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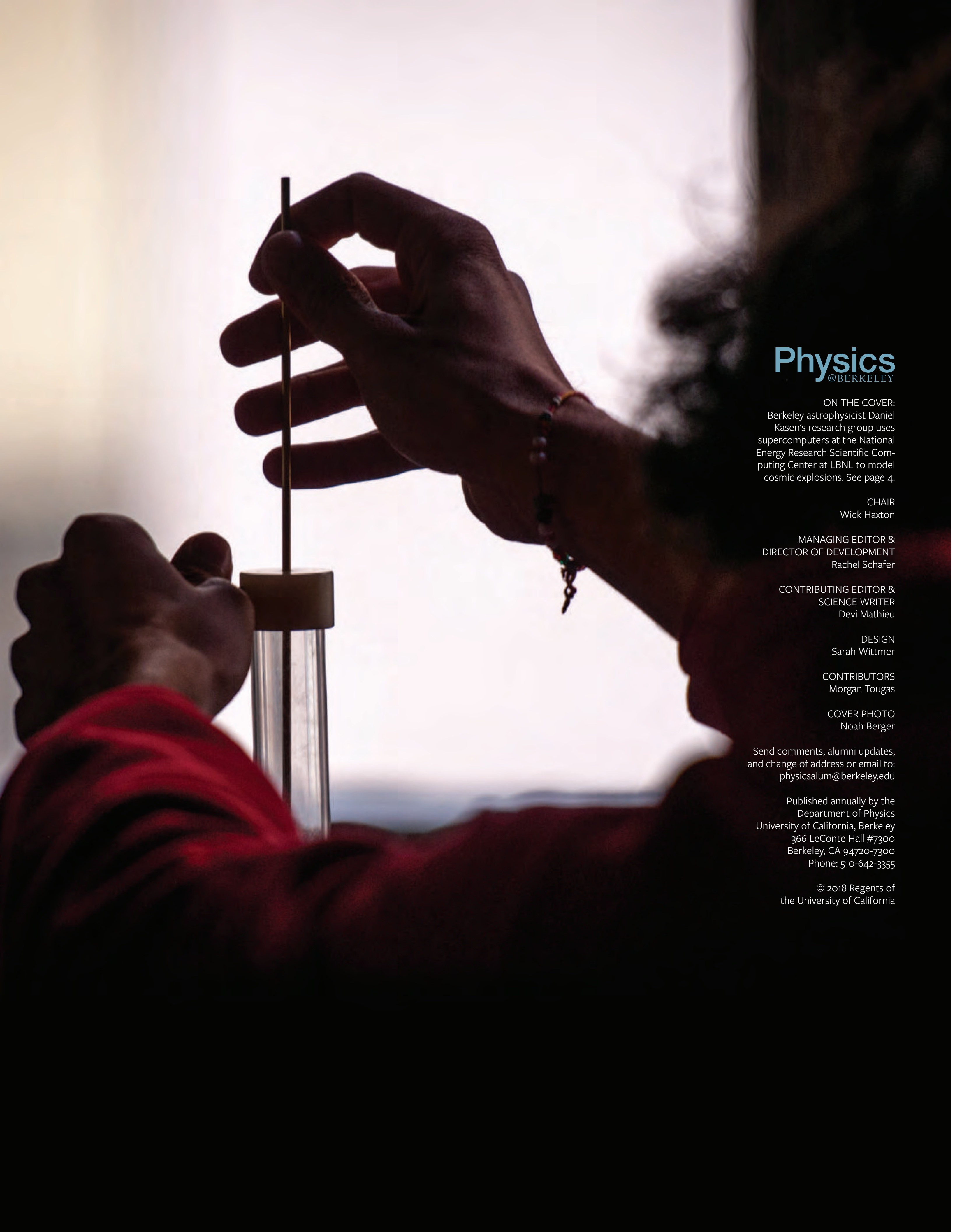
Titans *of the* Cosmos

Exploring the Mysteries of Neutron Star Mergers & Supermassive Black Holes



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ON THE COVER:
Berkeley astrophysicist Daniel Kasen's research group uses supercomputers at the National Energy Research Scientific Computing Center at LBNL to model cosmic explosions. See page 4.

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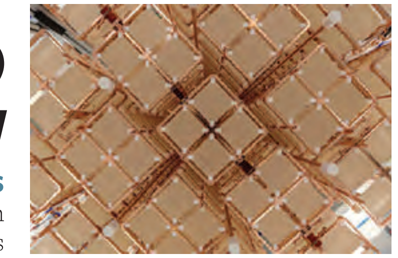


CHAIR'S LETTER

PHOTO: BEN AILES

Fall classes are underway, our introductory courses are packed, and we have good news on several fronts. On July 1 we welcomed our newest faculty member, condensed matter theorist Mike Zalatel. In August the 2018 Academic Rankings of World Universities were announced, with Berkeley Physics second, between MIT and Stanford – fine company. In September we learned that Professor Barbara Jacak will be awarded the 2019 Tom Bonner Prize of the American Physical Society for her leadership of the PHENIX detector at Brookhaven's Relativistic Heavy Ion Collider, and new graduate student Nick Sherman will receive the LeRoy Apker Award for outstanding undergraduate research in theoretical condensed matter and mathematical physics. Most recently, Assistant Professor Norman Yao has been named a Packard Fellow, one of the most prestigious awards available in STEM disciplines.

We are announcing the Physics Innovators Initiative (Pi²) – an effort to modernize introductory lab courses Physics 7 and 8, create a new Tinkering Studio, upgrade the Student Machine Shop, and create new instructional modules. These improvements, part of our efforts to support the University's call for more Discovery Experiences, will prepare physics undergraduates to become researchers in faculty laboratories.

We find ourselves strengthening our role internationally: interest in physics is exploding in Pacific Rim nations like China and Japan, and the Bay Area is admired for its successful integration of university research with Silicon Valley innovation. We have started Berkeley Partners in Education (BPIE) to host visiting undergraduates from overseas through our concurrent enrollment program. With Engineering, we are exploring the creation of a new Masters program in Engineering Physics to prepare physicist-engineers for success in the business world. This program is expected to draw students from the US and internationally. We are also considering international partnerships that could strengthen our efforts in cosmology and high performance computing – possibilities that will develop further over the next year or so.

Thank you for your support of Berkeley Physics!

Research Highlights

The blackbody attraction between a hot tungsten cylinder and a cesium atom is 20 times stronger than the gravitational attraction between them.

IMAGE: HOLGER MÜLLER

Heat-Enhanced Gravitational Attraction

Berkeley physics professor **Holger Müller** and colleagues have used their world-renowned expertise in atom interferometry to demonstrate that the warm glow of an object augments its gravitational attraction. The phenomenon is related to the physics behind devices known as optical tweezers, in which laser light attracts and traps atoms.

The Müller team's experiment confirms a theory, proposed by others, that ordinary light, or even infrared radiation, can have a similar effect on atoms. The team showed that the blackbody radiation of a heated tungsten cylinder attracted a cesium atom with a force 20 times greater than gravitation alone. Blackbody radiation is essentially the infrared radiation given off as an object cools.

The effect is so miniscule that its influence is usually insignificant. But it's something that must be taken into account when extraordinarily accurate measurements are needed. "The blackbody attraction has an impact wherever forces are measured precisely, including precision measurements of fundamental constants, tests of general relativity, measurements of gravity, and so on," says Müller.

As an example, blackbody attraction could have a measurable influence on a new generation of gravitational wave detectors, now being developed, that use lab-bench atom interferometers instead of the kilometers-long interferometers now in operation.

Precision Spectroscopy of AntiHydrogen

Berkeley physics professors **Joel Fajans** and **Jonathan Wurtele** have spent more than a decade exploring antihydrogen physics as part of the ALPHA collaboration at CERN. They are pioneers in the development and application of plasma physics techniques for synthesizing, trapping, and manipulating antihydrogen atoms. Since 2005, they have worked with more than 20 undergraduates, 6 graduate students, 3 postdocs, and physics lecturer **Andrew Charman** to conceptualize and implement experiments with antihydrogen.

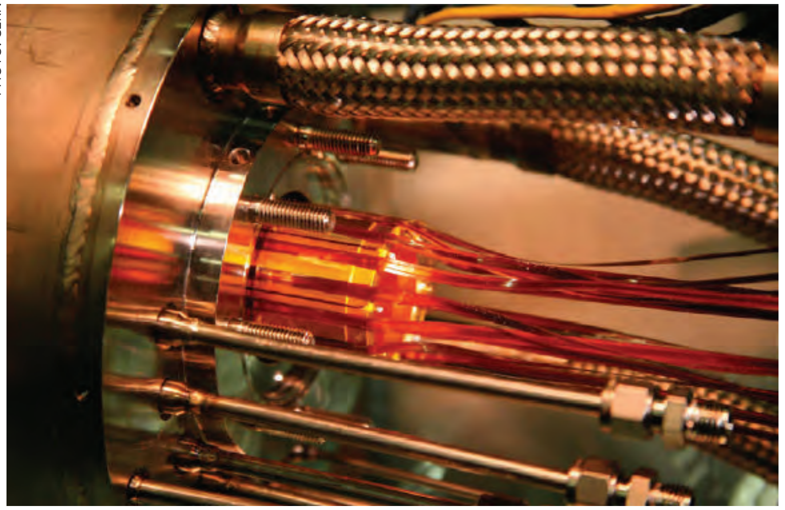
The Fajans and Wurtele group recently contributed technical improvements that increased ALPHA's trap rates by a factor of ten. This enhancement enabled ALPHA to make the most accurate measures yet of an important spectroscopic property known as the hyperfine structure of antihydrogen.

In an April 2018 issue of Nature, the ALPHA collaboration compared their antihydrogen spectral measurements with measurement of the same spectrum in ordinary hydrogen atoms and found agreement at a precision of two parts in a trillion.

According to all measures made so far, matter and antimatter are perfectly symmetrical opposites – they are exactly the same except for having opposite electrical charges. Finding even the smallest differences would revolutionize our understanding of fundamental physics and help unravel the mystery of why the universe is composed almost entirely of matter, even though equal amounts of matter and antimatter should, according to theory, have been created in the Big Bang.

ALPHA's recent success opens up the field of precision measurements of neutral antimatter. Future experiments will continue to compare fundamental atomic physics quantities of antihydrogen with those of its matter twin, hydrogen.

PHOTO: CERN



The ALPHA antimatter trap uses magnetic and electric fields to contain antimatter without bringing it into contact with matter.

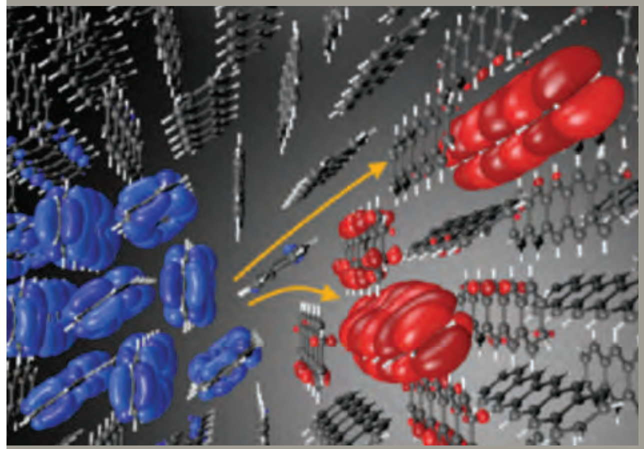


PHOTO: LAWRENCE BERKELEY NATIONAL LABORATORY

Improving Organic Solar Cells

Organic solar cells are made with materials that tend to be cheaper, more abundant, and more environmentally friendly than conventional solar cells. They also tend to be less efficient. A collaboration co-led by Berkeley physics professors **Steven G. Louie** and **Jeffrey B. Neaton**, working with postdocs **Sivan Refaely-Abramson** and **Felipe H. da Jornada**, identified a new mechanism for a process that could lead to dramatic gains in organic solar cell efficiency.

The process, called "singlet fission", holds promise for converting sunlight's energy to more electrical charges instead of losing it to heat. Singlet fission involves a light-created composite particle (called a bound electron-hole pair or exciton) composed of an electron with a negative charge, and a "partner hole" – a vacant electron in a material's chemical bonds. The partner hole behaves like a particle with a positive charge. In some organic solids, this composite can rapidly convert into two electron-hole pairs, doubling the material's charge-carrying potential and reducing heat loss.

Louie noted that the multidisciplinary team assembled for this study, in the recently established Department of Energy Center for Computational Study of Excited-State Phenomena in Energy Materials at Lawrence Berkeley National Laboratory, was especially capable of applying fresh thinking to a decade-old problem. "This is one of the first important topics that we could address, and now it's come to fruition," he said.

Left: A new mechanism that could improve the efficiency of organic solar cells was discovered at the Center for Computational Study of Excited-State Phenomena in Energy Materials, based at Lawrence Berkeley National Laboratory.

Probing the Nature of Neutrinos

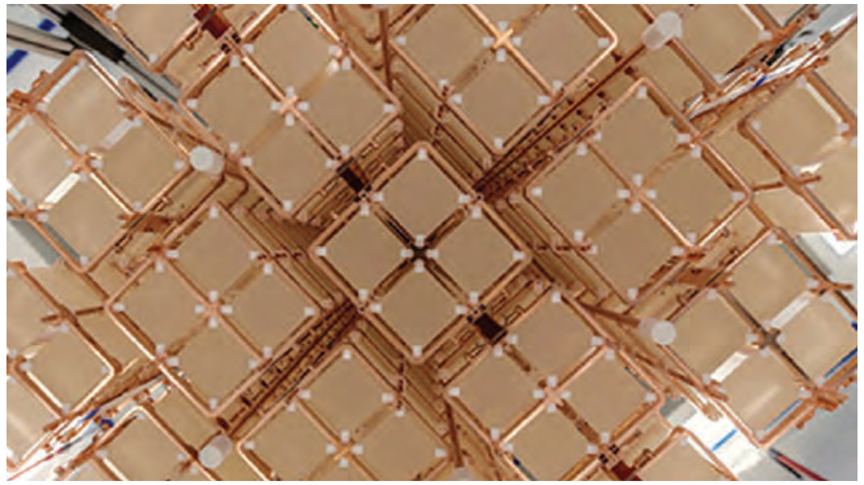
One of the biggest mysteries in physics – why there is more matter than antimatter in the universe – might be a little closer to a solution, thanks to the CUORE neutrino experiment.

CUORE (Cryogenic Underground Observatory for Rare Events) has set the most precise limits yet on the likelihood that neutrinos undergo a process called neutrinoless double beta decay in a Tellurium-130 isotope. It's a theoretical idea that, if shown to be true, would stretch the bounds of the Standard Model. It would indicate that neutrinos are their own antiparticles, making them a source for particle- antiparticle interactions that favor matter over antimatter.

If it exists, neutrinoless double-beta decay is so rare that Herculean efforts are required to detect it. CUORE is a large cryogenic detector – with 750 kg of tellurium dioxide crystals cooled down to temperatures around 10 milliKelvin. It detects subtle temperature variations that are created when a tellurium nucleus decays. With the large detector volume and very low temperatures, CUORE has been dubbed "the coldest cubic meter in the known universe".

CUORE began full operation in October 2017. Berkeley physics professor **Yury Kolomensky**, US spokesperson for the CUORE collaboration, leads the research team responsible for producing CUORE's temperature sensors, constructing, installing, and operating the detector, and now analyzing the data.

PHOTO: YURY SUVOROV, UCLA AND CUORE COLLABORATION



CUORE consists of a block-shaped array of tightly packed tellurium oxide crystals that transform nuclear decays into subtle temperature changes. To prevent false signals, it's encased in lead and positioned 1.5 km underground at Gran Sasso in Italy

Titans *of the* Cosmos

Exploring the Mysteries of Neutron Star Mergers and Supermassive Black Holes

PHOTOS BY NOAH BERGER

Neutron stars and black holes are the most dense of the known objects in our universe. Neutron stars turn out to be the progenitors of most of the elements in the periodic table. Black holes are critical to the growth and development of galaxies, and we've just begun to learn how amazingly massive they can become.

Two of Berkeley's eminent astrophysicists, **Daniel Kasen** and **Chung-Pei Ma,** are blending theory with astronomical observations to bring new understanding of these cosmic titans. Kasen's profile begins here, Ma's begins on page 8.

When Neutron Stars Collide

Berkeley astrophysicists predict – with astonishing accuracy – what the merger of two neutron stars looks like, and answer a longstanding question about how the cosmos creates heavy elements

Theoretical astrophysicist Daniel Kasen studies how cosmic explosions serve as probes of cosmology and fundamental physics. He is associate professor of physics and astrophysics at UC Berkeley, and a faculty scientist at Lawrence Berkeley National Laboratory. He earned his MS and PhD in physics from Berkeley and joined the faculty in 2010.

Cosmic Thunder and Lightning

A neutron star forms when a massive star runs out of fuel. The star's outer layers explode in a supernova. Its core collapses into a sphere so dense that protons and electrons are forced together to form neutrons. "Neutron stars are among the densest objects in the universe," **Kasen** explains, "with a mass something like our sun compressed into the size of a small city."

"Occasionally two neutron stars spiral together and collide violently," he continues. "That process generates gravitational waves and expels matter that radiates across the electromagnetic spectrum. You can learn about the cosmic origin of elements and the physics of neutron stars by studying the material that gets ejected as the two stars come together."

> "We're seeing the creation of a whole new field of study in astrophysics."

Gravitational waves are generated by disturbances in space-time caused by violent cosmic collisions. They are often described in terms of sound – a 'chirp' produced when the detector receives a gravitational wave (GW) signal. Kasen compares the signals coming from GW170817 to thunder and lightning. "Electromagnetic radiation is the lightning," he says. "Gravitational waves are the thunder."

The Birth of Multi-Messenger Physics

"This is the first time we've seen both gravitational waves and electromagnetic radiation from a single cosmic event," he adds. "And that's been a holy grail for astrophysics." The availability of different kinds of signals – messengers – to study the same event is called multi-messenger physics.

"Multi-messenger physics has important scientific implications," Kasen points out. "One of the main results from this event was confirmation that gravity waves travel at essentially the speed of light. Observers saw both light and gravitational waves arrive almost simultaneously, just as Einstein's General Theory of Relativity predicts. As a result, other theories of gravity that propose different speeds can now be ruled out."

"Not only could astronomers pinpoint the location and distance of this collision," he continues. "It became possible, for the first time, to directly study how ultra-dense matter is stretched and torn and fused into heavy elements in a violent collision."

Kasen and collaborators had been working for almost a decade to develop theoretical models detailing what could be happening when neutron stars collide and what the light coming from such an event would look like. Telescope observations of GW170817 gave them their first chance to see how their models

Dateline August 17, 2017

US-based LIGO detectors register a **gravitational wave** (GW) signal, designated GW170817. Previous GWs were generated by merging black holes. This signal differs in ways that suggest it was generated by two neutron stars spiraling in toward each other.

Within milliseconds, Europe's Virgo detector records the **same GW event**, enabling astronomers to triangulate the patch of sky from which it originated.

Less than two seconds later, NASA's Fermi space telescope receives a short burst of **gamma rays** from the same region – another clue that this GW came from a neutron star merger.

Telescopes around the world turn toward that patch of sky, searching for signals from the event. Their **observations are guided by theoretical models** of what a neutron star merger would look like, developed over the past several years by UC Berkeley astrophysicist Daniel Kasen and collaborators.

As data pour in, it becomes clear that GW170817 represents a number of **firsts** for astrophysics.

the first detection of GWs generated by a **neutron star merger**

the first detection of **electromagnetic radiation** associated with GWs

the first verification that GWs travel at the **speed of light**

the first confirmation that neutron stars are indeed composed of **neutrons**

the first proof that theoretical models of neutron star mergers developed by Kasen and collaborators match astrophysical observations, corroborating the theory that neutron star mergers are a significant source of **heavy elements** in the cosmos

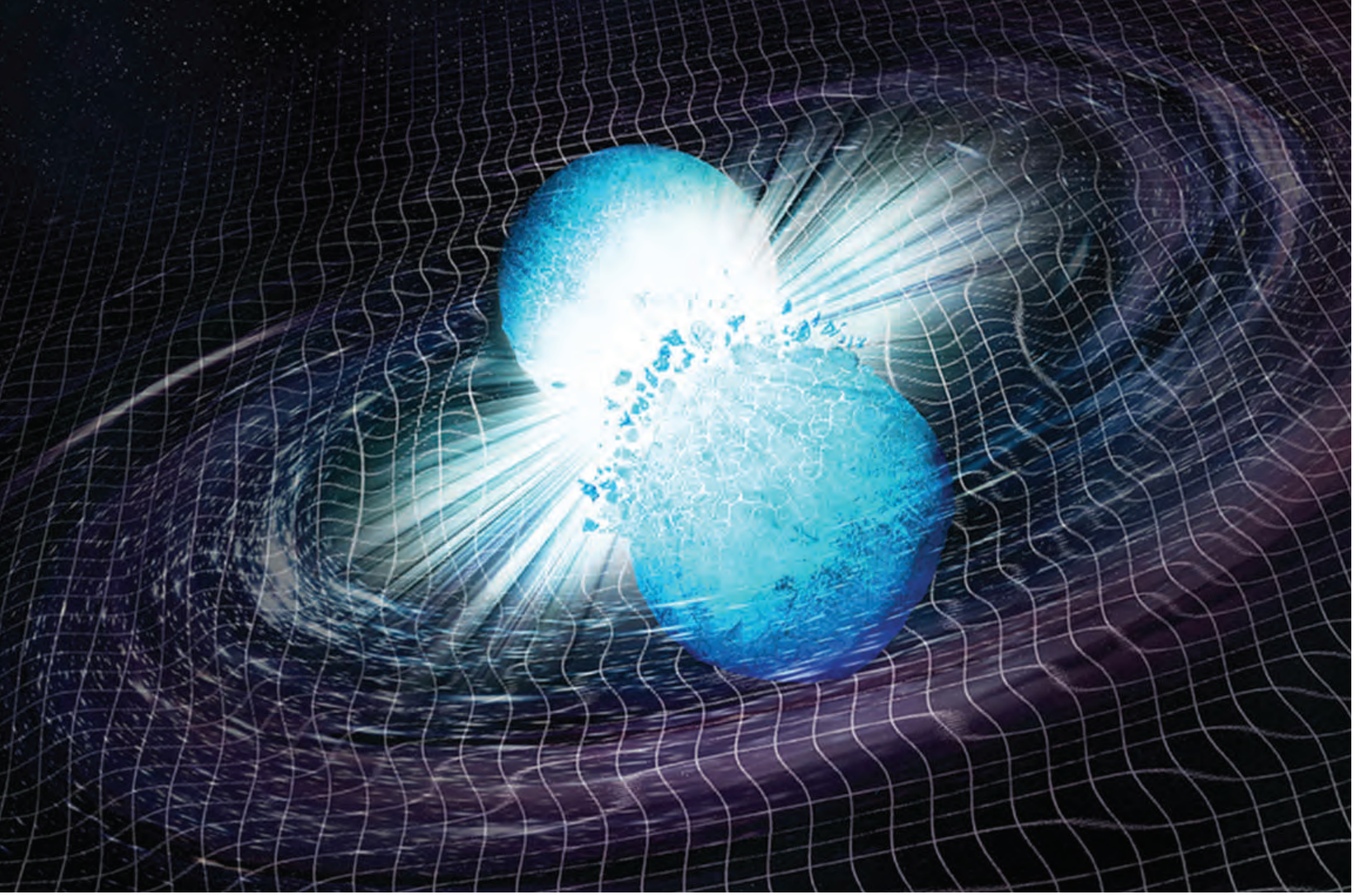


ILLUSTRATION: CXC/M. WEISS

compare with astronomical observations. "Luckily, at only 130 million light years away, this event was remarkably close to us," Kasen notes.

Eliot Quataert, Berkeley professor of astronomy and physics and one of Kasen's collaborators, said in a media release, "We were anticipating LIGO finding a neutron star merger in the coming years but to see it so nearby – for astronomers – and so bright in normal light has exceeded all of our wildest expectations. And, even more amazingly, it turns out that most of our predictions of what neutron star mergers would look like as seen by normal telescopes were right!"

Heavy Elements and Kilonova Models

Astronomers have long wondered where and how the cosmos creates heavy elements. Fusion reactions in the superheated cores of stars generate elements up to iron, with 26 protons in its nucleus. Building heavier elements requires increasing the number of protons in atomic nuclei, but electrical forces make it extremely difficult to push positively charged protons into an already positively charged nucleus.

"The forces of repulsion get more extreme as the atoms get heavier," Kasen explains. "The trick to going beyond iron is to bombard atoms with neutrons. Neutrons have no charge, so they can more easily enter the nucleus. Once captured, they decay into protons."

For decades, theorists had proposed that colliding neutron stars could provide the dynamic, neutron-rich conditions required to generate elements heavier than iron. And there was speculation that such an event would produce a radioactive glow in observable wavelengths of light, enabling astronomers to confirm heavy elements were forming. But no such event had been seen, and no one had delved deeply into the details.

In 2010, Kasen and Quataert co-authored a paper led by **Brian Metzger**, then a Berkeley graduate student who is now professor of astronomy and physics at Columbia. They were the first to estimate the brightness of glowing debris from a neutron star merger. Their calculations predicted an explosion that would burn a thousand times brighter than a stellar nova, prompting them to coin the term 'kilonova' to describe it.

Since then, Kasen and collaborators have been developing increasingly detailed kilonova models, using supercomputers to simulate not only the radioactive glow, but also the physics of the collision itself and the material ejected in the explosion.

"The Berkeley group did a lot of the pioneering work on what the light coming from a kilonova would look like." Kasen reports, "and how we can use it to infer the chemical makeup and speed of the debris cloud."

Theory usually follows observation – after a discovery, theorists work to explain what happened, why, and how. "Astronomy is primarily an observational science," Kasen points out. "This was one of those rare cases where theorists developed very detailed predictions of this phenomenon, then observers went out and found it."

Strong gravitational waves, like those detected as LIGO event GW170817, are produced when a neutron star merges with another neutron star. This artist's illustration shows two neutron stars spiraling in toward each other before eventually collapsing together to form a black hole. Debris expelled during the merger, depicted in purple, reassembles over time into heavy elements like gold and platinum.

> "Most of our predictions of what neutron star mergers would look like as seen by normal telescopes were right!"
> – Elliot Quataert

With no observational data to start from, Kasen and colleagues had to go back to first principles, creating kilonova simulations by integrating known fundamentals of everything from atomic and nuclear physics to electromagnetism, general relativity, and hydrodynamics. They also pushed into new territory, taking a deep dive into the quantum mechanics needed for their simulations. "In a sense," Kasen notes, "we had to build our atoms from the ground up, calculating how they absorb and emit light."

The depth and complexity of kilonova models require intensive computer power. Kasen and collaborators have thus far depended on the supercomputers at the National Energy Research Scientific Computing Center at Lawrence Berkeley National Lab. They are now embarking on a new project called Exastar, part of a broad effort supported by Department of Energy to build the next generation of supercomputers.

Models Match Observations

Details predicted by the team's kilonova models were confirmed by observations of the event itself. The overall brightness, the speed with which the glow faded, and even changes in color over time were well within expected ranges.

Jennifer Barnes, now an Einstein postdoctoral fellow at Columbia, worked with Kasen while she was a graduate student at Berkeley. "One of the interesting things we found," Kasen recalls, "was that some of these elements, in particular the lanthanides and actinides that sit at the bottom of the periodic table, are incredibly opaque. They block out visible light and reradiate it in red or infrared."

During the first hours after the merger, visible light glowed in the blue region of the spectrum, indicating formation of comparatively light elements like silver. Over the next several days the glow moved increasingly into the red, signaling formation of heavier elements like gold, platinum, and the lanthanides. The colors finally peaked at the predicted infrared wavelengths.

"Our group had special expertise in understanding the physics needed to visualize what we would see." Kasen said. "By comparing the data to our models, we also were able to determine the total mass of elements produced. It was the equivalent of six percent of the mass of the sun; about 2/3 of it composed of the heaviest elements and 1/3 of lighter elements. Within that mixture would be about 100 earth masses of gold and platinum, along with uranium, plutonium, and even some rare super-heavy elements like Berkelium and Californium."

"Now that we have data," he says, "we can probe physics in a new regime of extreme densities and temperatures. We're now looking at what we can rule out in terms of recently proposed theories, including some theories of dark matter."

A New Field of Study

Kasen and collaborators are fine-tuning their models in preparation for the chance to analyze more kilonovae. Just a few days after GW170817 was detected, LIGO was shut down and will come back on line in early 2019 with improved sensitivity. "They expect the rate of gravity wave detections to go up by almost a factor of ten," Kasen reports. "So my guess is they'll find many more kilonova events."

"What's so exciting," he concludes, "is that we're seeing the creation of a whole new field of study in astrophysics. What started out as theorists' imaginings has now been observed, and we have much to learn."

Dan Kasen with two of his graduate students, Hannah Klion and David Khatami

Titans *of* *the* Cosmos

Chung-Pei Ma is the Judy Chandler Webb Professor of Astronomy and Physics at UC Berkeley. Ma explores the formation of structure in the universe and the nature of dark matter, and is credited with discovering the most massive black holes found so far.

Supermassive Black Holes & the Evolution of Galaxies

Astrophysicist **Chung-Pei Ma** hunts for cosmic titans much larger and more massive than neutron stars. She searches for supermassive black holes weighing tens of billions of solar masses. In comparison, the black holes generating the gravitational waves detected by LIGO weigh less than 100 suns.

"Galaxies are the building blocks of the universe," Ma notes, "and black holes are a key component of any galaxy." Galaxies large enough to host supermassive black holes are thought to be among the oldest structures in the universe. "By studying today's most massive galaxies," she points out, "we're studying the longest accumulation of historical information about galaxy evolution."

In 2011, Ma's team discovered the most massive black hole ever recorded, weighing about 21 billion solar masses. It's 339 million light years away, at the center of galaxy NGC 4889. In 2016 her team reported a supermassive black hole at the center of galaxy NGC 1600, about 200 million light years from Earth, that measures 17 billion solar masses.

From Active Youth to Quiet Old Age

Ma and other theorists posit that the early universe contained very active galaxies with massive black holes at their cores. Their central black holes grew larger by devouring gas and dust from their host galaxies. And when neighboring galaxies merged, the black holes at their centers probably merged also. Over time, as surrounding materials were depleted, the galaxy and its now supermassive black hole settled into relative quiescence.

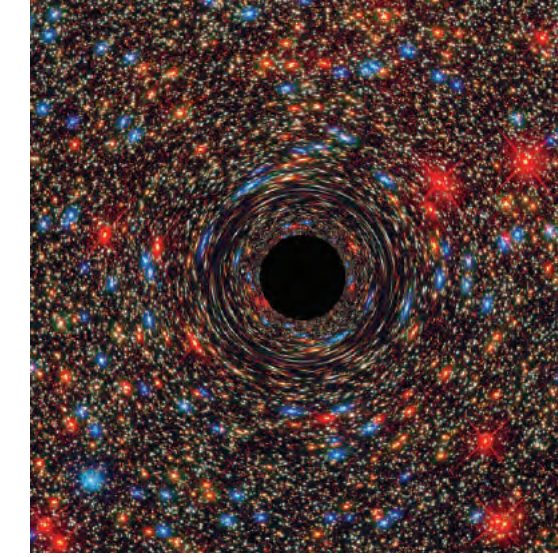
"We don't know in detail how gas is fed into the black hole," Ma reports, "or how the black hole in turn affects the appearance of the galaxies."

The MASSIVE Survey

To answer questions like these, Ma developed and now serves as lead scientist for the first-ever systematic search for supermassive black holes in the nearby universe. The MASSIVE Survey is measuring black holes at the center of the 100 most massive known galaxies in a region extending about 300 million light years from earth. The Survey will enable astronomers to observe giant galaxies and their supermassive black holes at various stages of evolution.

Gravitational attraction tends to clump galaxies into clusters, so it might seem that the largest galaxies with the largest black holes would be found only in the largest galaxy clusters. Not so, Ma reports. "When we look at the details, we see that very diverse environments host supermassive black holes. Of the 100 galaxies MASSIVE is targeting, only ten live in the largest clusters. We're interested in learning how giant galaxies form in more sparsely populated regions of space."

Another surprise: the supermassive black hole Ma reported in 2016, at the core of galaxy NGC 1600, is unexpectedly massive in relation to the size of its host galaxy – ten times more massive than usual. "It's a strange system," Ma reflects, "that requires theoretical explanation. We're hoping the MASSIVE Survey can tell us if there are others like it."



This computer simulation shows how the powerful gravitation of a black hole at the center of a galaxy distorts the motion of nearby stars.

SIMULATION: NASA, ESA, AND D. COE, J. (STSCL)

Theory Plus Observation

The MASSIVE Survey combines telescope observations with theoretical modeling. Observations gather detailed spectroscopic data for many parts of each galaxy, particularly, the stars very close to the black hole. "We need to be able to zoom in to the very center of these galaxies," she says. That's a primary reason why MASSIVE is limited to nearby galaxies.

"For the theoretical models," she continues, "we create mock observations of simulated galaxies on supercomputers. By varying the black hole mass that we assume for each model, along with a few other parameters, we can make different predictions for different velocities for the stars, and find the model that best fits observational data."

> "By studying today's most massive galaxies, we're studying the longest accumulation of historical information about galaxy evolution."

That's just to measure the mass. For the next step, Ma is collaborating with theorists all over the world to design cosmological simulations that can ferret out details of how supermassive black holes evolve.

Ma is also part of a global collaboration called NANOGrav that uses millisecond pulsars – very rapidly rotating neutron stars – to detect the mergers of binary black holes at galactic centers. "When galaxies merge," she says, "their central black holes form binaries that go into orbit around each other and eventually merge."

New Instrumentation

Having already combined theory with observation in her work, Ma is now stepping into the field of instrumentation. So far, MASSIVE is limited to observations from the northern hemisphere. To extend the survey to the southern sky, Ma is developing modifications to a spectrograph on the Magellan telescope in Chile. She says, "It's the best site in the southern hemisphere for expanding the search for supermassive black holes."

Physics Innovators Initiative – Pi^2

Educating the Next Generation of Innovators in Science and Industry

PHOTOS BY KEEGAN HOUSER

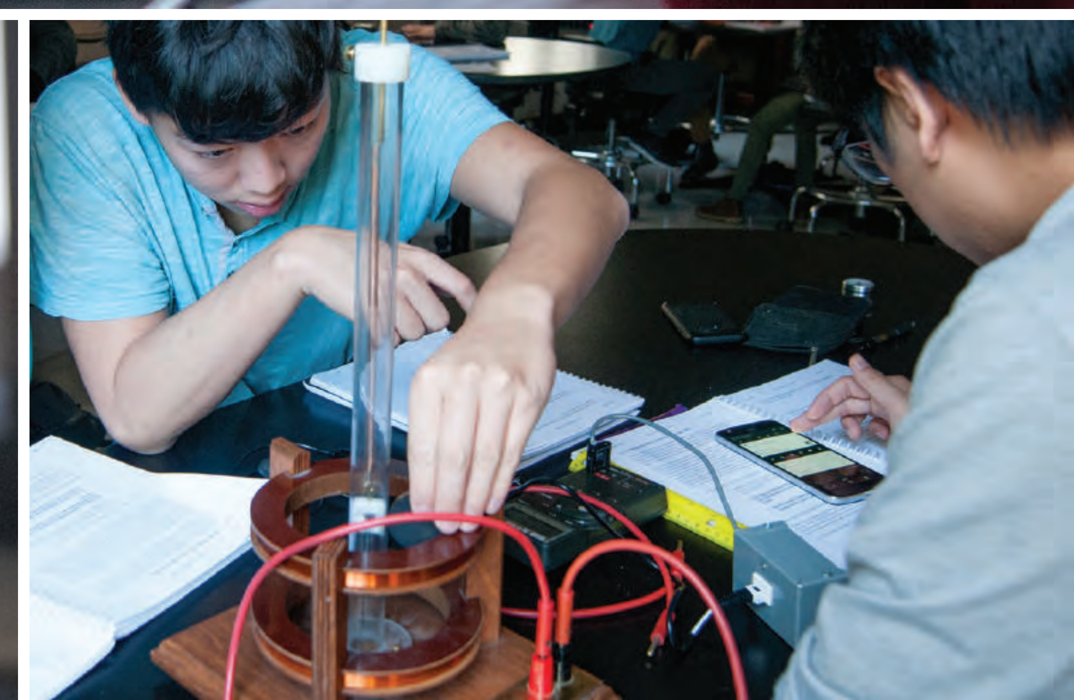
From the revolution in particle physics unleashed by Ernest Lawrence's invention of the cyclotron, to the era of precision cosmology pioneered by George Smoot and Saul Perlmutter, Berkeley Physics has a long history of helping shape the face of modern physics. The thread that links these and other scientific breakthroughs is the creative development of instruments and methods that enable us to probe ever deeper into hidden aspects of our world.

The educational mission of Berkeley Physics is to train the next generation of scientific innovators. The days are past when physics courses, even at the introductory level, can be taught by chalkboard and textbook alone. Today's students need to master more than facts and equations. They also need to be versed in the tools and methods of research and, with the guidance of our faculty, directly engaged in the process of discovery.

Berkeley Physics has unveiled a new vision for empowering and nurturing the creativity and curiosity of undergraduates. The Physics Innovators Initiative (Pi^2) is developing innovative ways for students to connect what they learn in classroom and lab with independent exploration and the excitement of discovery – in physics and beyond.

"Pi^2 is a new vision for an educational path that empowers students to pursue successful scientific careers," says **James Analytis**, associate professor of physics and faculty lead for Pi^2. "We want to make sure we're employing the best educational approaches for preparing them to explore, to invent new research methods and new technologies and use them in creative ways. We want them to reach their full potential as they mature into first-rate researchers."

The Physics Innovators Initiative (Pi^2) is developing innovative ways for students to connect what they learn in classroom and lab with independent exploration and the excitement of discovery.



Transforming Physics 7 and 8

Two of the most important courses Berkeley Physics offers for lower division students are Physics 7 and Physics 8. These two series comprise multiple semesters of lecture and laboratory sessions and serve more than 4,000 undergraduates every year from the Colleges of Chemistry, Engineering, and Letters and Science.

Physics 7 focuses on physics and engineering concepts and is intended for students pursuing degrees in physics, astronomy, chemistry, earth and planetary sciences, engineering, and statistics. Physics 8 is designed to help non-physics students understand basic concepts and support them in developing analytical and laboratory skills. It targets students in biosciences, pre-med, biochemistry, and architecture.

Pi^2 aims to reinvigorate both Physics 7 and Physics 8 by updating course content, redesigning lab activities, modernizing lab equipment, incorporating data science methodologies, and adding an online physics lab students can use anytime and anywhere. Pi^2 will create a new Tinkering Studio that offers a safe and creative place where students can independently explore the basics of equipment use, bolster their laboratory skills, and learn to design, build, and conduct their own experiments. Pi^2 will also upgrade the existing Student Machine Shop.

> ″By their junior and senior years, students will be ready to begin research careers.″
>
> James Analytis

According to physics chair **Wick Haxton**, ″The reinvention of Physics 7 and 8 is the foundation of a broader educational vision that aims to mold students into confident researchers – in physics or any other field they choose – by the time they leave Berkeley. Students who choose physics will be prepared to go on to the Physics 111 Advanced Lab, to learn about modern machining and fabrication in the upgraded Student Machine Shop, and to continue their scientific growth by working in one of our many research laboratories.″

Incorporating Data Science Tools and Methods

″There is a growing need for students to become conversant in data science,″ says Analytis, ″and this applies not only to physics but also to virtually all fields of study.″ An important component of the Pi2 curriculum development effort involves adding activities that teach students how to apply the tools and methods of data science.

"Berkeley has always been a leader in data science and is committed to strengthening its programs even further," notes physics professor **Marjorie Shapiro**, who frequently teaches Physics 8. "Through the Pi^2 initiative, the physics department will collaborate closely with members of the recently created Division of Data Science to ensure that our students learn how to interpret statistical data and how to apply cutting-edge data-science techniques to experimental problems. The lessons in critical thinking learned in these classes will serve them well independent of their future career paths."

Creating the New Tinkering Studio

An important component of Pi^2 is the design and construction of a new Tinkering Studio that will enable students to go beyond lab assignments and explore on their own. ″The Tinkering Studio will introduce students to the importance of learning how to use tools and build experiments,″ Analytis notes. ″It will boost confidence by giving them opportunities to create and design independently. And it will give them the kind of background that faculty research groups are looking for when they recruit undergraduates to join their projects.″

The Physics Tinkering Studio will contain tools students learn to use during regular lab sessions and give them access outside of scheduled lab times. Plans call for including up-to-date tools for automated processing and computer aided design as well as a plotter, 3D printers, laser cutters, and soldering and circuitry stations.

″By their junior and senior years, students will be ready to begin research careers,″ Analytis points out. ″They'll be well prepared to join the ranks of undergraduate researchers who make real contributions as they work at the forefront of research alongside faculty and grad students.″

Upgrading the Student Machine Shop

Once students have completed Physics 7 or 8, they will understand the utility of having a readily accessible, fully equipped Student Machine Shop. The planned upgrade will offer students experience with modern machining and fabrication techniques, including training for computer-aided design of experimental probes and an introduction to materials, machining, and probe design in the research lab. CNC machines will enable students to develop complex parts.

Getting Started

Implementation of the Pi^2 vision began this summer. The search for a new teaching fellow who will oversee curriculum development for lectures and labs for both Physics 7 and 8 is already underway. The aim is to have the new curriculum and the Tinkering Studio ready for Fall 2019 or Spring 2020. Improvements to the student machine shop have begun, with the acquisition of two new, high precision lathes; the scope and vision for further improvements are being developed this fall.

CalDay & Commencement

PHOTOS: SARAH WITTMER

Professor Bob Jacobsen demonstrates ″Fun with Physics″.

(Upper right) Physics graduates at Commencement.

CAL DAY 2018

On Saturday, April 21, Berkeley Physics hosted hundreds of visitors in LeConte Hall for this year's Cal Day. Guests enjoyed lectures, tours, and exhibits, including a brand new lecture on superconductivity presented by physics professor **James Analytis**. Cal Day is a campus-wide, daylong event that invites prospective students, their families, and other community members to come experience a taste of what the university has to offer.

(Left) Young visitors on CalDay participate in hands-on physics experiments.

(Right) 2017 Nobel Laureate Rainer Weiss delivered the commencement address.

PHYSICS & ASTRONOMY COMMENCEMENT 2018

The 2018 Physics and Astronomy Commencement ceremonies took place on May 15. Graduates and participating faculty members mingled together in the Lower Sproul courtyard before gathering in Zellerbach Auditorium to witness a total of 183 Physics degrees conferred to 37 PhDs, 43 MAs, and 103 BAs.

Physics department chair **Wick Haxton** welcomed the audience and began the proceedings. **Rainer Weiss**, 2017 Nobel laureate and professor emeritus of physics at the Massachusetts Institute of Technology, gave the commencement address. Student speakers were **Haynes Forest Stephens**, who received a BA in astrophysics, and **Jonathan Adam Jackson**, who received a BA in physics.

Katie Latimer was awarded the Physics Department Citation. **Alexey Drobhizhev** received the Lars Commins Memorial Award in Experimental Physics, established in honor of Lars Commins, an engineer and son of the late Berkeley Physics Professor Emeritus Eugene Commins. **Ting Cao** was awarded the Jackson C. Koo Award in Condensed Matter, established by Koo's widow, Rose, and intended to celebrate the accomplishments of a noteworthy graduate student in condensed matter physics.

The ceremonies were followed by a reception in the courtyard between LeConte and Birge Halls, where graduates and their families posed for photos and enjoyed light refreshments.

2018 Berkeley Physics AT A GLANCE

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

Undergraduate Physics Majors

311 Total # of students

235 | 76

103 BAs Awarded 2017-18

106 Transfer Students

Physics Faculty

Active Faculty 63

Emeritus Faculty 36

Members of the National Academy 13

Active Nobel Laureates 3

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

Graduate Physics Majors

Total # of students 286

232 | 54

37 PhDs Awarded 2017-18

21 Countries Students Are From

Berkeley Physics Alumni Nobel Prize Winners

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

BERKELEY 150 1868 ★ 2018

DEALING WITH DATA

BERKELEY LEADS THE WAY IN DATA SCIENCE EDUCATION

Until recent years, tools and techniques for working with high volumes of complex data were primarily the province of data-intensive disciplines like high-energy physics and cosmology. Today, those tools and techniques are growing increasingly sophisticated and proving increasingly valuable to multiple fields of inquiry – from physical and biological sciences to marketing, medicine, social science, and linguistics.

Also on the increase is the demand for experts in organizing, analyzing, and applying massive datasets. "It is estimated that over half of all businesses are now using big data analytics," says Berkeley Physics chair **Wick Haxton**. "Students recognize data science skills can enhance their career options, whether they remain in academic research or move into industry. Berkeley faculty are responding, designing new courses and providing new research experiences that will help our students acquire the tools they need to handle large data sets, whether the context is research or an industrial application."

Berkeley's New Division of Data Sciences

UC Berkeley is expanding its global leadership role in data science. A central step in this effort has been creation of a new campus division, the Division of Data Sciences. It's responsible for a campus-wide effort to incorporate the study of data science into the undergraduate curriculum, growing directly out of the widespread role of data science in research.

"Research universities across the nation are grappling with how best to address the emergence of data science," says **David Culler**, interim dean of the new division. "We're working to make it possible for students to build meaningful knowledge in data science techniques and implications and to engage early on in research discovery." He notes that, since 2015, UC Berkeley has created close to 50 new data science courses, and dozens of existing courses have added specialized data science modules.

As it takes form, the Division of Data Sciences is embracing input from students and faculty across campus. **Cathryn Carson**, head of the new division's education program, says, "We're engaging faculty and students not only from computer science and statistics but also physics, astronomy, environmental and life sciences, humanities, social science, all of whom are playing a role in shaping the division."

This fall marks the first semester that Berkeley students can sign up for a major in data science – a bachelor degree offered through the College of Letters and Science (L&S). Other degrees are in the planning stages, including a broad-based minor program.

Data Science Pioneers

Physics professor **Saul Perlmutter** is a strong supporter of data science endeavors on campus and beyond. He has famously said that software and data analysis tools have been key limiting factors for most of the scientific projects he has undertaken, including the work with supernova data that led to a Nobel prize in 2011.

Perlmutter describes data science as "a mixture of computer programming and statistics and their attendant conceptual tools, all tightly coupled to the domains of inquiry whose questions we are trying to answer. These methods enable researchers to ask questions and conduct experiments where data are complex or voluminous or comes in so quickly that very rapid decisions must be made about what to keep and what to throw out. Of course, what is complex to one researcher may be simple to another, so tools and education in data science need to address all levels of sophistication."

He points to particle physicists working on high-energy accelerator experiments as early pioneers in data science. "They developed techniques that have been put to use in other fields," he reports. "My own work in astrophysics was certainly made possible by access to large computers and the ability to use them to work with challenging data samples, guided by the particle physics experiments that came before. This is a Berkeley tradition in physics."

"Real data are messy," Perlmutter adds. "And it takes a lot of experience and training to apply data science methods to messy data. Educating our students sooner and with more depth in the techniques of strong data science means we'll be able to accomplish more, faster, in physics as well as other fields that depend on this capability."

New Physics Courses and Careers

Berkeley Physics is rolling out new and revised courses to strengthen the department's own data science program. "It's been a longstanding need in physics to teach students more about data analysis and statistics," says physics professor **Uroš Seljak**. Physics is offering two new courses, Physics 88 and Physics 151, that are also part of the new data science bachelor's degree program from L&S (see text box). Additional courses are in the planning stages.

"Students realize how important data science has become for a physics career," adds Seljak. "And they realize how a physics background can lead to a successful career in data science. Many of our former students have taken jobs in data science, especially in the Bay Area."

Physics professor Uroš Seljak teaches the new Physics 151 data science course for juniors, seniors, and graduate students.

PHOTO: KEEGAN HOUSER

NEW PHYSICS COURSES EQUIP STUDENTS FOR THE CHALLENGES OF BIG DATA

In Physics 151, students use actual datasets from Nobel prize-winning research to learn the ins and outs of data analysis and computing. They analyze data from LIGO, mining the hidden signals of gravitational waves, and use supernova data to determine the rate at which our universe is expanding.

"Physics 151 is an upper level course for undergraduates who are finishing their degrees and for beginning graduate students," reports physics professor Uroš Seljak. "It goes into more depth than previous courses, especially in terms of data analysis and statistical and computational methods." Seljak teaches the class, which was offered for the first time last spring.

Physics 88 covers computer programming and data analysis for freshmen and sophomores looking for an introduction to data science applications in physics. Much of its content overlaps with Physics 77, an existing introductory course meant primarily for physics majors. Students who enroll in Physics 88 take it in parallel with Data Science 8, a popular data science course offered by Division of Data Sciences. After a few weeks at the start of the semester they join Physics 77 already in progress.

"It's one of these beautiful cross-walks we're developing," explains Cathryn Carson, head of the Data Sciences Division's education program. "In this case, between courses that belong in both physics and data science. This arrangement is symbolic of Berkeley's broadly inclusive approach to the data science major."

2017-2018 Giving

344

Total Number of Donors

Our Donors Are:

81% Alumni

12% Friends

5% Staff, Faculty, Students

2% Corporations, Organizations & Foundations

15% of Physics Alumni are Donors

Physics Alumni & Donors

5608	Physics alumni population
849	Physics alumni who are donors
54	New donors for 2017-2018

The Lincoln Project

Sustaining the Financial Health of Public Research Universities

PHOTO: SARAH WITTMER

Physics professor Robert Birgeneau, Berkeley's Chancellor from 2004- 2013, co-directed the Lincoln Project at the American Academy of Arts & Sciences.

For decades, public research universities nationwide have faced a steady decline in public funding. UC Berkeley is no exception. In 1974, appropriations from the State of California covered more than 49% of Berkeley's budget. In 2008, state funding was down to 27% and, shockingly, plummeted to 11% in 2010. By 2018 it had risen slightly to 14%, but only because tuition was frozen for 6 years.

A significant portion of the burden has shifted to students. Over the past ten years alone, the share of the budget shouldered by tuition and fees has risen from 18% to 33%. As physics professor and former UC Berkeley chancellor **Robert Birgeneau** puts it, "This means that, in effect, Berkeley faculty and staff now are primarily employees of the students rather than the state!"

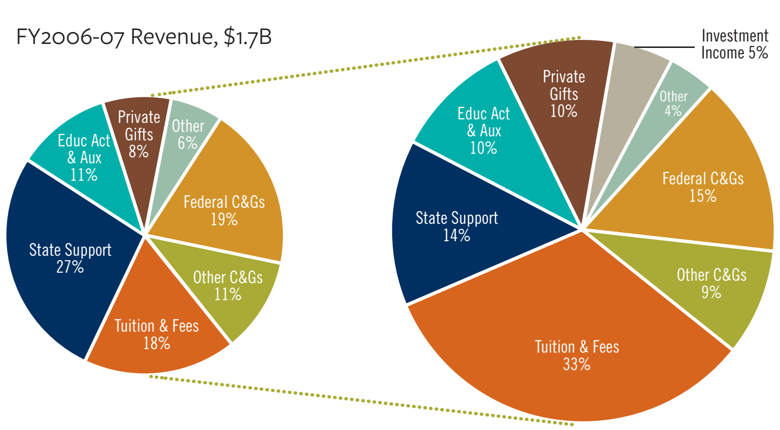
To help public research universities navigate these financial realities, the American Academy of Arts & Sciences launched The Lincoln Project: Excellence and Access in Public Higher Education in 2013. It was named in honor of Abraham Lincoln, who laid the groundwork for the nation's public university system when he signed the Morrill Act of 1862. Birgeneau served as co-chair for the project alongside former University of Michigan president Mary Sue Coleman. Though the Lincoln Project formally ended in 2016, follow-up events in various states have continued.

The Lincoln Project's mandate was to advocate for the importance of the nation's public colleges and universities, particularly public research universities, and to devise strategies to strengthen the basic financial model. Among recommendations offered in a report the Project released in 2016 are ideas for promoting renewed state funding and developing alternative sources of revenue – primarily from the federal government and American corporations – as well as creating partnerships with the private sector and facilitating student access to educational resources, including suggestions for simplifying financial aid.

"Perhaps the most unsettling conclusion of the Lincoln Project," Birgeneau reports, "is that the state disinvestment in public higher education that we experienced here in California in 2008 to 2010 is a national phenomenon and almost certainly irreversible, at least in the near term. This means that universities like Berkeley must have much more diverse sources of income including state and federal governments, students and their families, corporations, intellectual property, private foundations, and philanthropists. Indeed, private donors and foundations now are critical to enabling Berkeley to maintain its exemplary Access and Excellence. Fortunately, our friends and alumni have contributed generously to our campus and we are hopeful that this will continue indefinitely into the future."

In its 2016 report, the Lincoln Project emphasizes that "public research universities have been critical to the success of the nation and its citizens over the past 150 years, and the services they provide to the public and the roles they occupy in our communities will be as critical to American success in the century to come. It is therefore imperative that these universities be preserved and strengthened for the good of the nation and to the benefit of students, local communities, and the states."

Revenue Sources



From SLUGS to SQUIDS

John Clarke's Remarkable Career in Physics

John Clarke is the world's leading authority on Superconducting QUantum Interference Devices. He joined the Berkeley faculty in 1969, retired in 2010, and now serves as a Professor of the Graduate School.

PHOTO: PEG SKORPINSKY

Berkeley physicist **John Clarke** is enjoying an impressive career in scientific research. Through more than five decades of brilliant work, he has become the world's leading authority on the design, understanding, and application of SQUIDs – Superconducting Quantum Interference Devices. Clarke describes today's SQUIDs as "amazingly diverse, with applications that include physics, chemistry, biology, medicine, materials science, geophysics, cosmology, and quantum information." SQUIDs are iconic examples of the vital contributions physics offers to the well-being of society at large.

Clarke received his PhD from Cambridge University in 1968. While at Cambridge, he met many physicists who visited the Cavendish Laboratory, in particular two young faculty from Berkeley, **Paul Richards** and **Marvin Cohen**. Clarke says that discussions with them inspired him to apply to Berkeley as a postdoc. He came to campus in 1968, joined the faculty the following year, and especially remembers the supportive mentoring of Paul Richards during those early years.

This January, 50 years after his arrival in Berkeley, Clarke presented a colloquium to the Physics Department entitled *The Ubiquitous SQUID: from Cosmology to Medicine*. Cohen introduced the gathering by saying, in part, "John Clarke's approach to physics and education have benefitted from his gift of a clear, uncluttered mind. He has been a great teacher and mentor, and his contributions to science, which range from the properties of matter, to astrophysics, to biomedical physics, were always important advances that pushed these fields forward. In addition to his discoveries, inventions, and other achievements, he has trained people who are world leaders in science."

In his colloquium presentation, Clarke described how he became involved with SQUID technology, how SQUIDs work, how they have evolved, and how they are used today.

THE BIRTH OF THE SLUG

Clarke began his remarks by describing his first months as a graduate student at Cambridge. It was the fall of 1964. His advisor, Brian Pippard, offered him a thesis topic that required measuring voltages of 10^{-12} or 10^{-13} volts, two to three orders of magnitude smaller than the state of the art at the time.

For several weeks, Clarke pondered how to make a better voltmeter. Then a sequence of encounters ensued that would prove pivotal. In November, Brian Josephson, a fellow graduate student of Pippard, gave a talk on Josephson tunneling, a phenomenon he had first predicted only two years earlier and that had just been implemented to demonstrate the first SQUID.

The lecture inspired Pippard to come up with a new idea the very next day – a SQUID-based digital voltmeter that, according to calculations, could achieve a resolution of 10^{-15} volts, far better than what they'd been searching for. Clarke's job was to figure out how to build it.

"I played around for several weeks with bits of niobium wire and foil," Clarke remembered, "coming up with devices that sometimes worked but weren't very reproducible or reliable." One day during afternoon tea – a daily Cambridge tradition – Clarke's lab partner Paul Wraight made a suggestion: "Why don't you freeze a blob of solder on a length of niobium wire?"

"It was a brilliant idea." Clarke noted. "I went back to the lab right away, made it, immersed it in liquid helium in a cryostat – and it worked! All before dinner."

"When I showed the results to Brian Pippard the next morning," Clarke continued, "he was really excited. He unwittingly named the device as soon as he saw it, saying, 'It looks as though a slug crawled through the window overnight and expired on your desk.' All I had to do was to figure out what the acronym SLUG stood for: Superconducting Low-Inductance Undulatory Galvanometer. I used SLUGs in many applications for more than a decade, and it turned out to be an important progenitor of the modern SQUID."

SQUIDS TODAY

"The first practical SQUIDs were primitive by today's standards," Clarke explained. "Today's SQUIDs, fabricated from patterned, multilayer thin films on silicon wafers, offer extraordinary sensitivity to magnetic flux."

In his remarks, he highlighted their impact in a number of applications that exist today only because of the remarkable versatility of the SQUID.

MAGNETIC MEASUREMENT

"By far the biggest selling commercial device that uses SQUID technology," Clarke said, "is made by Quantum Design in San Diego. It's used to measure everything from high-temperature superconductors to blood samples. There are well over a thousand of these systems in use around the world."

GEOPHYSICAL PROSPECTING

Beginning in the late 1970s, Clarke and collaborators used niobium SQUIDs, cooled in liquid helium, for geophysical measurements. Decades later, Cathy Foley and colleagues at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia developed a system involving high transition temperature SQUIDs, cooled in liquid nitrogen, to search for mineral deposits. So far, Clarke noted, commercial versions of this system have located deposits worth an estimated ten billion dollars, including a two-billion dollar deposit of silver that had been missed by all other techniques.

COSMOLOGY

"SQUIDs are the enabling technology for reading out another superconducting device, the transition edge sensor (TES), used by research groups in cosmology all over the world," Clarke reported.

In particular, detection of the cosmic microwave background (CMB) depends entirely on the TES-SQUID combination. Clarke worked for several years with Physics Department faculty Paul Richards, Bill Holzapfel, and Adrian Lee and their groups to develop a multiplexed readout. Originally, one SQUID was required to read out each of the many sensors required for CMB detection. Clarke invented a scheme by which a single SQUID could read out multiple TESs, ultimately enabling the use of thousands of TESs on a given telescope.

SQUIDs are also the enabling technology in the search for the axion, a candidate particle for the cold dark matter that constitutes 80% of the mass of the universe. If the axion were shown to exist, it would resolve certain discrepancies between the Standard Model of particle physics and experimental observation. Two decades ago, Clarke, Michael Mueck (a member of Clarke's group from Germany) and colleagues developed a SQUID amplifier operating at hundreds of megahertz that, when cooled to a fraction of a degree kelvin, could achieve the quantum limit. "You can't do better than that," Clarke said in a recent press release. "The Axion Dark Matter eXperiment (ADMX), located at the University of Washington, Seattle is a complicated and expensive piece of machinery, and it took a while to build a detector to take advantage of the SQUID sensitivity." In April this year, ADMX achieved the sensitivity required to undertake a meaningful search for the axion.

Clarke also noted that low-noise, high frequency SQUID amplifiers have been used to read out quantum bits (qubits) for quantum computing.

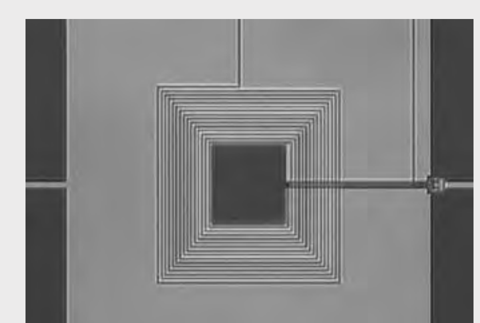
MEDICINE – MEG AND ULFMRI

Magnetoencephalography (MEG) systems monitor magnetic signals from the brain for a variety of research and diagnostic purposes, including pre-surgical mapping of brain tumors and monitoring of traumatic brain injury. SQUIDs are an essential component – today's commercial MEG systems typically contain more than 300 SQUIDs.

One of the most intriguing potential applications for SQUIDs is ultra-low frequency magnetic resonance imaging (ULFMRI), developed with the late Berkeley physicist **Erwin Hahn**, Berkeley chemist **Alex Pines**, and other collaborators. "A significant advantage of ULFMRI is that it offers much better contrast between certain types of tissue than conventional, high field MRI," Clarke explained. "For example, ULFMRI clearly resolved prostate cancer and normal tissue in ex vivo specimens. Clarke reported that he, in collaboration with **Ben Inglis** in Berkeley's Brain Imaging Center, and other groups around the world are making substantial progress toward new-generation ULFMRI systems that are likely to achieve significant improvements in spatial resolution in the next couple of years.

A webcast of the colloquium can be viewed online at physics.berkeley.edu.

The SLUG – a precursor of today's SQUIDs – was first built by John Clarke while he was a graduate student at Cambridge University. One of his SLUGs now resides in the museum of Cambridge's Cavendish Laboratory.

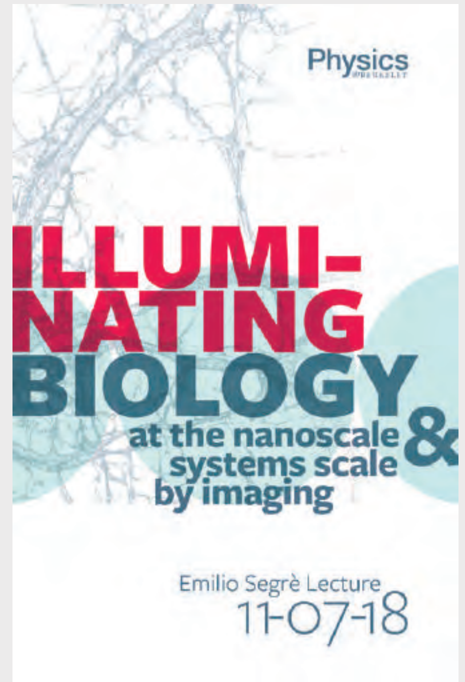


Today's SQUIDs are fabricated using a wafer scale process and photolithography.

Invited Lectures

THE 2018 EMILIO SEGRÈ LECTURE

Illuminating biology at the nanoscale and systems scale by imaging was presented by **Xiaowei Zhuang** on November 7. Zhuang is the Howard Hughes Medical Institute Investigator, David B. Arnold Jr. Professor of Science, Professor of Chemistry and Chemical Biology and Professor of Physics at Harvard University. In her talk, Zuang discussed the specific challenges of imaging the inner workings of a cell and presented two imaging methods her team has developed to overcome them. Their approach allows multicolor and three-dimensional imaging of living cells with nanometer-scale resolution.



THE 2018 OPPENHEIMER LECTURE

What happened before the big bang and other big questions about the universe were the subject of a presentation by **Michael S. Turner** (University of Chicago) on February 26, 2018. In this talk, Turner described how we can trace its history from the big-bang beginning 13.8 billion years ago through an early state of quantum fluctuations to a soup of quarks and other particles, from the formation of nuclei and atoms to the emergence of stars and galaxies, and finally to its continuing expansion today.

New Faculty

PHOTO: SARAH WITTMER

Mike Zalatel joined the Berkeley Physics faculty this summer. An Oakland native, he received his AA from Deep Springs College, his AB with highest honors in physics from Harvard University in 2009, and his PhD at Berkeley working with **Professor Joel Moore**. In 2017, after a postdoctoral position in the quantum computing division of Microsoft Research at Station Q in Santa Barbara, he joined the faculty at Princeton Physics in 2017. He says he is excited to be returning to Berkeley as the Thomas and Alison Schneider Chair in Physics.

Zalatel's research focuses on theoretical condensed matter physics and its intersection with quantum information and computational approaches. He aims to understand the behavior of electrons in "quantum" materials where entanglement and the strong interactions between electrons conspire to form new phases of matter. He is particularly interested in using ideas from quantum information to help design computational algorithms which can efficiently model these materials. Aside from the fundamental interest of exploring "emergent" phenomena that can arise from the interplay of quantum mechanics and many particles, he hopes to find new ways to harness these materials for the control and processing of quantum information.

Award-Winning New Course for Physics Transfer Students

Berkeley Physics has received a UC Berkeley Team Achievement Award from the College of Letters and Science for a new course that has already proved beneficial for physics majors who transfer to Berkeley from two-year institutions.

"We know from experience that transfer students transition to campus with varying levels of success," says **Claudia Trujillo**, Director of Student Services in Physics. "Research into the challenges faced by physics transfer students finds that most of them struggle to adjust to the pace and level of work required in upper division courses. Likewise, many transfer students experience feelings of isolation as they move away from their previous support systems, magnifying any academic challenges they might be experiencing."

The new course, Physics 198: Transfer Course for Physics Majors, was launched in Fall 2017, under the sponsorship of physics professor **Jonathan Wurtele**. The course is designed to address these social and academic impediments to a successful transition. It emerged from an evaluation of the needs of undergraduate transfer students conducted by the Physics Student Services team during the spring semester of 2017.

Physics 198 also features the participation of continuing transfer students who serve as "transfer peer mentors" and offer perspective and support for new students. Feedback demonstrated Physics 198 to be an unequivocal success and prompted the launch of a new summer outreach program. This program featured six mentors who were each assigned 8-10 incoming transfer students. These mentors were available to answer questions about courses, double-majoring, research, housing, and more.

The Department would like to acknowledge Physics students **Fernando Imiguez**, **Robert Pascua**, and **Alexander Fogle** for their invaluable contribution to this initiative. Physics 198 is made possible in part by the financial support of **Dr. Mel Pomerantz**, whose commitment to supporting Berkeley's physics majors is invaluable.

PHOTO: SARAH WITTMER

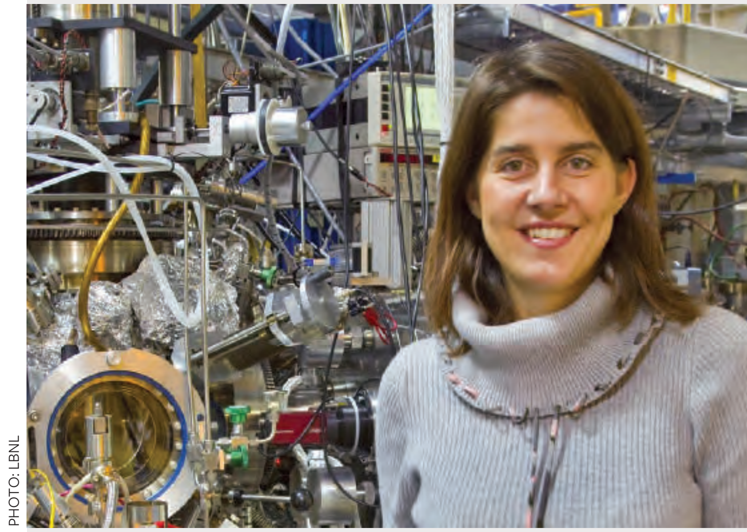


PHOTO: LBNL

Alessandra Lanzara, Berkeley's Charles Kittel Professor of Physics, specializes in condensed matter physics and materials science.

New Initiative for Sustainable Materials

Berkeley physics professor **Alessandra Lanzara** is leading a new initiative to explore novel approaches to materials design for sustainable living – approaches that could promise a rising quality of life for generations to come while preserving and replenishing the world's resources through revolutionary reimagining of the lifecycle of materials. As Berkeley's Charles Kittel Professor of Physics, Lanzara is using Kittel funding as the nucleus of this effort to develop what she describes as "agile materials".

The initiative, presently in its early stages, aims to develop materials with improved lifetime, performance, and manufacturing qualities that can replace shorter-lived and single-use materials currently in use.

"The area of sustainable materials is growing," Lanzara says, "and several companies are investing in it, from textile companies such as Nike to manufacturing and electronics companies like Apple. The Lego toy company has put hundreds of millions of dollars into materials research, and even Starbucks is investing in recyclable cups."

She describes her vision of the new initiative as "an ecosystem of interdisciplinary research teams collaborating at the boundary of basic and applied research, guided by modern ideas of artificial intelligence and robotics. The goal is to create the next generation of living materials that utilize biological pathways and can sense and respond to their environment, and to ready them for broad commercialization."

"It's a big area for us to grow," Lanzara adds. "Hopefully Berkeley will play a key role in it."

Alumni Updates

2010-2017

Hongling Lu (BA 2017, Physics and Computer Science)
Hongling Lu is a PhD student in Materials Science and Engineering at University of Michigan, working in Prof. Rachel Goldman's group. Lu is passionate about exploring the possibilities of wide-bandgap semiconductors in solving our current energy problems.

Gary Li (BA 2014, Physics and Astronomy)
In 2017, Gary Li presented a talk entitled, "Can Weak Plasma Rockets Get Us to Mars?" to the TEDx UCLA audience. Additionally, he attended the Caltech Space Challenge last year where he and 31 other multidisciplinary grad students competed to design a "lunarport," an in-space refueling station.

Liz George (PhD 2013)
Since receiving her PhD, Liz George has completed a post-doc at the Max Planck Institute for Extraterrestrial Physics in Germany. She now works as a Detector Engineer at the European Southern Observatory, where she's responsible for the focal plane of one of the first-light instruments for the Extremely Large Telescope.

Jasper Drisko (BA 2011)
Jasper Drisko received his PhD in physics from the University of Maryland in 2016. He is currently a postdoctoral research associate at the National Institute of Standards and Technology in Boulder CO, and was recently awarded a National Research Council postdoctoral fellowship.

2000-2009

Josh Walawender (BA 2000, Physics and Astrophysics)
Since receiving his BA, Josh Walawender has gone on to earn an MS and a PhD in Astrophysics from the University of Colorado at Boulder. He is currently a Support Astronomer at the W.M. Keck Observatory on the Mauna Kea volcano in Hawaii.

1970-1979

Carl Clawson (MA 1978, PhD 1982)
Carl Clawson has been working at Photon Kinetics in Beaverton, Oregon since 1990 where he makes various optical instruments. He lives with his wife in Hillsboro, Oregon. They have two grown daughters and one grandchild.

David Geller (BA 1973)
David Geller gives his physics education plenty of credit as the foundation for a very productive entrepreneurial career. He's worked in a wide range of arenas, from minerals prospecting and mapping to document management and advertising. He's founded several successful startups, including Veenome, a video analysis company, and Plexstar, a telecommunications firm. These days he's working on a new block-chain based financial startup.

James "Jim" Chelikowsky (PhD 1975)
Jim Chelikowsky is a professor of physics, chemical engineering, and chemistry and biochemistry as well as director of the Center for Computational Materials at the University of Texas at Austin. He is researching how silicon behaves at the quantum and atomic level.

Haluk "Hal" Aytac (MA 1974)
After receiving his MA, Hal began a 38-year long career in the semiconductor industry. He held positions in engineering, management, design, and architecture, and was granted four patents, one of which may have helped provide inspiration for devices such as the iPhone.

Bruce Cohen (MA 1972, PhD 1975)
Bruce Cohen retired in January of 2017 from Lawrence Livermore National Laboratory after 40 years of service, where he worked in the magnetic and laser fusion research programs. He was elected a Fellow of the American Physical Society Division of Plasma Physics in 1987.

1960-1969

Stephen W. Kahler (MA 1963, PhD 1968)
Stephen Kahler has been working as a Research Physicist for the Air Force Research Laboratory at Kirtland Air Force Base in Albuquerque, NM since 2011. His work there is in the Space Vehicles Directorate, dealing with solar eruptive events and forecasting of space weather.

Thomas Schneck (BA 1961)
After receiving his BA, Thomas Schneck embarked on a military tour and began working at Lawrence Livermore National Lab. He later became an independent patent attorney. In recent years, Schneck has taken up pro bono immigration defense, assisting women and children from Central America seeking US entry.

1950-1959

Ernest "Ernie" Malamud (BA 1954)
Ernie Malamud is retired and living in Paris, but continues to be active in accelerator physics and in development of materials and curriculum for science education. He is participating in a project to construct a major particle physics facility with both an electron collider and a proton collider within the same 100-km circumference tunnel.

Farewell

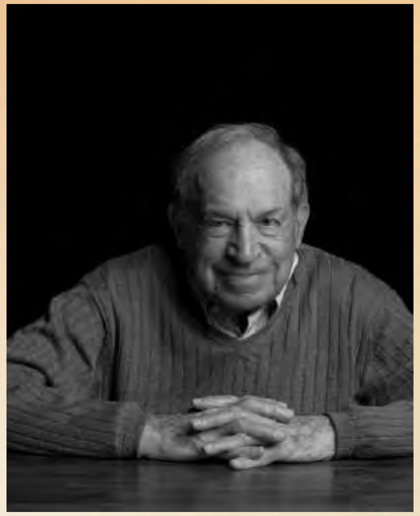


PHOTO: MINESH BACRANIA

Alumni

David Pines

Berkeley alumnus and world-renowned theoretical physicist David Pines (BA '44) passed away on May 3, 2018 at the age of 93. After receiving his bachelor's degree in physics from Berkeley, Pines completed his doctoral degree at Princeton in 1950. In 1984 he co-founded the Santa Fe Institute in New Mexico to study complex systems through a multidisciplinary approach. From 1999 to the time of his passing, Pines served as founding co-director of the Institute for Complex Adaptive Matter, an international research project headquartered at UC Berkeley.

Pines was also founding director from 1968 to 1971 and professor emeritus of physics and electrical and computer engineering in the Center for Advanced Study at the University of Illinois. Throughout his research career, Pines specialized in the area of "emergence", which seeks to uncover the most basic building blocks of our universe and develop simple equations to explain fundamental forces of nature.

Joseph Polchinski

Joseph Polchinski (PhD '80) passed away on February 2, 2018 at the age of 63. Polchinski was well known for promoting creative and complex answers to some of the toughest theoretical questions. He played an immense role in the development of string theory and helped provide a mathematical foundation for multiverse theory. From 1992 to 2017, Polchinski taught physics at UC Santa Barbara where he was also a permanent member of the Kavli Institute for Theoretical Physics. He was awarded the Dirac Medal in 2008 and shared a $3 million Breakthrough Prize in Fundamental Physics in 2017 with two collaborators.

Staff

Tom Pedersen

Tom Pederson, a Berkeley Physics staff member who worked for over 20 years in the department's machine shop, passed away on May 30, 2018 at the age of 78. From a young age, Tom loved building things and knew in high school that he would someday become a machinist. After high school, he spent 4 ½ years in the Air Force, working on airplanes, then moved to a staff position in the machine shop at Lawrence Berkeley National Laboratory. Tom's dedication to the physics department and its students, as well as his sincere care for the future of our country, is well remembered through his generous donation towards a scholarship to benefit Berkeley Physics graduate students.

Friend

Frances Townes

Frances Townes, wife of Nobel Prize-winning physicist Charles Townes, passed away on February 5, 2018, just over a week shy of her 102nd birthday. A longtime advocate for the homeless and those living in poverty, Townes founded the Berkeley Ecumenical Chaplaincy to the Homeless to bring together religious organizations to provide shelter and food to those in need. Townes was also deeply invested in furthering arts education. She transformed her 100th birthday celebration into a fundraiser for Youth Spirit Artworks, a program seeking to empower homeless and low-income Bay Area youth through art and career training. She published her autobiography, Misadventures of a Scientist's Wife, in 2007.

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