetic and superconducting—and methods to calculate them.

The text gives both theoretically and experimentally inclined students the knowledge needed for research and teaching careers in this field. It features 246 illustrations, 9 tables, and 100 homework problems, as well as numerous worked examples, for students to test their understanding.

Time Might Only Exist in Your Head. And Everyone Else's

Nick Stockton, *Wired*, 26 September 2016



Past. Present. Future... This linearity is called the arrow of time, and some physicists believe it only progresses that way because humans, and other beings with similar neurological wiring, exist to observe its passing.

Many physicists believe it emerges when enough tiny particles—individually governed by the weird rules of quantum mechanics—interact, and start displaying behavior that can be explained using classical physics. But two scientists argue, in a paper published today in *Annalen der physik*—the same journal that published Einstein's seminal articles on special and general relativity—that gravity isn't strong enough to force every object in the universe to follow the same past»present»future direction. Instead, time's arrow emerges from observers.

... "The position of electron, each atom, is governed by a probability," says **Yasunori Nomura**, a physicist at UC Berkeley. But once they interact with larger objects, or become things like baseballs, those individual probabilities combine, and the odds of all those collective electrons having superposition decreases.

That moment when particle physics merge with classical mechanics is called decoherence. In terms of physics, it is when time's direction becomes mathematically important. And so, most physicists believe time's arrow emerges from decoherence.

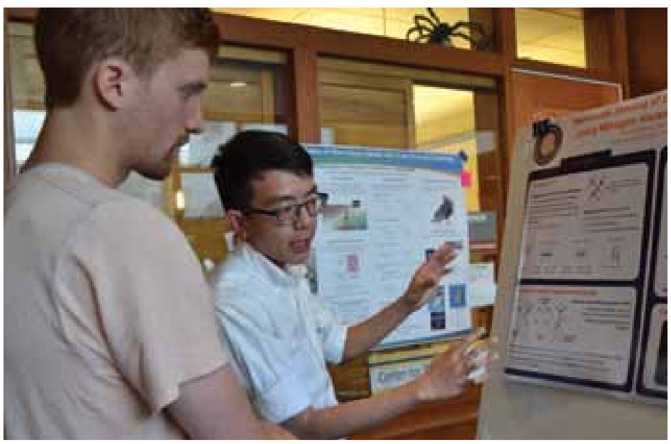
... the two scientists who penned this recent paper say that... gravity's effects kick in too slowly to account for a universal arrow of time.

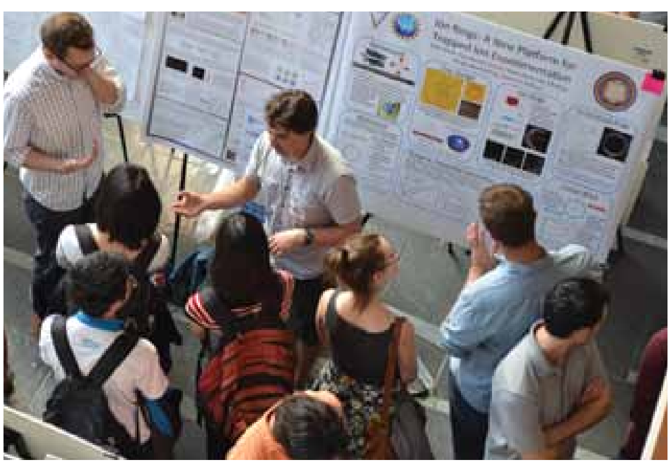
... Nomura says one flaw [in their reasoning] is figuring out how to measure whether this notion of "observer time" is real. "The answer depends on whether the concept of time can be defined mathematically without including observers in the system," he says. The authors argue that there is no way to subtract the observer from any equation, since equations are by default performed and analyzed by people.

Nomura says the authors also fail to account for the fact that the entire universe exists in a medium called spacetime, "So when you talk about spacetime, you already talking about a decohered system."

Annual Student Poster Sessions

Every fall, graduate students display their research projects at the traditional poster session, which is also an opportunity for new Berkeley Physics students to see research opportunities in one venue. Undergraduate students present their project posters in the spring.





Top: Amar Risbud (R) describes his undergraduate research project to a visitor. Middle: Graduate student Satcher Hsieh (R) explains his research to undergraduate Eric Parsonnet (L). Bottom: Students attend the Spring 2016 Graduate Student Poster Session.

Physics Undergraduate, Josh Prenot ’17, makes history at 2016 Rio Olympics

After breaking the national record at the U.S. Olympic trials for the 200-meter breaststroke and securing his spot on the U.S. Olympic swim team, Physics senior **Josh Prenot**, made history at the 2016 Rio Olympics for being the first American to win a medal in the 200-meter breaststroke event since 2004.

While Prenot made Olympic history with his 200-meter breaststroke, his specialty is the individual medley events. He also currently holds Cal’s fastest times for individual medley for both the 200-meter and 400-meter.

Prior to attending UC Berkeley, Prenot was home-schooled in his hometown of Santa Maria, California, where he also swam for the Santa Maria Swim Club. In addition to his many extracurricular talents through swim, Prenot has always been dedicated to his academics and has managed to balance both during his time at Cal.

Prenot’s academic advisor in the Physics Department, Claudia Trujillo, says that Josh is “a great example of our outstanding students. He’s studying physics, but he breaks a lot of stereotypes. He’s proof that you can do what you want.” Josh has been able to balance excelling as a physics major, competing in a collegiate atmosphere, and leading as top 10 in the world in his events. The Department is extremely proud of his accomplishments.

Photo: Peter H. Bick, *Swimming World* magazine

Segrè Summer Interns 2016

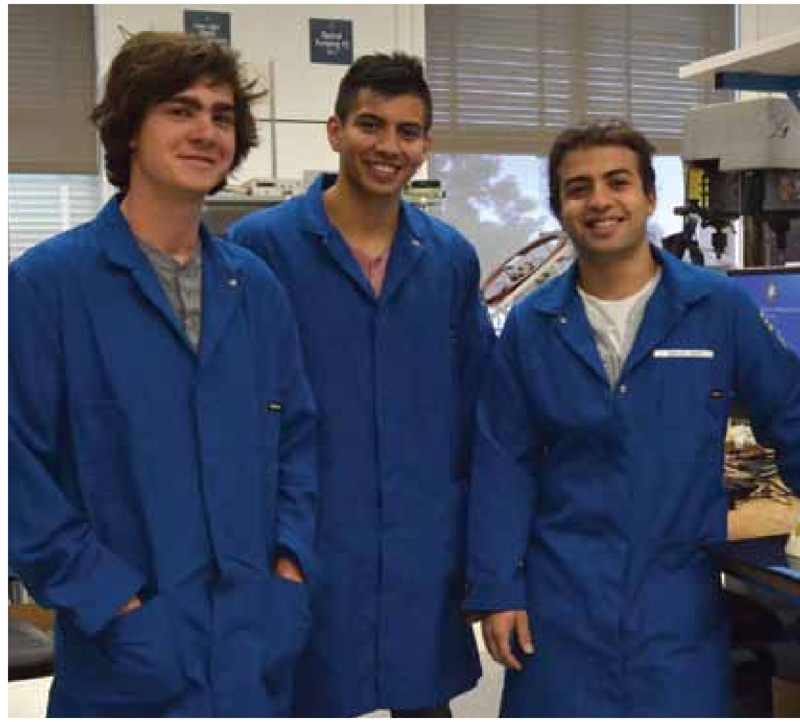
Berkeley's Emilio Segre Internship is a prestigious opportunity for three undergraduate students to enhance their experimental research skills by improving some of the experiments in Physics 111B, the Advanced Experimentation Laboratory. This year our interns started their eight-week internship programs in June and successfully completed all their tasks by the first week of August. The interns included **Daniel W. Naim** (who graduated in May), **Juan P. Castillo**, and **Hunter Akins**.

Daniel worked on the Quantum Interference and Entanglement (QIE) experiment. He spent a good amount of time on laser alignment and was able to collect data showing the violation of Bell's inequality. Daniel also presented his results in the AAPT summer meeting held at California State University at Sacramento. He writes in his summary report:

"When professor [Häffner] and I arrived, we began to set up our experiment and were greeted by the friendly faculty at the university. We presented to over 25 different academic guests, ranging from high school teachers to Brown [University faculty], divided into four groups. The professor spent most of the time talking about the physics behind the experiment; while I presented the data I took and informed other professors about the advanced experimentation lab at Berkeley."

Hunter made a great contribution to the Atomic Force Microscope (AFM) experiment where he formulated a procedure to measure the Boltzmann's constant by measuring the thermal fluctuations of the cantilever in free air. He also made many video instructions explaining the operations of various equipment used in different experiments.

Juan worked on our newly acquired 3D printer from setting it up to 3D printing of some of the sample holders used in the 111B lab. He also made adjustments to procedures on some of the experiments such as Josephson Junction and Gamma Ray Spectroscopy.



2016 Segre Summer Interns (L-R) Hunter Akins, Juan Castillo, and Daniel Naim.

All interns made major contributions in modifying the experimental instructions. They added different checkpoints in the write-ups, the purpose of which is to keep students on track and aware of what they would be doing in each experiment. These checkpoints are specifically designed to be checked by GSIs or professors and are geared towards the understanding of the equipment and the key concepts of each lab.

Berkeley's Emilio Segré Internships are made possible by a generous grant from Arlene and Doug Giancoli.

PHYSICS 2015-2016 UNDERGRADUATE SCHOLARSHIPS

L. Jackson Laslett Scholarship

Kyle Luther
Matthew McAllister
Brandon McKinzie

S.M. "Jack" and Avish Holmes Olsen Scholarship

Isabel Nora Angelo
Kevin Hayakawa
Brady Huynh
Helia Kamal
Alexander Madurowicz
Alex Wang

Isidore Pomerantz Scholarship

Unpil Baek
Sahil Chinoy
Omer Hazon
Winston Pouse
Yanjie Jack Qiu
Jung Pu Tsui
Yihua Mike Zhong

Paul and Chor Gee Undergraduate Endowed Scholarship Fund

Brian Timar

Bingham Memorial Scholarship

Kevin Chen
Yitian Chen
Remy Delva
Yuval Gannot
Chatipat Lorpaiboon
Kathryn McClain
Eric Parsonnet
Nathanan Tantivasadakarn

Bernard Fries Memorial Scholarship Fund

Lauren Capelluto
Brian Ki-Hon Chan
Ares Hernandez
Aditya Ranganathan
Varun Ranga Raj
Nikita Shalimov
Benjamin Sheff
Zhaozhong Shi
Ryan Smith
Matthew Sorensen
Leo Steinmetz
Clayton Strawn
Saavanth Velury
Oliver Wang

Physics Ph.D Degrees

Summer 2015

Miguel Demetrius Daal
Adviser: Bernard Sadoulet
Kinetic Inductance Detectors for Dark Matter Searches

Kevin Torres Grosvenor
Adviser: Petr Horava
Exploring Landscapes of Naturalness with Lifshitz Field Theories

Brian Quinn Henning
Adviser: Hitoshi Murayama
Precision Higgs Physics, Effective Field Theory, and Dark Matter

Derek Wayne Vigil Fowler
Adviser: Steven G. Louie
Quasiparticle scattering, lifetimes, and using the GW approximation

David Ren-Hwa Yu
Adviser: Beate Heinemann
Searches for new phenomena using events with three or more charged leptons in pp collisions at √s = 8 TeV with the ATLAS detector at the LHC

Claire Elizabeth Zukowski
Adviser: Raphael Bousso
General Properties of Landscapes: Vacuum Structure, Dynamics and Statistics

Fall 2015

Michele Kotiuga
Adviser: Jeffrey Neaton
Charge Transport in Molecular Junctions: A Study of Level-Alignment, Thermoelectric Properties, and Environmental Effects

Ryan Ewy Olf
Adviser: Dan Stamper-Kurn
Creating, imaging, and exploiting collective excitations of a multicomponent Bose-Einstein condensate

Berkeley Physics Undergraduate Research Scholars (BPURS)

Fall 2015

Justin Baik	Seth Hirsh	Amar Risbud
Andrew Berger	Ramin Khajeh	Logan Rudd
Alexander Giuffrida	Avery Kim	Zhaozhong Shi
Demy Delva	Meng Luo	Nana Shumiya
Omer Hazon	Kevin Nuckolls	Caroline Su

Spring 2016

Justin Baik	Omer Hazon	Malena Rice
Andrew Berger	Seth Hirsh	Logan Rudd
Thomas Bloom	Edgar Ibarra	Nana Shumiya
Jacob Bryon	Ramin Khajeh	Carlos Sierra
Alexander Chuang	Meng Luo	Leo Steinmetz
Remy Delva	Austin McDowell	Caroline Su
Christopher Dock	Ryan McPeters	Taylor Wingard
Yi-Shiou Duh	Kevin Nuckolls	Zhiyen Zheng
Alexander Giuffrida	Yanjie Qiu	

Cory Drew Schillaci
Adviser: Wick Haxton
Effective Interactions for Few-Body Physics

Bo Zeng
Adviser: Feng Wang
Manipulating Light with Nano-Photonic Structures

Spring 2016

Jacquelyn Kay Brosamer
Adviser: Marjorie Shapiro
Measurement of jets produced in top quark events using the emu final state with 2 b-tagged jets in pp collisions at 8 TeV with the ATLAS detector

Robert Najem Clarke
Adviser: Marjorie Shapiro
A Search for Lepton-Flavor-Violating Decays of the 125 GeV Higgs Boson with Hadronically Decaying Tau leptons in the 20.3 fb^{-1}, \ sqrt{s} =8 TeV Dataset Collected in 2012 by the ATLAS Detector at the Large Hadron Collider

Philipp Dumitrescu
Adviser: Ashvin Vishwanath
Strongly Correlated Electron Systems Near Criticality: From Nodal Semimetals to High-Temperature Superconductors

Aidin Fathalizadeh
Adviser: Alex Zettl
Synthesis, Characterization, and Fabrication of Boron Nitride and Carbon Nanomaterials and their Applications, and the Extended Pressure Inductively Coupled Plasma Synthesis of Boron Nitride Nanotubes

Punit R. Gandhi
Adviser: Edgar Knobloch
Localized states in driven dissipative systems with time-periodic modulation

Jason Shih An Horng
Adviser: Feng Wang
Exploring Graphene Physics for Optical Sensing

Nadir Jeevanjee
Advisers: David Romps and Jonathan Wurtele
Cold Pools, Effective Buoyancy, and Atmospheric Convection

Daniel Michael Lecoanet
Adviser: Eliot Quataert
Internal Wave Generation by Convection

Dan Mainemer Katz
Adviser: Raphael Bousso
Neutrino Masses in the Landscape and Global-Local Dualities in Eternal Inflation

Sarah E. Marzen
Adviser: Michael DeWeese
Bio-inspired problems in rate-distortion theory

Kevin Patrick O'Brien
Advisers: Xiang Zhang and Feng Wang
Nonlinear Light-Matter Interactions in Metamaterials

Arran Thomas James Phipps
Adviser: Bernard Sadoulet
Ionization Collection in Detectors of the Cryogenic Dark Matter Search

Alex L Roberts
Adviser: Yasunori Nomura
Higgs Physics and Cosmology

Nathaniel Jacob Roth
Adviser: Daniel Kasen
Modeling the Observational Signatures and Feeding of Super-massive Black Holes using Monte Carlo Radiative Transfer

Sydney Frances Schreppler
Adviser: Dan Stamper-Kurn
Quantum Measurement with Atomic Cavity Optomechanics

Josiah Schwab
Adviser: Eliot Quataert
The Long-Term Outcomes of Double White Dwarf Mergers

Ali Sucipto Tan
Adviser: Zi Qiang Qiu
Interface and Topology in Magnetism

Chayut Thanapirom
Adviser: Michael DeWeese
Neural Representation Learning with Denoising Autoencorder Framework

Sean Jason Weinberg
Adviser: Yasunori Nomura
Fixing Gauge Redundancy in Quantum Gravity

Zhivun, Elena
Adviser: Dmitry Budker
Vector AC Stark shift in 133Cs atomic magnetometers with antirelaraxion coated cells

GRADUATE STUDENT FELLOWSHIPS

National Science Foundation Fellowship
Jessica Avva
Andreas Biekert
Samuel Ciocys
Benjamin Dickens
Jennet Dickinson
Emma Dowd
Jordan Dudley
Brendan Folie
Justin Gerber
Matthew Gilbert
John Groh
Benjamin Horowitz
Satcher Hsieh
Nicholas Huang
Robert Kealhofer
Gilbert Lopez
Leigh Martin
Margaret McCarter
Robert McGehee
Christopher Mogni
Nityan Nair
Kelsey Oliver-Mallory
Abigail Polin
Alejandro Ruiz
Thomas Schuster
Katelin Schutz
Caroline Sofiatti Nunes
Erik Urban

Hertz Fellowship
Adam Stooke

National Defense Science and Engineering Graduate Fellowship
Andrew Eddins
Sophie Weber

DOE (Dept. of Energy)
Fabio Iunes Sanches
Alison Saunders

Kwanjeong Educational Foundation
Jihwan Oh

NSERC - Canadian Fellowship
Michael Fang
Nicolas Ferland

University of California Fellowship
Kodiak Murphy
QinQin Yu

The Friends of Warren Hellman Fund
Kamphol Akkaravarawong
Francisco Leal Machado

The Mary and David Sessler Endowment Fund
Kate Kamdin
Steven Martis

Heising-Simons Fellowship
Thomas Schuster

The Charles H. Townes Graduate Fellowship
Devon Hambleton

The Stuart Freedman Memorial Fellowship Fund in Physics
Donez Horton-Bailey

Rosevear Gateway I-House Scholarship
Man-Yat Chu

PHYSICS PRIZES & AWARDS

Department Citation
Brian Martin Timar

Lars Commins Memorial Award in Experimental Physics
Dillon Wong

Brantley-Tuttle Tahoe Award
Ziqi Yan

Jackson C. Koo Award
Mollie Elisheva Schwartz

The Leo Falicov Graduate Student Fellowship Fund in Physics
Benjamin Dickens

Student Service Award
Ivan Aguilar
Kelly Marie Backes
Kathryn Chu
Paul Riggins
Isabella Urdinaran

Outstanding Graduate Student Instructor Awards
Hunter Ray Burroughs
Siva Ranjit Darbha
Matthew Dethlefsen
Irina Ene
Len Takahashi Evans
Michael Girard
Jonah Benjamin Haber
Illan Feiman Halpern
H. R. Huber
Ryan Joseph Janish
Stephanie Alexandra Mack
Ali Madani
Bill Masson
Kacey Lynn Meaker
Ionut-Dragos Potirniche
Vetri Velan

The Class of 2016

Warm weather and sunny skies provided the backdrop for Commencement 2016 on May 15, when Berkeley Physics and Astronomy students celebrated their graduation with families and friends in Zellerbach Auditorium.

The ceremony featured an address titled “Viewing the Invisible in Life” by keynote speaker **Xiaowei Zhuang**, Berkeley Physics alumna (PhD ’06) and the David B. Arnold Jr. Professor of Science at Harvard University as well as **Steve Boggs**, Chair of the Department of Physics. **Kyle Luther** served as the student speaker.

In academic year 2015-16, Bachelor degrees were awarded to 145 students, Masters degrees were earned by 31 students, and PhDs were conferred upon 36 doctoral candidates.

The day began with a celebratory patio brunch hosted by Berkeley Physics to recognize 26 graduate and undergraduate students with prizes and awards for their work and achievements during the academic year.

Student Service Awards were given to **Ivan Aguilar, Kelly Marie Backes, Kathryn Chu, Paul Riggins,** and **Isabella Urdinaran**.

Outstanding Graduate Student Instructor Awards went to **Hunter Ray Burroughs, Siva Ranjit Darbha, Matthew Dethlefsen, Irina Ene, Len Takahashi Evans, Michael Girard, Jonah Benjamin Haber, Illan Feiman Halpern, H. R. Huber, Ryan Joseph Janish, Stephanie Alexandra Mack, Ali Madani, Bill Masson, Kacey Lynn Meaker, Ionut-Dragos Potirniche, Vetri Velan,** and **Albert Yuen.**

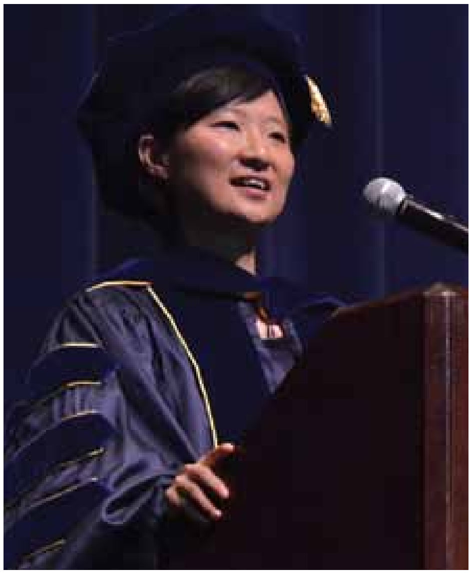
The Lars Commins Memorial Award was given to graduate student **Dillon Wong.** Lars, son of the late Berkeley Physics Professor Emeritus Eugene Commins, was an accomplished engineer with a deep interest in experimental physics. This award was created in his honor in 2004 to uphold the rich tradition of experimental physics at Berkeley.

The **Jackson C. Koo Award in Condensed Matter Physics** went to **Mollie Elisheva Schwartz**. Koo’s widow, Rose, created this recognition in 2009 for high achievement by a graduate student in condensed matter physics.

Brian Martin Timar received the **Department Citation** for his outstanding achievement as an undergraduate student in scholarship and research.

Photo: Ben Ailes

Berkeley Physics Student Award Winners pictured with department chair Steve Boggs, second from right.



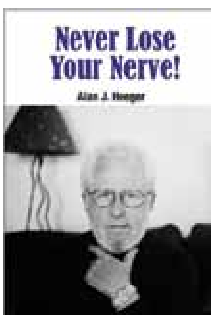
Class Notes

1960

Arthur Gossard (PhD '60) has been awarded the National Medal of Technology and Innovation, one of the nation's highest honors for advancing the fields of science and technology. Gossard joined the faculty at UC Santa Barbara in 1987 and is now Professor Emeritus of Materials and Electrical & Computer Engineering. He is a member of the National Academy of Engineering and the National Academy of Science. Gossard's research involves molecular beam epitaxy, the growth of quantum wells, superlattices, magnetic semiconductors, and metal/semiconductor nanocomposites and their applications to high-performance electrical and optical devices, and the physics of low-dimensional structures.

Additionally, Gossard also has been involved in the formation of Superconductor Technologies, Inc., the application of high-temperature superconductivity to mobile phone networks, and to ocean-based high-efficiency wind turbines for generating electrical power.

1961



Alan J. Heeger (PhD '61), Nobel Laureate, published a new book, *Never Lose Your Nerve!* in 2015. The book recounts his 2000 Nobel victory in an autobiographical fashion and explores the world of professional science. Heeger describes his inspirations and personal experiences and acknowledges the mentors who helped shape his professional drive.

Heeger's journey into physics began during his undergraduate career at the University of Nebraska. After receiving a doctorate in the field from UC Berkeley, He taught for 20 years at the University of Pennsylvania, where most of his Nobel-winning work began. Heeger is now a professor at UC Santa Barbara.

1966

Herschel Snodgrass, (PhD '66) After 30 years with Lewis & Clark College's Physics Department, Berkeley Alumnus Herschel Snodgrass has retired. Professor Snodgrass's Physics education began at Reed College and eventually at the University of Maryland and UC Berkeley for graduate school. He was very politically active during his time at Berkeley and was one of the student leaders of the free speech movement. Because the Berkeley Physics Department was just as politically engaged in the student movements, Snodgrass was offered a teaching position shortly after attaining his degree in 1966. After his time at Berkeley, Snodgrass went back to Reed in the 1980s to teach. Shortly after, he was offered a position at Lewis & Clark's Physics Department.

Since then, Snodgrass has spent his time as professor of Physics at Lewis & Clark helping students with research and publishing papers. Additionally, he was one of the 10 people named in Astrophysics News of the Year in 1987. Snodgrass has even had the opportunity to teach his son while he was an undergraduate at Lewis & Clark. In his retirement, Herschel plans to continue travelling and working on his music. He also has a book in the works that he will be completing titled *Beyond the Realm of the Senses*.

1992

Andrew Westphal, (PhD '92) Andrew Westphal is a senior fellow at the UC Berkeley Space Sciences Laboratory. He developed the citizen science approach for a game called Stall Catchers. Stall Catchers allows for players to watch videos of real blood vessels in search of clogged capillaries where blood does not flow. Capillary stalls have been found to be a leading component in Alzheimer's research. Because data analysis in Alzheimer's research can be extremely time-consuming, researchers are hopeful that the citizen science approach will speed up research in finding a cure for Alzheimer's.

Stall Catchers is a free game that anyone can play on a laptop, tablet, or smartphone. It has been tested by over 100 people, most of whom are citizen science volunteers. Not only will this game allow for accelerated research results in Alzheimer's disease research, but it will also allow the public to directly contribute to fighting for a cure for Alzheimer's.

1995

Amber Miller (BA '95) was named Dean of USC Dornsife College of Letters, Arts and Sciences in May 2016. She previously served as Dean of Science for the Faculty of Arts and Sciences and Professor of Physics at Columbia University, where she was a member of the faculty from 2002.

Miller earned her PhD from Princeton in 2000. She has published over 100 articles in the field of early universe cosmology, and her decanal work at Columbia was focused on enhancing the basic sciences and building and strengthening ties between science, engineering, the medical center, and other units in the university. An authority on the interface between science and policy, she has taught courses such as "Science, Policy, and Critical Thinking", "Weapons of Mass Destruction", and "Physics for Poets". She also served two years as the Chief Science Advisor to the NYPD Counterterrorism Bureau.

1997

Josh Miele, (BA '97) found empowerment and inspiration through the blind community during his time at UC Berkeley. Since then, he has made amazing strides in helping the blind community through his work in technology. Right before his final semester as an undergraduate, Miele briefly left to work for a startup company that made Macintosh computers more accessible for blind people. He returned to Cal to finish his degree in Physics and later acquired his PhD in Psychoacoustics in 2003.

In a recent interview with Cal Alumni Association's *California Magazine,* Miele discussed his current work for the Smith-Kettlewell Eye Research Institute, which allows him to work on making technology and programs more accessible for blind people. One of his projects, YouDescribe, is an enhanced video program for YouTube in which recorded voices describe what can't be seen. Similarly, Miele's Blind Arduino project works with a tiny programmable computer that ultimately creates more accessibility in technology for blind people. Users can create code through the software in Arduino that uses electronic sensors, lights, and motors as a source of interaction.

Miele is a pioneer in paving the way for blind people to have equal opportunities in science and learning. Additionally, he has collaborated with the Lighthouse for the Blind and Visually Impaired in San Francisco to create accessible maps for the BART stations in the Bay Area. This map comes with Braille, large print, and audio via a LiveScribe Smartpen, which reads off information from the map. This is useful and empowering for the blind community as it not only allows them to independently travel through public transit much more easily, but it also allows them to find out the price of ticket fares and bus schedules.

2008

Jacob Howard (BA '08) completed undergraduate degree in both Physics and Mathematics in 2008. He went on to attain his PhD at Oxford. Since then he has traveled the world doing research, specifically in splitting atoms. He worked at the CERN Laboratory in Geneva, Switzerland during his time at Oxford, where he was part of the Nobel-winning ATLAS program of the Higgs-Boson research.

2014

Gary Li (BA '14), UCLA Aerospace Engineering graduate student, won first place at the UCLA Grad Slam this year and went on to compete at the UC-wide Grad Slam in Oakland. As a former UC Berkeley Physics and Astrophysics student, Li made the Department proud with his presentation on "Traveling to Mars with immortal plasma rockets".

Li's research focuses on replacing traditional chemical rockets that are used for space propulsion with more efficient plasma thrusters. He explained some of the downsides to this method, including ions that break off of the thruster's wall. However, he is looking into best materials for the "plasma redeposition" effect, which allows the thruster's inner wall to repair itself and would enable spaceships that carry less fuel to travel much farther. After Li achieves his PhD, he wishes to work in the field of space exploration, working on applied research and development.

IN MEMORY

Harry Heckman, Jr (1923-2016)

Harry Heckman, Senior Scientist Emeritus at Lawrence Berkeley National Laboratory, passed away at his Berkeley home on February 23. He was 92.

Heckman earned his BA in 1948 and his PhD in physics in 1953, both from UC Berkeley. He enjoyed a long and distinguished career at Berkeley Lab in high energy physics and relativistic ion physics. Heckman analyzed spacecraft data and worked on ion distributions in the earth's radiation belt that are now known as "butterfly pitch-angle distributions."

Among his many experiments, Heckman worked on a team to determine the range-momentum relation for charged particles in Ilford G.5 emulsion of known density. He also joined a colleague to recover experimental data from earth-oriented satellites and report on the spatial and temporal properties of energetic trapped protons at low satellite altitudes.

In 1978 the German government honored Heckman with the Alexander von Humboldt Award for Senior US Scientists, which allowed him to conduct independent research at the University of Frankfurt in 1978-79.

After retiring from Berkeley Lab, Heckman built an experimental aircraft and was a member of Concord's Experimental Aircraft Association. He is survived by his wife of 60 years, Kathleen, and their two children, John and Martha.

Ed Lofgren (1914-2016)

Edward Joseph Lofgren, a pioneering scientist at UC Berkeley's Radiation Laboratory, died on Sept 16 at the age of 102.

Lofgren was a close associate of E.O. Lawrence, and chief physicist for the development, construction, and operation of the Bevatron, an early particle accelerator at Berkeley Lab. He also served as associate laboratory director.

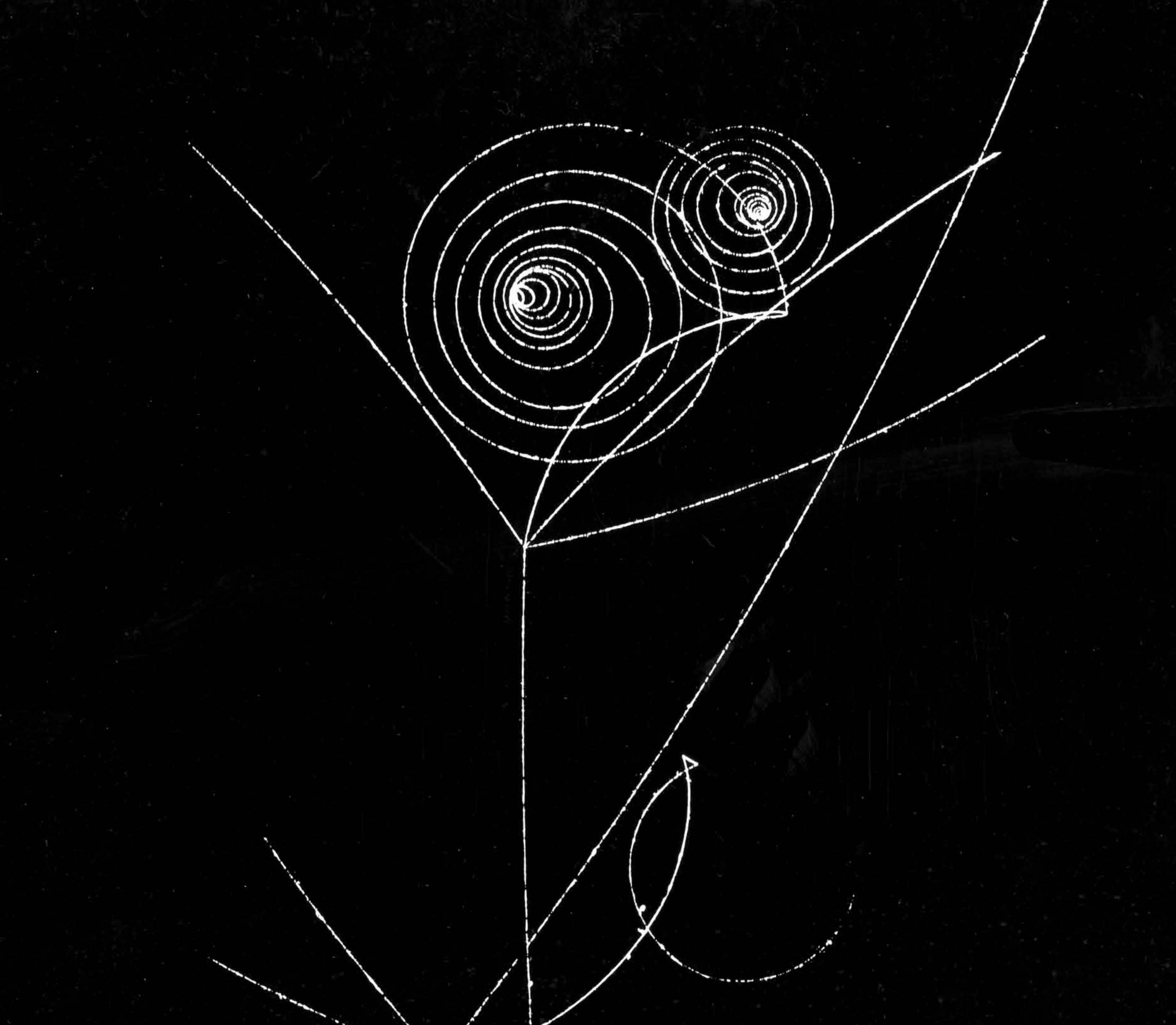
As an undergraduate at UC Berkeley, he worked on a cloud-chamber spectrometer aimed at measuring meson masses. He earned a bachelor degree in 1938. In 1940 he joined the Rad Lab's staff as a research assistant.

Lofgren helped develop E. O. Lawrence's Calutron for enriching uraium-235 for the Manhattan Project. In 1944 he moved to Los Alamos to join the Luis Alvarez group, working on detonators for the atomic bomb. After the war, Lofgren returned to Berkeley and received his PhD in 1946.

In 1949, Lofgren helped boost the energy of the Bevatron to 6 billion electron volts—making it the world's highest-energy accelerator at that time.

Lofgren retired in 1949. His long, prolific, and inspiring career contributed immensely to the evolution of accelerators as important research tools. He is survived by three daughters, four grandchildern, and two great-grandchildren.

Adapted from an obituary written by Glenn Roberts, Jr



September 21, 2016 marked the 90th birthday of Donald A. Glaser, inventor of the bubble chamber—an ingenious device that makes visible the pathways of ionized particles as they travel through the atmosphere. Much of what is known about particle physics today was initially discovered through patterns, like those shown here, revealed in a bubble chamber. The invention earned Glaser the 1961 Nobel Prize in physics, awarded one year after he joined the Berkeley Physics faculty. During his career he shifted his focus from particle physics to molecular biology and neurobiology. He died February 28, 2013.

University of California, Berkeley
Department of Physics
366 LeConte Hall, #7300
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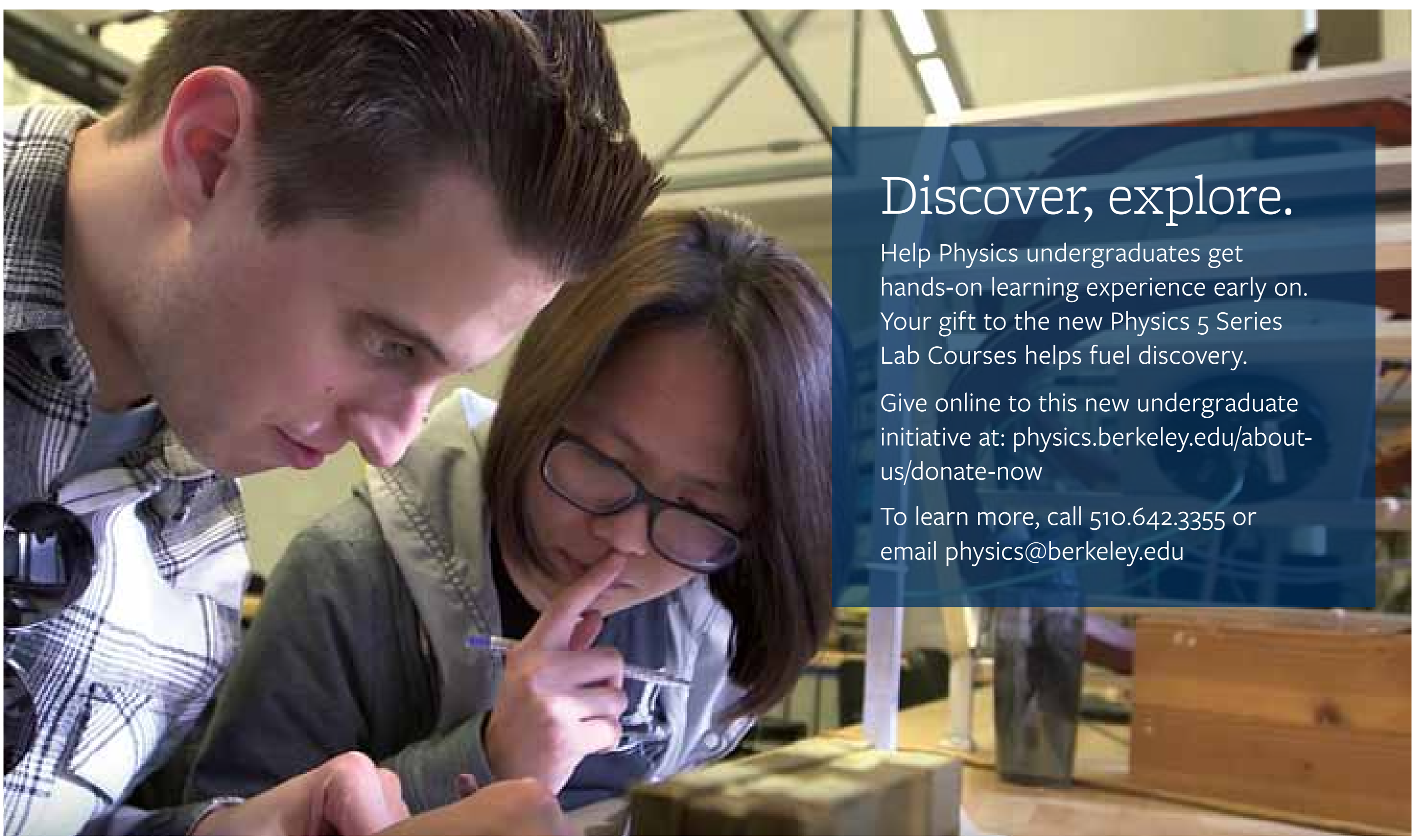

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