Letter from Dean Frances Hellman

Dear Friend,

What a tumultuous and unpredictable year this has been. We’ve been challenged by a viral pandemic, rampant wildfires, and deep anger over systemic racism and inequality. Then, in October, came the wonderful news that two UC Berkeley science faculty had won a Nobel Prize. The Nobel Prize in Physics was shared by Reinhard Genzel, professor emeritus of physics and astronomy, for observations that provided the first evidence for a black hole at the center of the Milky Way. Then biochemist Jennifer Doudna shared the Nobel Prize in Chemistry for the discovery of genome editing tool CRISPR-Cas9. Doudna credits Department of Earth & Planetary Science Professor Jill Banfield (featured in last year’s division newsletter) with igniting her curiosity about the enigmatic bacterial gene sequences called CRISPR.

At the end of this academic year, I will conclude my tenure as dean of the Division of Mathematical and Physical Sciences (MPS). Over the coming months, I plan to focus on the concerns of my faculty, staff, and students, who have expressed the need for action to be more welcoming and supportive of all people.

On June 10, for instance, each MPS department participated in the nationwide #shutdownSTEM Day, suspending all normal operations to reflect on racial issues. The same month, physics faculty voted to remove the name LeConte from its two buildings. The brothers John LeConte, Berkeley’s first physicist, first faculty member, and initial acting university president, and Joseph LeConte, a naturalist and geologist, served in the Confederate Army and used science to subjugate Black people. A formal petition to un-name the hall was submitted to campus leadership, and the Chancellor’s recommendation for un-naming went to the UC Office of the President.

Last year, I established a Task Force on Undergraduate Diversity, Equity, Inclusion, and Advancement to recommend concrete changes to address the known problem of differential outcomes, where the percentage of underrepresented students decreases from admission to declaration of major. I highlight here two of their recommendations that we are undertaking. First is the creation of MPS Scholars, dedicated to providing underrepresented, first-generation, or low-income students with the support they need to progress through an MPS major and achieve success after graduation. The second is to redesign discussion sections and improve training for graduate student instructors. (See page 4 for more details.)

I hope to make progress on these crucial efforts while addressing two consequences of the pandemic: leaving my successor with a stable budget and alleviating student stress. I won’t give up the best part of this job, sharing in the contagious excitement of our faculty and students about their research — which we do with you through this newsletter. Please enjoy its contents, and thank you for your support.

With gratitude,

Frances Hellman

Cover: The Horsehead and Flame nebulae in the first-light image from the Zwicky Transient Facility, an automated sky survey that incorporates Machine Learning technology in its discovery process. See page 8. Credit: Caltech Optical Observatories
The idea is that the same physical principles guide the formation of all types of clouds,” says Gao. “What I have done is to take this model and bring it out to the rest of the galaxy, making it able to simulate silicate clouds and iron clouds and salt clouds.

One particularly common cloud type, concludes Gao’s model, consists of droplets of silicon and oxygen (like melted quartz crystals or sand grains). Silicate clouds condense easily and dominate cloud cover over a range of temperature between 900 to 2,000 Kelvin. An abundance of silicate clouds could explain the highly reflective daysides detected on some hot Jupiters.

On even hotter gas giants — with temperatures around 2,800 Kelvin or 4,600 degrees Fahrenheit — aluminum and titanium oxides can condense into high-level clouds. At the coolest exoplanets, ultraviolet light from the host star converts methane into a long-chain hydrocarbon haze akin to smog.

Since the 51 Pegasi b Fellowship’s inception in 2017, Berkeley has hosted four fellows, including Marta Bryan, Sivan Ginzburg, and Gao, who is now a Sagan Fellow at UC Santa Cruz. Berkeley’s current fellow, Cheng Li, also studies atmospheres around giant planets — using spacecraft observations, numerical models, and calculations to simulate the climate of planets in and beyond the solar system. As a team member on the Juno mission to Jupiter, he contributed to the scientific strategy for the probe’s measurement of water and ammonia concentrations on the planet and will use Juno data to refine theories about the atmosphere of other gas giants.
IN THE WAKE OF #SHUTDOWNSTEM DAY on June 10, Department of Physics faculty and staff received a letter signed by 96 graduate students, 23 undergraduates, and 9 postdoctoral researchers (along with nine staff and two faculty members who signed in solidarity). The letter demanded “deep and positive change” and outlined specific steps for “building a pro-Black, anti-racist department.”

Berkeley quantum physicist and Ford Foundation postdoctoral fellow Charles D. Brown II wrote an essay published in Physics Today and on The Berkeley Blog describing how: “Black physicists are forced to deal with a toxic combination of persistent scrutiny and suspicion, fear of retribution for voicing our concerns, denial that bias and discrimination exist, and isolation — all while working to broaden and deepen human knowledge.” Brown recounted several isolating incidents during his college education that “led me to seriously question whether I belong in physics.” He called for creating departmental norms that are inclusive and value the presence and contributions of Black physicists at all academic levels, combined with active recruiting and developing of Black scientists.

A recent survey of intended math or physical sciences undergraduates who declared a different major at Berkeley found that challenging courses, program structure, and uncertainty about career paths were impediments to sustained student interest. With the right support, resources, and instructors, more students would have remained in an MPS major.

With these calls to action, the MPS division is actively rethinking its approach to teaching, advising, and peer support. The dean’s Task Force on Undergraduate Diversity, Equity, Inclusion, and Advancement recently recommended several proactive steps. One top priority is creating cohorts of MPS Scholars. Similar to existing programs in computer science and data science, MPS Scholars will emphasize underrepresented minorities, low-income, and first-generation students and provide them with reliable and consistent advising and information as well as mentoring by near-peers and faculty. A dedicated course for first-year students will lay the foundation for undergraduate success, and MPS Scholars will receive additional consideration for paid research, teaching, and tutoring positions. The division is underwriting an initial pilot program but will seek long-term private support for MPS Scholars.
A second priority for MPS involves assessing and improving training for graduate student instructors to promote inclusiveness and equity in the classroom. This is an opportunity to reimagine what happens in a course’s discussion sections by standardizing the instructors’ pedagogical preparation, while giving undergraduates more opportunity to select a section that is designed around their preferred approach or environment for learning.

“Our new initiatives are focused on creating a truly inclusive undergraduate scientific community” says MPS Assistant Dean Colette Patt. “We are determined to both meaningfully increase access for students from underrepresented groups and establish the conditions for equitable success in our majors. We want to be sure that all students have the opportunity to enjoy learning math and science in an environment where they know that they belong, where they can count on being welcomed and supported.”

Including and supporting a broader diversity of undergraduates is a first step, but not enough if deeper structural inequalities and cultural climate continue to enable exclusivity. To help foster diversity among graduate students, MPS is reviving the annual Berkeley Edge conference in a virtual format, for college seniors to obtain an inside look at what Berkeley offers in physical sciences research and training. Previously, the conference generated a significant percentage of diverse graduate students who likely would not have applied to Berkeley. MPS intends to approach Ph.D. alumni working in academia to recommend potential graduate student candidates, and alumni could also help by being models of professional paths available to physical science students.

Paying Tribute to Physics Pioneers

Physics undergraduate Ana Lyons ’22 was motivated by the national reckoning around racism to create posters in tribute to Black American physicists. Her first six in a planned series of twelve posters include two individuals with a Berkeley connection: Professor Harry Lee Morrison, who in 1972 became Berkeley’s first Black faculty member in physics, and Claudia Alexander, a geophysics alumna who worked for the U.S. Geological Survey and the Jet Propulsion Laboratory.

“I’ve always loved drawing and painting, and creating a series of portraits of influential Black physicists seemed like a cool way to contribute,” says Lyons. “[I]t’s been a great way to mesh my love of physics and my love of art.” Intending to pursue a Ph.D., Lyons participates on the Dark Energy Spectroscopic Instrument (DESI) research project, which surveys the night sky for spectra to study the effects of dark energy on the expanding universe.
This year, members of the MPS division, along with the entire campus community, learned how to innovate on the fly after in-person instruction and research were curtailed in response to COVID-19. Here are a few stories of how some found new ways to make a difference.

Research

AMONG THE MANY Berkeley faculty and graduate students who diverted their research to address the coronavirus crisis was — somewhat surprisingly — an astrophysicist. As co-director of the Berkeley Center for Cosmological Physics, Uros Seljak usually spends his research time pondering the nature of dark matter. He also analyzes astronomical time-series data for anomalies that might distinguish exoplanets in a sea of stars. Professor Seljak thought that similar analysis could infer how lethal the SARS-CoV2 virus was becoming.

He obtained extensive mortality data for 1,648 towns in Italy from January to April of this year and for the same period in each year since 2015. The data included an individual’s date of death as well as the deceased’s age. Italy’s first official death due to COVID-19 occurred in late February, so assuming that many of the deaths during subsequent weeks were attributable to this cause, Seljak and colleagues could make an estimate based on previous years’ data for expected mortality in the absence of COVID-19. Then they could compare that figure with both the actual mortality data for 2020 and the Italian government’s official death toll due to the virus.

They found reasonably close alignment between the official and actual mortality numbers for younger victims. However, as the victims’ age at death increased above 60, so did the discrepancy between the two statistics.

For people 70 years and older, the researchers estimated thousands more deaths than had been officially recorded. By April, actual mortality was nearly double the official estimate of around 20,000 deaths, probably due to uncounted deaths among elderly people who never went to a hospital or were tested for the virus.

Teaching

MPS SOLICITED PROPOSALS from its departments to facilitate remote learning and student engagement for Fall 2020 courses and funded nearly two dozen projects totaling more than $200,000. Requests for support ranged from additional graduate student instructors and upgrades of online quiz, exam, and grading platforms to equipment such as iPads and electric pencils for instructors to replicate blackboard demonstrations.

For some entry-level physics classes, grants are supporting: producing laboratory experiment videos and instructional materials; hosting department-sponsored “lecture re-watch” sessions; and reproducing the atmosphere of a student study hall as a virtual collaborative learning space, where students can meet and connect for peer-to-peer guidance.
In Fall 2019, seismologist Richard Allen recorded new video lectures for his course “Earthquakes in Your Backyard” to accommodate 440 students. For the current semester, Professor Allen used a grant to edit the videos for modular delivery of content so that lecture time could be used for student-instructor and student-student discussions. He also recreated the course’s popular field trip tracing the location of the Hayward Fault with audio and video versions, so that students could either take a socially distanced in-person tour or watch from home.

For the upper-division course “Optical Astronomy,” funding for electrical and hardware improvements enabled students to operate from home the 30-inch telescope at Leuschner Observatory, shown at right. The current semester’s course refocused its emphasis around the observatory, located east of campus, in order to provide students with real-life experience in data acquisition and analysis that are central to observational astronomy.

A colleague of CalTeach Berkeley director Elisa Stone suggested contacting campus staff working from home to assess the need for tutors to help their children with remote learning. Soon, every CalTeach student had been paired with a child of a campus employee — including Stone’s 7-year-old daughter so she could observe directly how this experiment worked. During the spring semester, 78 schoolchildren were tutored in STEM subjects by CalTeach students. The students also helped with frontline work like delivering meals and educational supplies to families of children in the program’s partner schools.

Tutoring work continued for 40 student assistants over the summer, while others supported teachers by developing hands-on activities and demonstrations to enrich STEM education. With an external grant, CalTeach has begun a partnership with Berkeley High School to provide 20 paid math and science tutors for low-income Black and Latinx students. Tutoring is also the topic of a new course added to CalTeach’s curriculum, on the educated guess that the local community will have a continuing need for talented trained tutors.
ON AUGUST 23, 2011, A STAR EXPLODED
in a branch of the Pinwheel Galaxy. The
brightest and closest stellar explosion
seen from Earth for 25 years, it was a
Type Ia supernova captured 11 hours
after its demise. Swift detection gave
scientists a valuable head start in
studying the phenomenon. This event
also validated the Machine Learning
(ML) algorithm developed by Berkeley
astronomer Joshua Bloom, which
brought this supernova to light by flagging
it as an anomaly for further scrutiny.

The new chair of the Department of
Astronomy, Bloom is among a small but
growing number of scientists in his field
who have adopted ML as an increasingly
vital tool. Initially used in searching
images of star fields for obscure or
conspicuous changes, ML has evolved
in recent years from accelerating
discovery at scale to advancing and
scaling automated inference about
what has been found. Such systems for
robust, real-time discovery and inference
will be needed to analyze massive daily
data streams from next-generation sky
surveys and orbiting observatories.

“We’re trying to systematize discovery
and inference,” says Bloom, “and it’s very
clear that machine learning is becoming
a very critical part of that whole
process.”

Bloom’s group now emphasizes a more
challenging approach that develops and
deploys deep learning neural networks.
His team trains these unsupervised
systems to, for instance: look at data
from millions of uncategorized objects;
determine their relevant features; and
generate light curves that reveal a
source’s period, phase, and amplitude.
They are also embedding constraints
from real physics into neural networks
in order for the networks to learn more
quickly and improve their results.

Machine Learning is currently assisting
the search for and study of celestial
objects by the Zwicky Transient Facility
at Palomar Observatory. This survey in
the northern sky gathers four terabytes
of data each night. But much more data
will come in from the ten-year Legacy
Survey of Space and Time (LSST) at
the Vera C. Rubin Observatory (above)
in Chile, which is soon to start nightly
scans of the southern sky. Bloom hopes
to incorporate ML-accelerated inference
into the analysis of LSST data.

He is also planning to imbue ML into the
search for thousands of microlensing
stars (and potential nearby exoplanets)
by NASA’s Roman Space Telescope.
Launching later this decade, the Roman
observatory will have a field of view one
hundred times that of the workhorse
Hubble Space Telescope and will
transmit 500 times more data each day.

Acknowledging that ML is technically
tough and rife with potential pitfalls,
Bloom believes it offers a competitive
edge — especially if you have to
interrogate immense quantities of data
or need a shortcut to costly, time-
consuming supercomputer calculations.

“It’s often not the right tool to use. The
question is, what are you going to get
out of it if you do it well and you do it
right?,” he says. “ML isn’t the end goal
but a vector to the discovery and the
understanding of the universe we’re all
trying to get to.”

Berkeley’s
Prize-winning Role
in Finding Black Hole

A portion of the 2020 Nobel Prize
in Physics was awarded to Reinhard
Genzel, professor emeritus of
physics and astronomy at Berkeley
and director of the Max Planck
Institute for Extraterrestrial Physics.
While still a postdoctoral researcher
with Berkeley physicist and Nobel
laureate Charles Townes, Genzel
began seeking observational
evidence that a supermassive black
hole lurked in the middle of the
Milky Way.

Painstakingly precise measurements
of star mass and orbital paths
around the galactic center 25,000
light-years away culminated with
the conclusion by Genzel’s group
and a second team, led by UCLA
astronomer Andrea Ghez, that
the stars orbited an unseen object
with the mass of four million suns.
Berkeley Associate Professor of
Astronomy Jessica Lu earned her
Ph.D. with Ghez pursuing this black
hole and continues to collaborate
with her. Genzel and Ghez shared
the Nobel Prize with theoretical
physicist Roger Penrose.

Says Department of Physics Chair
James Analytis, “This honor shows
how Berkeley physics leads the way
in many of the important
discoveries in physics, and that is
as much a reflection of the caliber
of our students as it is because of
our faculty.”
THE GRADUAL TUG OF AN OCEAN TIDE seems more gentle than the sudden jolt from an earthquake, but both of these forces can reshape the Earth. While many geophysicists study seismic waves that propagate through the planet after earthquakes, Harriet Lau is lured by the tides. The same gravitational force from the sun and the moon that is responsible for daily aquatic tides also generates tides inside the Earth, flexing rock from the surface to depth.

“You and I will go up and down 40 centimeters twice today from this motion, but it’s so slow we don’t really realize it,” says Lau, an assistant professor in the Department of Earth & Planetary Science. “It makes me nauseous when I think about it.” Other solid Earth tides occur on cycles of a fortnight and even 18 years.

Using seismic waves to generate detailed images of Earth’s interior has become a well-developed technique in recent decades. As Lau describes it, “You can do a little bit of math and basically get an X-ray of the Earth.” While pursuing her Ph.D. at Harvard, Lau adapted this technique of seismic tomography to analyze a steady stream of data from GPS satellites, which capture millimeter-scale geographic variations in warping from solid Earth tides. She suspected that this signal could hold clues to Earth’s inner structure.

Like an egg, Earth consists of three primary layers: a thin, brittle crust, a viscous middle section called the mantle, and a partly solid, iron-nickel core. To understand how our planet works on the inside, it helps to know the density at various depths. Relative density determines whether material rises or sinks as it flows. “Seismic tomography, as useful as it is, just really can’t get a handle on that,” says Lau. “It turns out that tides are very sensitive to density, and in particular density in the deep mantle.”

Lau’s tidal tomography research may help finally resolve an enduring mystery about middle Earth: the nature of two continent-sized regions far beneath Africa and the Pacific Ocean, situated at the base of the mantle. Known as Large Low Shear Velocity Provinces (LLSVPs), each of these bulbous blobs rises more than 1,000 kilometers. “That’s like half the mantle in terms of height, so they’re massive,” says Lau. Geophysicists have been aware of the blobs’ presence from the early days of seismic tomography, but no one knows what they consist of, how or when they formed, or whether they influence Earth’s dynamic activity.

Seismic waves slow down as they pass through these vast provinces, which means the blobs could be either hotter or denser than the surrounding mantle. Lau’s models based on tidal tomography suggest that LLSVPs are made of something dense — possibly oceanic basin rock swept down by subduction, or primordial rock that has never seen the planet’s surface, or perhaps iron and nickel pulled from the core. “If the bases of these LLSVPs are in fact made of denser material,” she says, “you’d imagine that stuff would just stick around.” It’s still anyone’s guess what makes up the LLSVPs, so stick around as geophysicists like Lau strive for the answer.

Earth tides involve deformation of the whole earth and GPS measurements of this deformation can tell us about the interior structure thousands of kilometers beneath our feet.
EVER FEEL LIKE you were in over your head during math class? Unfortunately, this seems to be a familiar sensation for incoming students at Berkeley, where most undergraduates take a course in mathematics. Beyond being unprepared to understand some core concepts, students who struggle through a gateway math course often stop studying a scientific or technical field.

“For most STEM students, they need to be applying all of their math toolkit to very complicated problem sets, and if they do not have a full toolkit, it’s going to be really challenging to stay in STEM majors,” says UC Berkeley Foundation trustee Kathy Kwan ’87, M.B.A., M.P.H. ’93. She has spearheaded an ongoing effort with MPS and the Department of Mathematics to assess student aptitude and advise them about appropriate course choices.

Dean Frances Hellman is concerned about a nationwide trend of undergraduates who intend to declare a STEM major but drop out after an unsuccessful encounter with a prerequisite class. In recent decades, the STEM dropout rate has been around two-thirds for underrepresented students — twice the rate for white males. Hellman says, “It seemed likely that this persistence gap could originate largely in math backgrounds, so we set out to study that.”

After investigating available options, the team selected an online resource called ALEKS (for Assessment and LEarning in Knowledge Spaces), which combines a math preparation assessment with personalized opportunities to sharpen skills in any of 11 topics. “With ALEKS,” says Hellman, “students can identify specific areas of weakness and pursue independent study of these. It’s not just an assessment tool but also a teaching tool.”

With support from the Eustace-Kwan Family Foundation, a pilot test of ALEKS with more than 600 students took place in Fall 2017, followed by a spring rollout for all students enrolled in four different calculus and pre-calculus courses. By now, some 5,000 students have participated in the study. Using a tool like ALEKS enables determining the math strengths and weaknesses for thousands of students at once.

When those results came in, says Kwan, “I almost had a nervous breakdown, because a lot more students were not as good at math as we anticipated.” Across all student demographics, surprisingly wide knowledge gaps were revealed in five of the topical modules on ALEKS: relations and functions, quadratic and polynomial functions, rational expressions and functions, exponentials and logarithms, and trigonometry. A higher proportion of the unprepared students come from low-income families or underrepresented groups.

To help bridge the gap, mathematics teaching professor Alex Paulin and lecturer Kelli Talaska created online modules to address the five problematic topics with content appropriate to Berkeley’s lower-division math classes. With only a week’s notice, more than 900 students signed up for the instructors’ intensive summer pilot for Pre-Calculus Essentials. About 200 of the students elected to participate in peer groups led by an undergraduate tutor recruited and trained by the Student Learning Center. For three weeks, these groups met daily to discuss lessons and work together on problems. The tutors successfully created communities and instilled confidence in their students that carried over into the fall semester’s classes. MPS will investigate how these interventions improve student success, while planning how to sustain efforts to assess and support so many undergraduates.
Berkeley Physicists Lead New National Centers

THIS SUMMER, the National Science Foundation (NSF) announced significant grants to create two new collaborative research centers in which Berkeley’s Department of Physics plays a leading role. First, the Network for Neutrinos, Nuclear Astrophysics and Symmetries (N3AS) Physics Frontier Center will advance research on the exotic state of matter inside neutron stars — the super-dense remains of exploded stars — and use these most extreme environments for testing physics under unearthly conditions.

Led by professor and former department chair Wick Haxton, N3AS builds upon the foundation of a research hub established in 2017 at Berkeley and Lawrence Berkeley National Laboratory and supported by NSF and the Heising-Simons Foundation. The new designation as a Physics Frontier Center comes with $10.9 million over five years to expand both the participating community of researchers and the scope of scientific inquiry. N3AS will occupy a renovated third floor section of Old LeConte Hall.

Linking 14 research institutions across the United States and abroad, N3AS will support a dozen postdoctoral fellows who have “the freedom to move among the sites, learning the physics they need to know to make progress from a variety of world experts,” says Haxton. It will also recruit diverse undergraduate students into research. “We operate as a single team, combining our expertise in order to tackle the complex...problems that are beyond the capacity of a single investigator.” Solving those problems could have profound influence on the future of astrophysics as well as nuclear and particle physics.

A second NSF initiative provides $25 million over five years and positions Berkeley as an intellectual leader of quantum information science. The Quantum Leap Challenge Institute (QLCI) for Present and Future Quantum Computation, led by Berkeley in partnership with seven other universities, will harness experimental and theoretical expertise to address fundamental challenges of quantum computing, including developing scalable quantum computers and training a quantum-smart workforce. Twenty-seven scientists and engineers from the participating institutions will collaborate, in partnership with industry and government labs.

“[W]e are on the precipice of a really big move toward quantum computing,” says professor of physics and institute director Dan Stamper-Kurn. “I don’t know the time scale — Is it 100 years or ten years? — but we are talking about exponential increases in capability.”

It took decades to realize the digital revolution and make computers commonplace in homes and offices — as well as in our pockets. Getting to faster, better quantum computers and networks that manipulate subatomic particles to store and process information in radically new ways will require a similar effort. So, NSF launched three QLCIs simultaneously to take on different aspects of the challenge. Berkeley’s center will emphasize developing algorithms able to exploit the potential power of quantum computation.

“We think that the development of the quantum computer will be a real scientific revolution,” says Stamper-Kurn. “If you have a chance to revolutionize what a computer is, then you revolutionize just about everything else.”

For more, please visit PHYSICS.BERKELEY.EDU
Large Investments in Data Science and Deep Learning

Big data profoundly affects how academia, government, and industry operate. As part of a new initiative around Transdisciplinary Research in Principles of Data Science, the National Science Foundation (NSF) awarded $12.5 million in August to UC Berkeley, MIT, and five other universities for the creation of the Foundations of Data Science Institute (FODSI). At Berkeley, the new institute’s co-director is statistics professor Peter Bartlett, with faculty principal investigators Josh Hug, Michael Jordan, Martin Wainwright, and Bin Yu. A total of 20 Berkeley faculty will help advance FODSI’s foci of research: modeling, inference, computational efficiency, and societal impacts.

Data science encompasses a broad convergence of academic disciplines — statistics, mathematics, and computer science to name a few — that are coming together to address the theoretical, technical, and ethical issues of the big data revolution. Says Bartlett, “We’re starting to see a confluence of efforts in pursuing a better understanding of how to solve scientific and societal problems by leveraging all of these disciplines. It’s important to consider possible solutions from many different perspectives.” As part of broadening its perspective, FODSI plans to recruit workshop participants from groups traditionally underrepresented in data science fields to work with senior researchers.

A week before the announcement of funding for FODSI, the NSF and the Simons Foundation awarded $10 million to a Berkeley-based international research effort toward deeper understanding of deep learning, the widely used artificial intelligence approach for teaching computers to learn from data. Peter Bartlett and Bin Yu will co-lead the Collaboration on the Theoretical Foundations of Deep Learning. Better understanding of the mechanisms that underpin deep learning and enable it to function will allow researchers to address its limitations, including sensitivity to data manipulation. “This is really cutting-edge research at the frontier of data science theory and practice,” Yu says. “It’s leading us intellectually where we want to go with deep learning.”