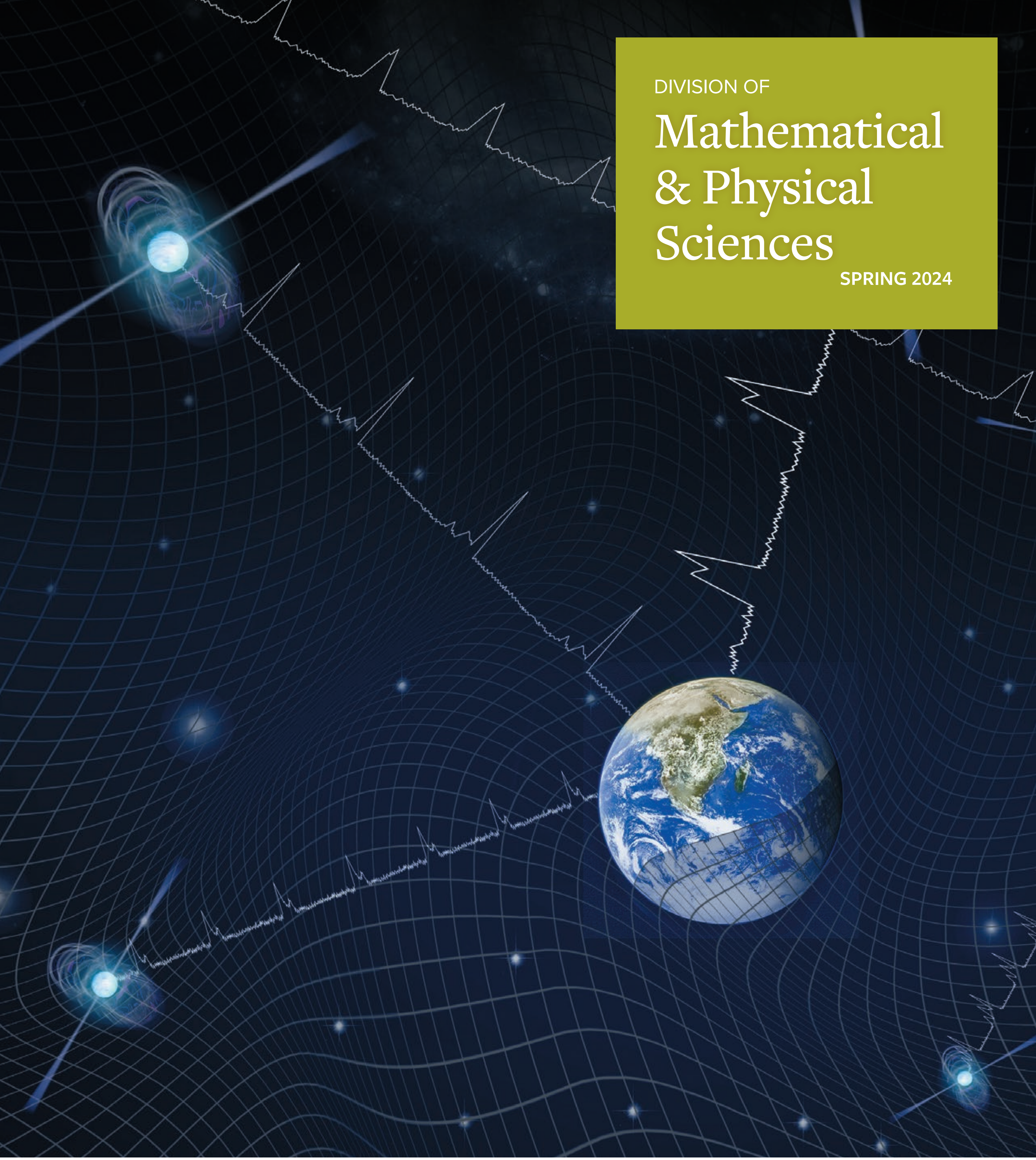
DIVISION OF

Mathematical & Physical Sciences

SPRING 2024



Berkeley College *of* Letters & Science

ASTRONOMY | EARTH & PLANETARY SCIENCE | MATHEMATICS | PHYSICS

Letter from Dean Steven Kahn

The past year was an eventful one at Berkeley. In Spring 2023, the Regents approved the first new college on campus in 50 years, the College of Computing, Data Sciences, and Society. Chancellor Carol T. Christ announced her plan to retire this year, and on July 1 we will welcome Rich Lyons as our new chancellor. Most significantly, 2023 ended with the university successfully concluding Light the Way: The Campaign for Berkeley, which surpassed $7.3 billion in philanthropic support for faculty, graduate students, and undergraduates. The Division of Mathematical & Physical Sciences (MPS) met our goal to raise $175 million during the campaign.

A notable highlight each year at MPS is the arrival of new faculty members. We welcome: in Earth & Planetary Science, Madison Douglas and Weiqiang Zhu (see page 6); in Mathematics, Svetlana Jitomirskaya, Hannah Larson, and Andrew Marks; and in Physics, Rául Briceño and Luca Victor Iliesiu. Looking ahead, we are in the process of hiring additional faculty in earth science, mathematics, physics, and space sciences.

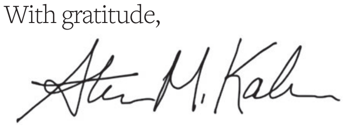
Our research efforts received notable government recognition. In March this year, I met with state lawmakers alongside Physics Chair Irfan Siddiqi to elevate the importance of quantum computing and highlight Berkeley's role in educating our students for professional opportunities and ensuring that California remains an epicenter of computer innovation. The National Science Foundation also completed successful five-year reviews of two campus research centers it supports: the Challenge Institute for Quantum Computation (CIQC), led by Professor Dan Stamper-Kurn, and the Network for Neutrinos, Nuclear Astrophysics and Symmetries (N3AS) led by Professor Wick Haxton.

Motivated by the urgent need for a new space for the Department of Mathematics and to improve the student experience and experimental research infrastructure for the Department of Physics, last year we completed a master planning process that provides a viable solution. After carefully considering a range of options, we narrowed down to two and selected the one that will be less expensive and less disruptive to execute.

Our plan is to replace seismically challenged Evans Hall with a new building for mathematics on the site of Donner Laboratory, the world's first center for applying atomic energy in biology and medicine. We will also construct an enticing entrance to the current physics complex — a new four-floor learning pavilion — as well as renovate and design labs for cutting-edge research in Physics South and Birge halls (see renderings on facing page).

I'll conclude by conveying my heartfelt thanks and appreciation to all of our donors and friends who played a part in making the Light the Way campaign such a triumphant success. Fiat Lux!

With gratitude,



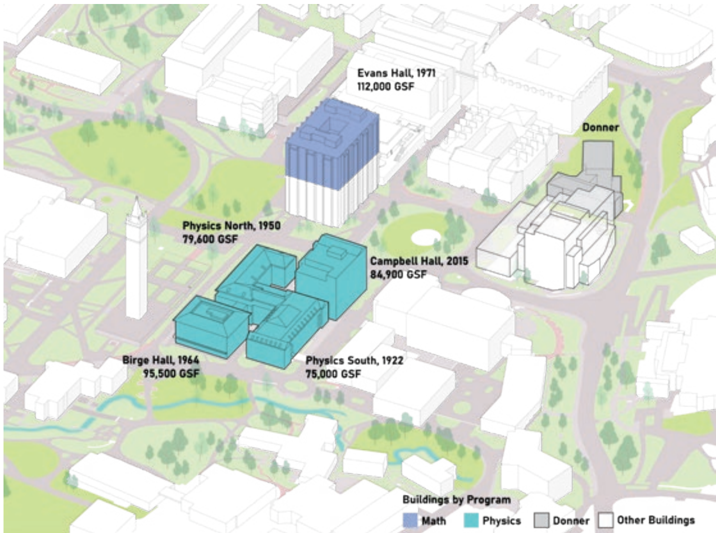
Steven Kahn
Dean of Mathematical & Physical Sciences

If you need any of these materials in an alternative format, including electronic, large print, or braille, please contact Melanie VandenBerghe at mevanden@berkeley.edu to make a request. Please allow 7-10 days in cases of brailled materials requests.

Cover art: An array of millisecond pulsars in the Milky Way assist the search for background low-frequency gravitational waves permeating the universe. (See page 4.)

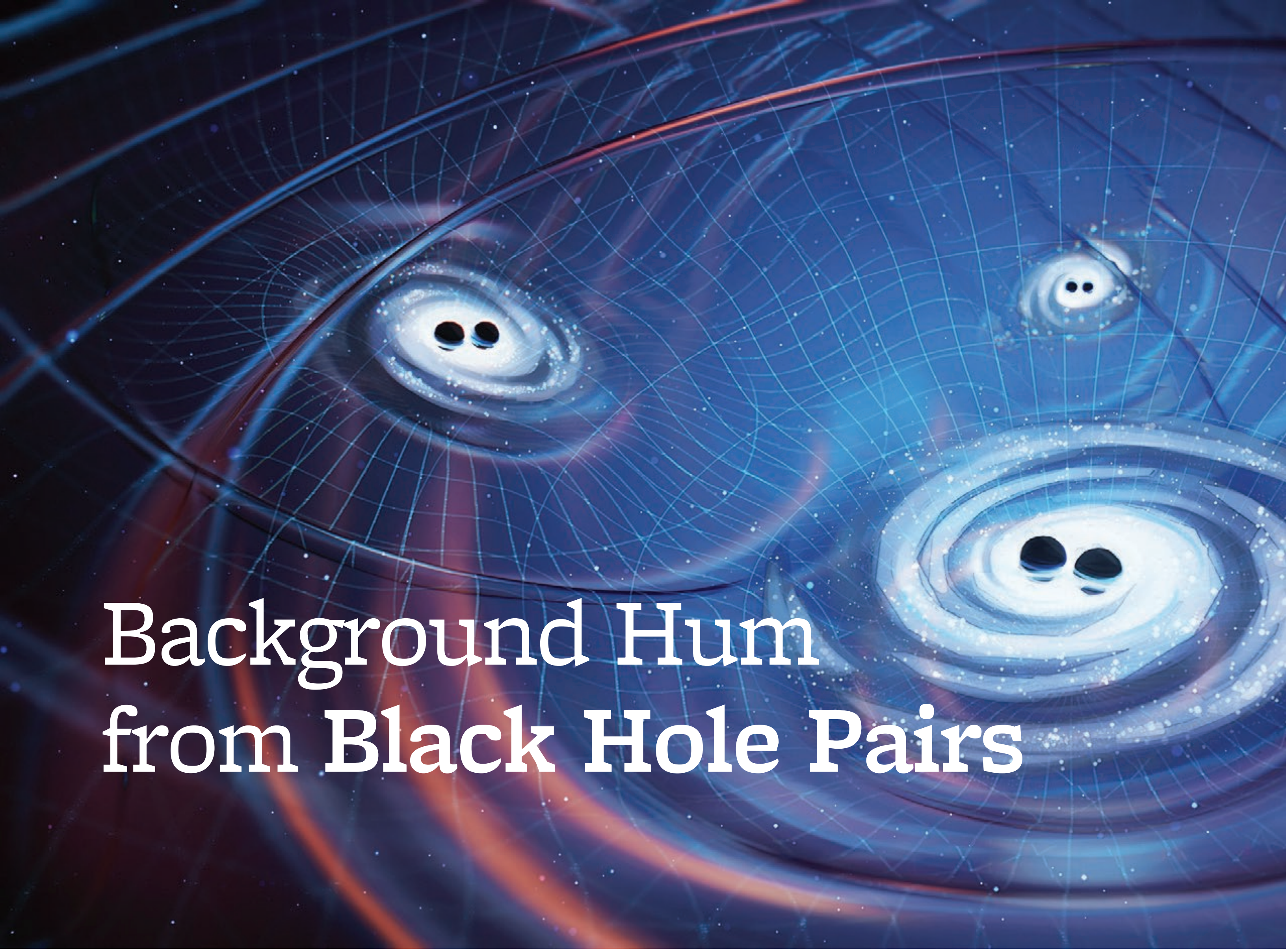
Credit: Tonia Klein/NANOGrav

Providing New Spaces *for* Math and Physics



IN 2023 THE DIVISION OF MATHEMATICAL & PHYSICAL SCIENCES (MPS) completed a Math and Physics Master Plan to conceive solutions for both departments' immediate and long-term space and infrastructure needs. The top illustration shows the current campus configuration of buildings used by math and physics. It is a top priority of the university to replace Evans Hall, rather than to undertake more costly seismic retrofitting. This necessitates finding a new home for the Department of Mathematics, currently occupying four floors of Evans Hall. As the university's Long-Range Development Plan recommends replacing the Donner Lab building northeast of Evans, the MPS division's master plan proposes a new building on the Donner site to house mathematics and possibly some of physics, enhancing opportunities for intellectual cross-fertilization.

Another concept outlined in the master plan is building a Learning Pavilion Addition between Birge Hall and Physics South to fully connect the physics campus. As currently envisioned, the Learning Pavilion would create an enticing entryway with natural light, views of the Campanile esplanade, and — most important — teaching labs and informal learning spaces on each floor. The bottom illustration depicts one idea for the interior space. Depending on available funding, moving some instructional facilities to the Learning Pavilion could enable renovations in the adjacent buildings to provide large, flexible research labs that meet the experimental needs of current and future physics faculty and students. (Illustration credit: Courtesy of Payette + LMSa)



Background Hum from **Black Hole Pairs**

Artist's rendering of black hole binaries emitting gravitational waves. Credit: Olena Shmahalo/NANOGrav

LAST SUMMER, AN INTERNATIONAL COLLABORATION of nearly 200 astronomers and astrophysicists reported the first detection of faint gravitational waves, apparently emanating from supermassive black hole pairs locked in a death spiral. This conclusion comes from studying 15 years of data collected by The North American Nanohertz Observatory for Gravitational Waves, or NANOGrav, which explores the low-frequency gravitational wave universe with the help of dozens of pulsars and several enormous radio telescopes.

"This is very exciting as a new tool. This opens up a completely new window for supermassive black hole studies," says Chung-Pei Ma, the Judy Chandler Webb Professor in the Physical Sciences and a member of the NANOGrav research team. The technique should also provide insights into the evolution and growth of galaxies.

Pulsars are a type of neutron star, the super-dense remnant of a rapidly rotating star that releases beams of radio waves. First discovered in 1967 by British graduate student Jocelyn Bell-Burnell, a few thousand pulsars have been found.

In 1982, Berkeley astronomer Donald Backer revealed a new category of pulsar called millisecond pulsars. The name reflects the fact that they rotate with extraordinary speed and ultra-precise regularity — spinning hundreds of times per second. Backer proposed that radio telescopes could be deployed to observe these pulsars and search for

The late Donald Backer envisioned research with pulsar timing arrays.

the gravitational wave energy released from supermassive black holes forming ripples in spacetime. As these waves emanate through the universe, they slightly distort the shape of spacetime.

Backer invented and developed digital systems for such subtle detection, and his results from decades of experiments demonstrated the idea's promise. Backer helped launch the development of NANOGrav, but he died suddenly in 2010, the year the project received its first funding from the National Science Foundation.

Here's how NANOGrav works. Imagine a millisecond pulsar being like a cosmic combination of lighthouse and clocktower; each time its rotating radio beam points toward our planet, we receive a pulse. Their precision regularity permits pulses to be timed, and the timing measurements serve as a means to locate the distinctive background signature of low-frequency gravitational waves.

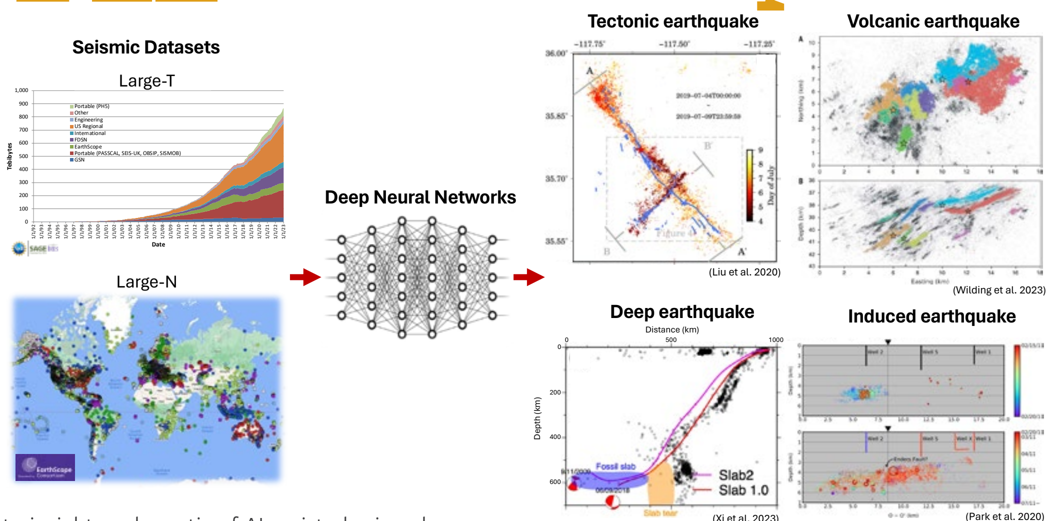
NANOGrav collects data from multiple millisecond pulsars, a so-called "pulsar timing array," that becomes more sensitive to long-period gravitational waves as it grows larger. These waves are too low-frequency to be detected by other gravitational wave interferometers such as LIGO and LISA. The NANOGrav array has grown from just 11 pulsars to include more than 80.

Observing the pulsar array are some of the world's largest telescopes: the Green Bank Telescope in West Virginia, the Very Large Array in New Mexico, the CHIME Telescope in British Columbia, and — until its collapse in December 2020 after a hurricane — the Arecibo Telescope in Puerto Rico, which had been the largest, most sensitive radio telescope anywhere.

"The signal that we're seeing is from a cosmological population over space and over time, in 3D," says Ma of the recent results. "A collection of many, many of these [supermassive black hole] binaries collectively give us this background."

"At one point, scientists were concerned that supermassive black holes in binaries would orbit each other forever, never coming close enough together to generate a signal like this," says Luke Kelley, assistant adjunct professor of astronomy at Berkeley and chair of NANOGrav's astrophysics working group. "But now, we finally have strong evidence that many of these extremely massive and close binaries do exist. Once the two black holes get close enough to be seen by pulsar timing arrays, nothing can stop them from merging within just a few million years."

AI for Earthquakes



From dataset to insights: schematic of AI-assisted seismology

WHEN WE THINK ABOUT EARTHQUAKES, we tend to dwell on when and where the next "Big One" will hit. Weiqiang Zhu chooses to focus his attention on all the rest — the little ones we may not even feel.

Catastrophic quakes deservedly grab the attention and headlines. The 7.8-magnitude event that hit Turkey and Syria in February 2023 caused more than 59,000 deaths. Fortunately, such disasters are relatively rare, says Zhu, an assistant professor in the Department of Earth & Planetary Science.

Much more frequent are earthquakes of around Richter magnitude 3.0 and below. In the United States alone, there are thousands of them each month. These common quakes can contain valuable information for seismologists.

"The goal is not only detecting these small earthquakes, but also to figure out what the small earthquakes can tell us," says Zhu. "Studying these small events may help us understand how the big ones occur."

As Zhu was starting his doctoral studies at Stanford University, the artificial intelligence program AlphaGo defeated world champion Go player Lee Sedol in a series of matches. That motivated Zhu to explore whether AI could assist seismic detection and discovery. He's become an expert on developing deep learning algorithms to locate and analyze the signals buried in seismic data.

Already a data-rich field, seismology is experiencing exponential growth in the volume of data collected. This is partly due to a dense and expanding network of seismometers, especially in tectonically active places such as California. Additionally, seismologists have turned to a new technology, Distributed Acoustic Sensing (DAS), that converts undersea fiberoptic communication cables into high-resolution seismographic sensors — able to generate terabytes of data daily. (A terabyte is equal to one trillion bytes.)

AI alleviates the herculean task of preparing and processing vast seismic data. As part of his dissertation research, Zhu developed and trained a deep neural network called PhaseNet that reviews seismograms and determines, with enhanced efficiency and accuracy, the telltale arrival times of seismic waves emanating from an earthquake's location.

Such data-driven detection exposes earthquakes caused by various sources, including tectonic or volcanic activity and oil and gas extraction. And information retrieved from studying many smaller quakes can reveal important details about the spatial and temporal evolution of seismicity, the architecture of fault zones, or the structure of the inner Earth.

"I think it's very exciting that we can turn all this data into some useful information," says Zhu, who envisions collaborating with an "AI seismologist" to process incoming data automatically, efficiently, and comprehensively.

Mathematics Alum Leads Chinese Research Institute

Director Shing-Tung Yau at BIMSA's launch event

HE'S BEEN CALLED THE "EMPEROR OF MATH" by *The New York Times*. To a long list of accolades that includes the Fields Medal, the National Medal of Science, and election to the U.S. National Academy of Sciences, Berkeley alumnus Shing-Tung Yau has added becoming director of the visionary new Beijing Institute of Mathematical Sciences and Applications (BIMSA).

Launched with a gala ceremony in July 2023, BIMSA is focused on forward-looking, systematic research in all areas of mathematics and its intersections with physics, finance, and computer science. The institute is co-sponsored by Beijing's municipal government and Tsinghua University, where Yau is a faculty member. BIMSA has recruited prominent mathematicians and scientists from around the world as full-time faculty research fellows, including quantum field theorist Nicolai Reshetikhin, a Professor of the Graduate School in Berkeley's Department of Mathematics.

BIMSA occupies a temporary facility on Yanqi Lake while renovations proceed at a former cement plant near the Great Wall that will house the institute's labs, data centers, classrooms, lecture halls, and offices. According to Yau, "we are poised to seize this big opportunity and make the goal of becoming one of the world's top 10 mathematical centers a reality" — an aspiration that complements a broader ambition for Beijing's Huairou district to become a global innovation hub comparable to Silicon Valley.

"Our priority should be given to both innovation and development," Yau says. "While learning state-of-the-art technologies from foreign counterparts, we should also create our own technologies and knowledge system."

BIMSA's official debut coincided with the first International Congress of Basic Science, which featured the presentation of Frontiers of Science Awards to several young scholars who "contribute wisdom and energy to humankind's study of the mysteries of the natural world." Award recipients from among Berkeley's Mathematical & Physical Sciences researchers included: mathematicians Richard Bamler, Marina Iliopoulou, Kewen Wu, and Ruixiang Zhang; and theoretical physicists Erik Aldape, Ehud Altman, Tessa Cookmeyer, Aavishkar Patel, Geoffrey Pennington, and Tom Rudelius.

Dean of Mathematical & Physical Sciences Steve Kahn attended BIMSA's opening celebration and visited universities in Beijiing and Hong Kong. He says, "It was wonderful to connect with many of our very accomplished alumni in China, and I look forward to further interaction and collaboration."

As a teenager, Yau was inspired by a magazine article written by Berkeley mathematician Shiing-Shen Chern, one of the 20th-century's greatest geometers. He would soon, at age 20, study under Chern, who founded Berkeley's Mathematical Sciences Research Institute (now the Simons Laufer Mathematical Sciences Institute). Yau earned his Ph.D. in two years and soon became a pioneer of geometric analysis and a critical contributor to string theory.

In 1982, Yau became the first Chinese mathematician to receive the Fields Medal, his discipline's most prestigious prize. Yau's academic career took him from coast to coast, including faculty positions at Stanford, Princeton, and Harvard, before he returned to China in 2022.

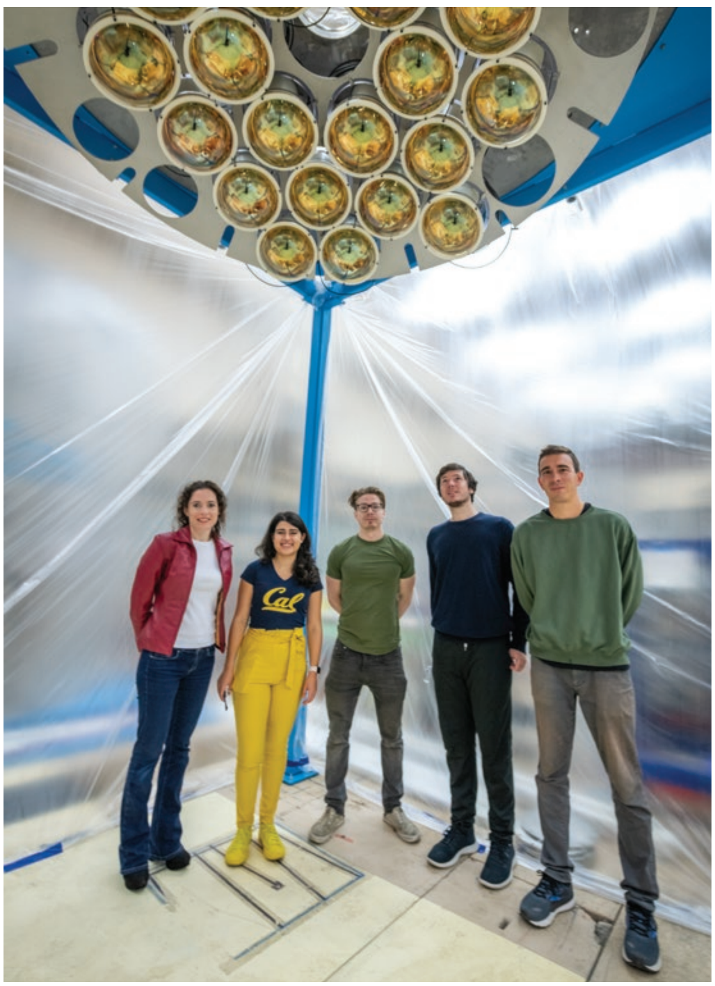
PHYSICS

Enduring Enigma *of* Neutrinos

YOU DON'T NOTICE THEM, BUT NEUTRINOS ARE ALL AROUND US — and zipping through us near the speed of light. Billions are produced by nuclear fusion in the sun every second, or they occur as byproducts of other chemical reactions. That they barely interact with anything makes neutrinos challenging to detect but handy for scientific research.

"Because they are so weakly interacting, neutrinos provide a unique probe of otherwise unreachable regions," says Associate Professor of Physics Gabriel Orebi Gann, from the inner Earth, to the sun, to distant supernovae. Neutrinos could hold clues to how the universe formed, but they are mysterious in their own right.

The ubiquitous neutrino comes in three types, each paired with a charged particle — either an electron, muon, or tau. They can shift from one type to another and back again. It was long unclear whether neutrinos possessed any mass, and while their precise mass remains unknown, it is much less than that of any other fundamental particle.



Professor Gabriel Orebi-Gann (at left) with Eos team researhers.

Uniquely among particles in the standard model of physics, neutrinos could also potentially be their own antiparticle, or a Majorana particle. That matters because of matter. Most interactions in nature generate equal amounts of both physical matter and antimatter that has the same mass and opposite charge. But the universe, thankfully, has a heavy preponderance of matter. How did this asymmetry arise? If a neutrino can simultaneously be both particle and antiparticle, that could help explain how the universe developed.

"The question of the nature of the neutrino, whether they are their own antiparticle or not, has major implications," says Orebi Gann. "And it's a really exciting moment in particle physics, because no matter the answer, there's something we don't understand." If they are Majorana particles, then neutrinos behave differently from all other particles; If they aren't, then the matter-antimatter imbalance remains a conundrum.

To explore this frontier of physics, Orebi Gann and Berkeley colleagues recently built a detector named Eos, for the Titan goddess of dawn. Eos comprises an 11-foot-high steel tank enclosing an acrylic vessel containing liquid scintillator. Above and below the tanks are detector arrays sensitive to single photons of light.

The product of an international scientific collaboration, Eos is a proof-of-concept design for a much larger proposed detector named Theia (the goddess of light and mother of Eos). It will test the technological capabilities of a next-generation neutrino detector that combines technological elements from existing detectors to achieve higher sensitivity and resolution.

Says Orebi Gann, "The bottom line is in this single detector we could use neutrinos to probe nature...but we could also study the fundamental nature of matter."

For more, please visit PHYSICS.BERKELEY.EDU

You Belong Here: the Message of MPS Scholars

Mathematics student Marius Castro (center) at MPS Scholars retreat.

First-year student Alejandra Meza connected with faculty and fellow students.

photos: Brittany Hosea-Small

Standing on Asilomar State Beach just west of Monterey, Marius Castro talked with dozens of fellow UC Berkeley students for hours under the moonlight. The moment felt special to Castro, like he was in a movie. In actuality, he was attending the first annual MPS Scholars retreat.

"Everybody I met had such good vibes," says Castro, a third-year student double majoring in applied mathematics and computer science. "I probably made more connections with faculty, alumni, and Ph.D. students in that single weekend than I have during the rest of my time at Cal."

The March 2024 retreat was open to any Berkeley student majoring in physics, astronomy, mathematics, or earth and planetary science. Even after doubling capacity to 100 undergraduate and 15 graduate students, the program could not accommodate the high demand.

Undergraduates heard advice from faculty, alums, and graduate students in keynote speeches and panel discussions. They practiced their own public speaking skills in brief presentations. Three department chairs counseled students on their academic pursuits. After a long day, attendees bonded over bonfire s'mores and faculty-led tidepooling, stargazing, and geology trips.

Until Asilomar, Castro had never thought a Ph.D. would be in his future. "I'm a first-generation student of color from a low-income background, so no one has ever sat down with me and let me know how real of an option that was," he says. "I walked away from that retreat with a very real contemplation of continuing my education past Cal for the first time in my life."

MPS Scholars Associate Director Claire-Marie Kooi is thrilled whenever a student discovers their purpose. "It is a wonderful experience to watch MPS Scholars connect with each other, faculty, staff, and their future selves," says Kooi. "Each person is unique, and so is their path to success in the mathematical and physical sciences."

Even with the university's high admissions bar, many undergraduates struggle with imposter syndrome, a misplaced fear that they are less deserving than their peers. Attendees appreciated hearing the repeated message that they are meant to be at UC Berkeley.

Alejandra Meza, a first-year student who intends to major in physics and astrophysics, was eager to learn from attendees who have built successful careers, such as astronomy professors Courtney Dressing and Jessica Lu. Says Meza, "I felt I made great connections with faculty members and my peers, which helped me feel a greater sense of belonging in my major."

Castro has kept in touch with several attendees and plans to take classes with his retreat roommate next semester. "It's hard to describe my gratitude for the MPS Scholars team," says Castro. "They provided the most beneficial, yet relaxed, space I've experienced at UC Berkeley."

Advancing Humanity Through **Science** and **Community**

WILLIAM "BILL" WING YEN CHU USED TO ENJOY POKER AND GOLF until those hobbies were overtaken by a new passion: philanthropy.

Chu had been pondering his place in the world, wanting to leave a positive legacy on humanity's well-being far into the future. Chu knew his vision would need to involve many people, but he was unsatisfied with the established pathways for donors. He decided to start his own nonprofit instead.

Hearts to Humanity Eternal — shortened to H2H8 (the 8 representing the infinity symbol) — is the radical experiment that formed in 2020 out of Chu's efforts to rethink what a grantmaking organization can be. H2H8 offers research grants of $3,500 to $10,000 to students at UC Berkeley's Division of Mathematical & Physical Sciences and College of Engineering who are studying big questions with potentially far-reaching benefits for society. In addition, the organization offers a robust engagement program focusing on community building, training, teamwork, and mentorship.

"What we are ultimately aiming to do is build a growing, inclusive, collaborative community of philanthropists and STEM researchers to advance humanity," says Chu. "We believe that science is one of the more direct ways to help humanity survive the future."

To help him run the organization, Chu recruited Chung Chan, Stephen Kwan, and Terence Chu (no relation). Berkeley was a natural launching pad, given the founders' personal connections to the campus. They also appreciated Berkeley's ability to attract creative thinkers from a broad range of backgrounds.

"I found that the students here are much more diverse, knowledgeable, and open, and they think a lot more about humanity," says Kwan, who studied and taught at several universities.

Supporting students with financial needs was an additional consideration for the H2H8 founders. They know the transformative effect a college education can have on students who don't come from wealth. And, unlike most federal programs, H2H8's research grants are available to anyone, regardless of citizenship status.

"I've spent over three decades in Silicon Valley working on high-tech projects, so I look back and think I had a pretty rewarding experience," says Chan. "I credit it to Berkeley. I wanted to pay back the university for the good education I received."

Bill Chu, Chan, and Kwan gathered last June for lunch at the Faculty Club with five students they funded. While

An H2H8 field trip

H2H8 founders and their grantees gather at UC Berkeley.

all grant recipients enter H2H8's Explorer program, the organization asks several to serve as Guardians, who mentor other students, host group lunches, and plan community-building events.

The H2H8 founders had just delivered a check for over half a million dollars to the university for the 2023 class of grantees, bringing H2H8's total number of sponsored students to 135. They were feeling bullish about the new cohort and eager to speak with the current Guardians about improving the program for the coming school year.

Some of their grantees are already making waves. Sajant Anand, a graduate student in physics who attended the Guardian lunch, had co-authored a study earlier in the week that demonstrated a milestone achievement: a new technique enabling current quantum computers to compete with classical supercomputers in performing accurate calculations.

Despite having been quoted in *The New York Times* only a few days earlier, Anand was humble about the attention. He explained the experiment's setup at lunch as Massimo Pascale and Emma Turtelboom, graduate students in astronomy, nodded along. Both Pascale and Turtelboom have physics backgrounds — as is often the case in astronomy — and had studied quantum mechanics.

The scene demonstrated another intended benefit of the program: breaking down silos between scientific disciplines.

Though it can be a lot of work, the philanthropists enjoy reviewing the faculty-nominated candidates' research projects during the grant application process and talking with grantees at community events.

"Meeting the students is a fantastic experience for me," says Kwan. "They make me feel like I'm doing something good."

"I found the interviews with the applicants to be most rewarding," says Terence Chu. "I found them mature and very dedicated to their field of study. I can see the promising future in them."

Ultimately, H2H8 aims to grow to other universities beyond Berkeley. For now, they're focused on creating a sustainable organization. The founders built H2H8 to outlive themselves. They hope that today's students become the success stories of tomorrow, staying involved with the organization to "carry the torch forward," as Chan put it.

"I'm proud of these Explorers because it's a very good community," says Bill Chu. "If we can do it successfully in Berkeley, eventually, it can happen at any university."

To learn more about Hearts to Humanity Eternal, visit **h2h8.com**.

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Basic Science Continues to Light the Way

Having completed its eighth consecutive season, the virtual event series “Basic Science Lights the Way” continues to bring large audiences together over Zoom to learn about groundbreaking research at UC Berkeley. Our Spring 2024 offerings included: **What Black Holes Reveal About Gravity’s Strangest Properties, Berkeley Science Breakthroughs in the News, The Science of Teaching, and From Neanderthals to Plants to Pathogens: Human Co-evolution with Other Organisms**.

Featuring some of Berkeley’s most renowned scientists, as well as rising-star faculty and researchers, “Basic Science Lights the Way” has something for everyone who believes in the importance of fundamental scientific research. To register for upcoming events or watch videos of all previous sessions, please visit **basicscience.berkeley.edu**.

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