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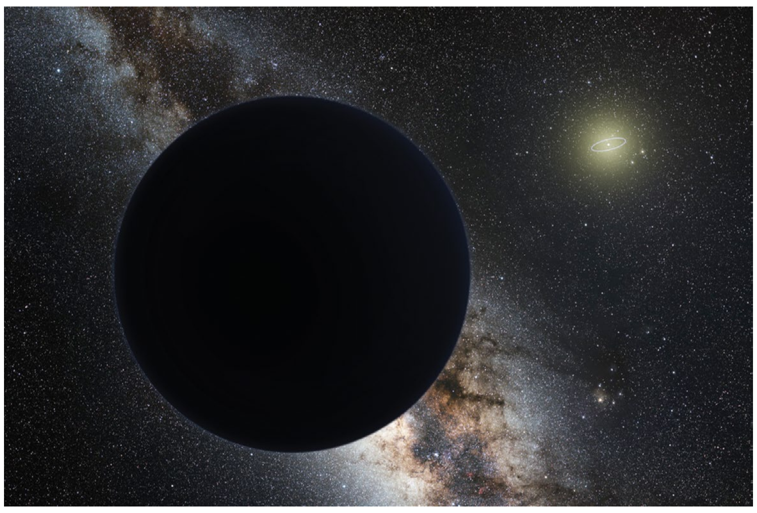
The Hunt for Planet Nine

Since Pluto was demoted to a "dwarf planet" in 2006, a Caltech team has been searching for a hypothesized planet on the edge of the Solar System.

BY LIZ BOATMAN



Artist's impression of a hypothetical Planet Nine. Neptune's orbit rings the Sun. Credit: Nagualdesign/Tom Ruen. Background from ESO/S. Brunier.

In August 2006, hundreds of astronomers gathered at the International Astronomical Union (IAU) meeting in Prague to debate a planet-sized problem. A Caltech astronomer had recently discovered a string of objects in the Kuiper Belt, an icy band on the outskirts of the solar system. The objects — Haumea, Makemake, Quaoar, Sedna, and Eris — were as large as or larger than the planet Pluto. Were they planets, too?

If so, Pluto and Charon, Pluto's largest moon, would be the only binary planet in the solar system. It would also make the Caltech astronomer, Mike Brown, "the greatest planetary discoverer of all time," he says.

It was a title he didn't want. "I just found it very depressing," Brown says. "It was clear [to me] by the late 1990s that Pluto was part of this Kuiper Belt and that it should not have been classified as a planet to begin with." If Pluto didn't deserve planetary status, neither did the other objects Brown had discovered.

Brown doubted that the IAU astronomers would agree, he says. He didn't attend the meeting, opting instead to "hide out" on a family trip to an island off Washington state.

But to Brown's surprise, the IAU didn't decide that the Kuiper Belt objects were planets. Instead, the astronomers created a new classification scheme. Pluto and the other objects were now *dwarf* planets.

Pluto had actually never been Brown's focus — his team was working to catalog new Kuiper Belt objects. But they began to notice an odd pattern: A subset of those objects had orbital inclinations and geometries that defied explanation.

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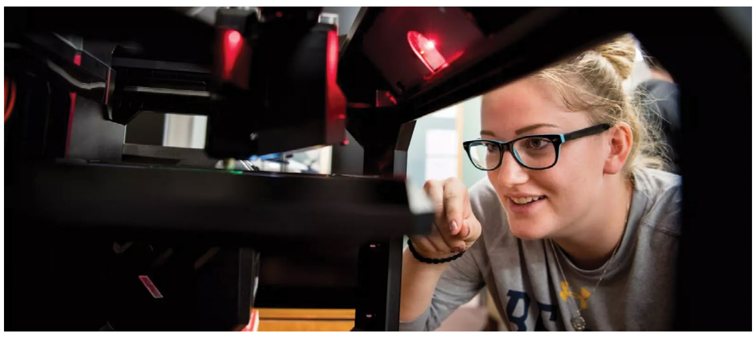
To Bolster Enrollment, Some Colleges Are Emphasizing Engineering Physics Degrees

Beloit College in Wisconsin and the University of Maine model different approaches to engineering physics.

BY LIZ BOATMAN



A Beloit student works with a 3D printer at the college's makerspace. Beloit's new engineering physics program has relied in part on existing campus resources, like the makerspace. Credit: Howard Korn / Beloit College

Across the United States, enrollment in undergraduate physics programs has been sliding, but engineering — which traditionally pulls from similar student demographic groups — has fared better. Some schools, like Beloit College in southern Wisconsin, are taking the hint.

At Beloit, the physics department saw a new engineering physics major as an opportunity to attract two to three new students per year, says physics chair Britt Scharringhausen. "Like any college, we're dealing with changing student demographics, and students coming in with different kinds of interests."

While engineering programs are typically taught out of dedicated en-

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APS Innovation Fund Supports "Vibrant" US-Africa Collaborations in Modeling Electronic Structure

Despite the pandemic and even armed conflict, partnerships between researchers in the US and Africa persist.

BY LIZ BOATMAN

Two physicists from Kenya and Nigeria work with a physicist in Illinois in 2022, a collaboration borne out of the USAfrI initiative. Credit: Amy Young

Richard Martin, a professor emeritus in physics at the University of Illinois, Urbana-Champaign (UIUC), first met Nithaya Chetty in 1987. Chetty was a graduate student who had come to the US as a Fulbright Fellow, an achievement for a young Black scientist who had grown up during apartheid in South Africa. Just three years later, Chetty earned his doctorate for research on semiconductor surfaces as a student in Martin's group. In 1995, after apartheid ended, Chetty returned to his home country, intent on supporting other young South Africans. Today, he is the Dean of the Faculty of Science at the University of the Witwatersrand in Johannesburg.

Chetty and Martin's work together was far from over. In 2008, Chetty founded a workshop series called the African School on Electronic

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Physicists and Biologists Uncover New Evidence of Octopuses' Complex Sleep

Interdisciplinary collaborators found that the brainy cephalopods behave in their sleep like they do while awake. Are they dreaming?

BY SOPHIA CHEN

Neuroscientist Sam Reiter frequently takes his students at night to catch octopuses in the ankle-deep tide pools on Okinawa, the southernmost of Japan's main islands. But netting an octopus involves a learning curve — particularly because they change color to blend into the environment. "Usually the first time someone goes, they don't see an octopus," says Reiter. "But people with more experience will see many of them."

Reiter and his team bring the animals back to his lab at the Okinawa Institute of Science and Technology, where they study how the octopus's brain activity gives rise to its complex behavior, from camouflaging itself to coordinating its many arms.

But cephalopods aren't the only strange creatures Reiter interacts with. He also works with a physicist. Leenoy Meshulam, a postdoc and physicist at the University of Washington, collaborates with Reiter across the Pacific Ocean.

The team recently found that, during a particular stage of sleep, octopuses exhibit color patterns and neural activity similar to those they exhibit while awake. Their conclusions, presented at the APS March Meeting this year and published in *Nature* on June 28, are based on extensive image analysis of multiple octopuses' skin patterns and electric measurements of their neural activity. The team hypothesizes that octopuses could be reliving their waking experiences, such as hiding from a predator, and exhibiting the skin

Octopus laqueus *is white and motionless during quiet sleep, but researchers have observed that, every hour or so, the octopus has a burst of active sleep.* Credit: Shawn Miller | okinawanaturephotography.com

pattern associated with the experience, in a behavior akin to dreaming — though this is far from certain.

Octopuses are unusual among invertebrates because they experience two-stage sleep, like vertebrates. In two-stage sleep, the animal experiences a stage called active sleep and a second, quieter stage. In vertebrates, this stage is often called slow-wave sleep, or deep sleep. (Humans dream during active sleep, also known as the rapid eye movement stage; during slow-wave sleep, the body repairs and regrows.)

Other invertebrates, such as insects and worms, generally undergo a single sleep stage. "They just have one kind of sleep where the brain just kind of goes quiet," says Reiter.

This implies that octopuses have evolved two-stage sleep independently of vertebrates, which suggests that active sleep could be a "general feature of complex cognition," says Meshulam.

The research is right up Meshulam's alley. She's working to develop theoretical frameworks to describe the octopus's behavior. "My jam in life is to study things that have multiple scales," she says. In organisms, the scales span the macroscopic — such as the octopus's behavior in response to a predator — to the microscopic, such as the pigment granules inside cells involved in camouflage called chromatophores.

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Jim Hartle, 1939-2023

Giant of quantum cosmology dies at 83

BY DANIEL GARISTO

James Hartle at the Sante Fe Institute in 2011. Credit: Copyright 2023 www.insightfoto.com

Jim Hartle, a theoretical physicist whose boundary-defying work sought to unite the quantum world with a cosmos shaped by gravity, died May 17, in Switzerland. He was 83.

"What Jim developed, more than anyone else, was a quantum mechanical way of thinking about cosmology," says Thomas Hertog, a cosmologist at KU Leuven and a frequent collaborator of Hartle's.

Hartle was an APS Fellow and Guggenheim Fellow, and in 1991, he was elected to the National Academy of Sciences. Despite his accomplishments — the 2009 Einstein Prize cited a "broad range of fundamental contributions to relativistic stars, quantum fields in curved spacetime, and especially quantum cosmology" — Hartle was averse to the spotlight. "He so easily could have tried to grab some of that limelight that shone on Stephen [Hawking]," says David Craig, a general relativist at Oregon State University and one of Hartle's students. "He never did."

Jim Hartle was born Aug. 17, 1939, in Baltimore. His parents, Anna Elizabeth Burkett Hartle and Charles James Hartle, moved frequently due to Charles' job at IBM. During Jim's teenage years, they returned to Baltimore, and he attended the Gilman School, learning from physics teacher Bill Porter, whom he later thanked for "starting me off on this trail." In college at Princeton, Jim initially studied engineering but changed course after meeting theoretical physicist John Wheeler, who became a lifelong mentor — and, eventually, family. Years later, during a stint in Chicago, he asked Wheeler, "what ever happened to that attractive niece of yours?" "And Johnny said, 'She just lives a few blocks away from here. Why don't you give her a call?' So he did, and that was that," says Mary Jo Wheeler Hartle, who married Jim in 1984.

At Caltech for graduate school, Hartle worked on particle physics under Murray Gell-Mann. After graduating in 1964, he briefly taught at Princeton before joining the faculty at the University of California, Santa Barbara, which he would help build into a theory powerhouse with the Institute for Theoretical Physics. In 1967, Hartle began working with Kip Thorne to calculate the dynamics of rotating neutron stars. "We would work late into the night and start again the next day," Thorne says. The two got along so well that they organized regular gatherings between their research groups, which eventually became the Pacific Coast Gravity Meetings.

Hartle also began to tackle questions about the foundations of quantum mechanics. "He had these

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THIS MONTH IN PHYSICS HISTORY

August 1856: Eunice Foote Concludes That Carbon Dioxide Could Warm the Atmosphere, Three Years Before John Tyndall Did

Well over a century later, female historians rediscovered Foote's work — and were themselves overshadowed.

BY TESS JOOSSE

In 1856, an American woman named Eunice Newton Foote conducted a series of homespun experiments. She set up 30-inch-long cylinders, each with a thermometer inside, and each filled with different gases and gaseous mixtures — moist air, dry air, carbon dioxide, oxygen, and hydrogen. Foote placed the cylinders in the sun and charted how the gases warmed. The cylinder containing carbon dioxide warmed the most, she noted, and stayed at its high temperature for a long time after she took it out of the sun.

Artist's depiction of Eunice Newton Foote. Credit: Carlyn Iverson / NOAA Climate.gov

Foote wrote up these data into a short paper with a stunningly prescient conclusion. Of carbon dioxide, she wrote: "An atmosphere of that gas would give to our earth a high temperature," describing the phenomenon we now call the greenhouse effect, the main cause of climate change. The paper, titled "Circumstances Affecting the Heat of the Sun's Rays," was presented at a meeting of the American Association for the Advancement of Science (AAAS) on Aug. 23, 1856.

Then Foote and her work faded into obscurity. The Irish physicist John Tyndall, who reached similar conclusions from more intricate experiments three years later, is widely regarded as the discoverer of the greenhouse effect and the father of climate science.

> Of carbon dioxide, Foote wrote: "An atmosphere of that gas would give to our earth a high temperature."

But Foote wasn't wholly forgotten. Starting in the 1970s, several female historians of science identified Foote as one of a class of nineteenth-century women who were educated and who "too shared in the popular enthusiasm for science which emerged" in pre-Civil War America, as historian Deborah Jean Warner wrote in 1978. But these historians did not yet connect Foote's work to the issue of climate change.

It was a geneticist and women studies scholar named Elizabeth Wagner Reed who recognized the importance of Foote's results. In her 1992 book *American Women in Science Before the Civil War*, Reed affirmed that Foote "demonstrate[ed] what we call the greenhouse effect today and is a phenomenon which is of concern to us even now."

Reed's own contributions to science were obscured for many years. Among the first researchers to study evolution in the fruit fly *Drosophila*, one of the most widely used model organisms in science today, Reed worked on studies in tandem with her husband. Though he himself acknowledged her contributions, she received little public recognition.

"Elizabeth Reed encountered and resisted sex discrimination throughout her career," wrote her daughter Catherine in an afterword to the 1992 book. "She researched and wrote this book to refute the claim that there had never been women scientists."

Indeed, there had long been women scientists, including Foote. Born Eunice Newton on July 17, 1819, in Connecticut, she grew up in New York state and attended the Troy Female Seminary, the first institution of higher education for women in the United States. Here, Foote and other attendees studied languages, philosophy, and mathematics. They also were permitted to take science courses taught in novel hands-on laboratories at the nearby Rensselaer School (now Rensselaer Polytechnic Institute).

In 1841 she married a patent lawyer named Elisha Foote, and the couple moved to Seneca Falls, New York. There they befriended Elizabeth Cady Stanton, a prominent leader in the women's rights movement. Both Eunice and Elisha attended the landmark Seneca Falls Convention in July 1848 and signed its resulting "Declaration of Sentiments," which critiqued gender inequality and proclaimed women's inalienable rights.

Along the way, Foote began conducting experiments in a home laboratory. Her gas-heating experiments might have been inspired by Joseph Henry, a family friend and director of the Smithsonian Institution, says John Perlin, a visiting scholar at the University of California, Santa Barbara, who has written about Foote. Henry was interested in how weather and climate impacted agriculture, Perlin explains.

After Foote wrote up her results, Henry read her paper aloud at the AAAS meeting in Albany on Aug. 23, 1856. While the AAAS allowed women to be members and did not prohibit them from presenting work, it seems to have been uncommon for them to do so. The research — and Eunice's gender — received some attention in the press: A writeup in *Scientific American* proclaimed, "the experiments of Mrs. Foot [sic] afford abundant evidence of the ability of women to investigate any subject with originality and precision."

Foote's work was also summarized in *The Annual of Scientific Discovery*, an anthology published in 1857. But it appeared that those who knew of her results did not know what to make of them, including Henry. According to a write-up of the AAAS meeting in the *New York Daily Tribune*, Henry said "that although the experiments were interesting and valuable, there were … difficulties encompassing any attempt to interpret their significance." Foote's paper was then published in the *American Journal of Science and Arts* under Eunice's own name, alongside a paper by Elisha, also an amateur scientist.

Foote did present her own research at the following year's meeting, reading a paper on static electricity. This work was the last publication of Foote's scientific career, though she filed patents for several inventions, including a rubber sole to silence squeaking shoes and a paper-making machine, before her death in 1888.

Tyndall, the erstwhile originator of climate science, casts a shadow over Foote's story. While her contri-

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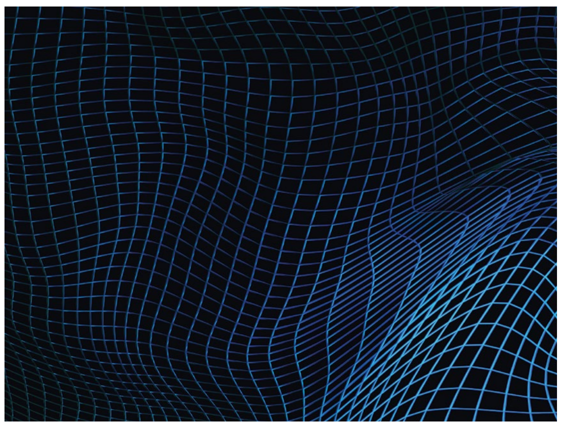
Simulating Spacetime with Quantum Mechanical Materials

At the annual APS Division of Atomic, Molecular and Optical Physics meeting, physicists made the case for a new way of modeling a universe.

BY SOPHIA CHEN



Humans have long built models of the vast, mysterious universe. From celestial spheres that map the constellations to computer-based simulations of dark matter, these approximations give their users more tangible objects to study.

Now, physicists are exploring a new paradigm by building models out of quantum mechanical materials, such as Bose-Einstein condensates and devices that transmit single photons. These models are a new type of simulation, potentially able to probe questions beyond the reach of conventional computing — like how to reconcile the predictions of general relativity and quantum mechanics, theories that physicists have struggled to unite.

This June, physicists gathered at the Division of Atomic, Molecular and Optical Physics (DAMOP) meeting in Spokane, Washington, to present research in this field in a session called “Quantum Matter in Synthetic Curved Spacetimes.”

“Quantum matter” refers to “many interacting particles . . . that obey quantum mechanics,” says Joseph Maciejko of the University of Alberta in Canada. In simulations, researchers can manipulate these particles’ interactions to mimic the effects of gravity in different universes, including flat, spherical, or hyperbolic ones.

The physicists use the word “synthetic” to convey that current simulations are more loosely inspired by nature than reflective of it. “We don't simulate the universe — we try to implement a simple theoretical model,” says Markus Oberthaler of the University of Heidelberg in Germany. For example, his team used a Bose-Einstein condensate to simulate quantum fields in a curved universe with just two spatial dimensions. (Our universe has three.)

Maciejko, meanwhile, presented theoretical work motivated by an experiment from Princeton collaborators that used devices called waveguide resonators, small cavities that selectively trap and transmit individual photons. Arranged in a grid of heptagons and triangles, the devices enabled photons to move around as though in a two-dimensional hyperbolic space —a sort of Pringles-chip-shaped universe, says Maciejko.

Studying quantum phenomena in a hyperbolic space could be useful for string theory, which aims to unite quantum mechanics and general relativity. However, Maciejko is studying this simulation as an interesting object in its own right, separate from cosmology. In essence, Maciejko's Princeton collaborators have created a new type of crystal geometry, with particles arranged on a curved, hyperbolic lattice — in contrast to the lattices of natural crystals, such as ice or silicon, which are composed of straight lines in Euclidean space.

Maciejko presented research in which his team adapted electronic band theory to this type of crystal. Normally, band theory describes the allowed energies of a material's electrons, which then determines the material's bulk properties, such as whether it can conduct electricity. But in the hyperbolic crystal that Maciejko studied, band theory predicted the frequencies of photons that would transmit through the device.

This research brings together subfields of physics conventionally siloed from one another. Con-

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Stranger still, these oddballs were clustered on one side of the solar system, not randomly distributed throughout the Kuiper Belt.

Perhaps it was observational bias, and similar objects did exist in other locations but hadn't been seen yet. Maybe Brown's data was wrong. Or maybe there was an undiscovered planet, much larger than Pluto. But Brown, the infamous “planet killer,” thought another planet seemed unlikely.

When Pluto was glimpsed in 1930, “it was the only thing out there beyond Neptune that had ever been seen before,” says Brown. Astronomers leapt at the chance to declare it the ninth planet. But in the end, Pluto “was an accidental discovery of something that they thought was going to be a planet, and it wasn't,” says Brown.

Now, Brown's observations of these Kuiper Belt objects, oddly clustered and tilted, were best explained by a ninth planet, he says. But Brown didn't want to be the next astronomer searching for a planet to solve a set of mysteries. He didn't want a Pluto repeat. To explain their observations, “we tried so hard to come up with anything else,” says Brown. “Nothing else worked.”

Finally, something clicked. “It's real — there's actually a giant planet out there,” Brown remembers realizing. “[My] heart just kind of dropped.” In 2016, Brown and his colleague Konstantin Batygin published a paper in *The Astronomical Journal*, presenting their evidence for “Planet Nine.”

Around then, a doctoral student at the University of Michigan named Juliette Becker was studying a strange Kuiper Belt object herself. A decade earlier, Becker had been a ninth grader when her teacher told the class that Pluto was no longer a planet. Many students were confused. Becker remembers thinking, “What happened to Pluto? Where did it go?”

Now an aspiring astronomer, Becker's object, BP519, was odd, with an orbit tilted by 54 degrees from the plane of the solar system. “The big question I was trying to answer was how this distant object could have such a high inclination,” she says.

That's when Becker stumbled across Brown and Batygin's paper on Planet Nine. Seeing a possible connection, she ran new simulations of the solar system with both BP519 and Planet Nine. “The amazing thing was, if we started BP519 out in a disc with all other Kuiper Belt objects and put Planet Nine in the simulation,” she says, it “recreated the current geometry of BP519's orbit.” Becker's “weird” object turned out to be a key piece of evidence for Planet Nine.

After Becker completed her doctorate in 2019, Batygin invited her to Caltech. As a postdoc in his research group, she worked to help craft the theory for Planet Nine and constrain its orbital parameters.

Today, the theoretical portion is largely wrapped up — at least, based on known Kuiper Belt objects, says Becker. The team predicts that Planet Nine will be six or seven times the mass of Earth, residing so far from the Sun that one sweep around would take 10,000 Earth-years.

The team doesn't know how the hypothesized Planet Nine might have come to be. It might have formed close to Uranus and Neptune, Brown says, but then passed “too close to one of those larger planets — to Saturn, more likely — and then was ejected to the outer part of the solar system, where it's been lurking.”

Now, the team must find observational evidence, surveying the sky or existing images, watching for any “speck” that changes position between frames. That speck could be Planet Nine.

Now the team must find observational evidence, surveying the sky or existing images, watching for any “speck” that changes position between frames. ”

“A part of me thought that it was going to be bright enough that it would be found within a few years, and it was just a matter of who's going to find it first,” says Becker. But it's been six years since she saw the first evidence of Planet Nine's existence. This fall, she's starting her own faculty career at the University of Wisconsin, Madison.

And what if the Planet Nine theory is wrong? Many astronomers think so, and plenty of other explanations for the Kuiper Belt objects have been offered.

If Planet Nine isn't out there, that's okay, says Brown. He likes that science self-corrects. But “if we're going to be wrong,” he says, “we would like to tell everybody we're wrong before someone else tells us.”

Liz Boatman is a staff writer for APS News.

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In 2022, 15 faculty from African institutions visited the US, a culminating event of USAfrI. Credit: Michael Martin

Structure Methods and Applications, or ASESMA; roughly 30 African students and faculty attended its inaugural event in Cape Town. Martin, who retired the same year, joined the effort and has helped Chetty organize ASESMA ever since.

In 2019, Martin — eager to do more to support African scientists' work — teamed up with Renata Wentzcovitch, who had given a seminar at the 2012 ASESMA workshop. Wentzcovitch, originally from Brazil and now a professor of physics and environmental science at Columbia University in New York, had stumbled upon the APS Innovation Fund and seen an opportunity to organize workshops that would foster long-term collaborations between African and US-based electronic structure researchers.

Wentzcovitch brought on two more partners: Sinéad Griffin, a staff scientist at California's Lawrence Berkeley National Laboratory (Berkeley Lab) and a passionate supporter of ASESMA's efforts, and Omololu Akin-Ojo, director of the ICTP East African Institute for Fundamental Research (ICTP-EAIFR) in Rwanda.

They applied to the APS Innovation Fund, received a grant of $138,000, and launched the US-Africa Initiative for Electronic Structure, or USAfrI. “The ability to jumpstart collaborations with the APS Innovation Fund was just wonderful,” says Martin.

But within months, the COVID-19 pandemic had begun to derail plans, forcing online a series of workshops that the team had hoped to hold in-person. Still, the travel restrictions had a silver lining: Because COVID normalized virtual meetings, participation in USAfrI activities expanded. Scientists from across Africa and North America logged on for four virtual workshops over two years.

The project culminated in 2022, when 15 African faculty came to the US for an in-person, multi-week visit. That June, scientists from Cameroon, the Democratic Republic of the Congo, Ghana, Ethiopia, Kenya, Nigeria, Rwanda, South Africa, and Tanzania — visas in-hand and travel restrictions eased — boarded flights to New York City.

ICTP-EAIFR's status as a physics hub in Africa contributed to the team's success in bringing together scientists from across the continent, says Akin-Ojo.

In the US, the researchers attended the Annual Workshop on Recent Developments in Electronic Structure, held at Columbia that year. Then they spent a day touring Brookhaven National Laboratory, where they learned about opportunities for virtual access to the lab's supercomputing facilities, which researchers anywhere in the world can apply to use.

Afterward, the researchers boarded planes once again, but not to return home. Instead, they dispersed across the US to spend several weeks at institutions where researchers had volunteered to host them — including UIUC, Columbia, Brookhaven and Berkeley National Labs, Cornell University, Rutgers University, Stanford University, the University of California at Berkeley, the University of Colorado, the El Paso and Dallas campuses of the University of Texas, the University of Washington, and the University of Western Washington. Amy Young at UIUC was instrumental in coordinating these activities, says Wentzcovitch.

“It worked out very well,” says Akin-Ojo, and led to incredible collaborations. For example, Adewumi Popoola, a physicist at the Federal University of Technology in Nigeria, just published a paper on narrow band-gap compounds for use in thermoelectrics with Robert DiStasio, a collaborator at Columbia. And Qin Wu and Deya Lu at Brookhaven have continued to support Yedilfana Mekonnen at Addis Ababa University in Ethiopia with remote access to the lab's computing facilities.

For researchers from less-resourced institutions, “people should know just how much stamina and personal strength it takes . . . to participate in an international collaboration,” says Martin. And some African scientists are trying to sustain their research in the face of serious conflict, he says — like Sara Abass at the Al Neelain University in Sudan, who is collaborating with André Schleife, a materials scientist at UIUC. The two have stayed in touch, even though in April 2023, competing armed forces launched a battle to assume control of Sudan's capital, Khartoum, where Abass lives.

Despite the challenges, “the APS Innovation Fund really helped us to broaden the US-based community that interacts with African researchers,” Wentzcovitch says. More than 100 US scientists expressed interest in hosting African researchers, and there are now 18 US scientists actively involved for the first time.

Some of these people will meet again, says Wentzcovitch: In June, Schleife from UIUC and Alex Urban from Columbia are flying to Rwanda to join their African collaborators at the 7th ASESMA workshop. And some US researchers looking to make new connections — such as Houlong Zhang at Arizona State University and Cyrus Dryer from Stony Brook University — will attend, as well. “It is great that the USAfrI collaborations are continuing beyond the period of the grant,” says Akin-Ojo.

Wentzcovitch is going, too, and she's excited. The last time she was at ASESMA, she gave a public lecture at a high school. She says the energy in the room was palpable. Plus, her talk was followed by an African drum concert. “That's the kind of experience you'll never forget,” she says.

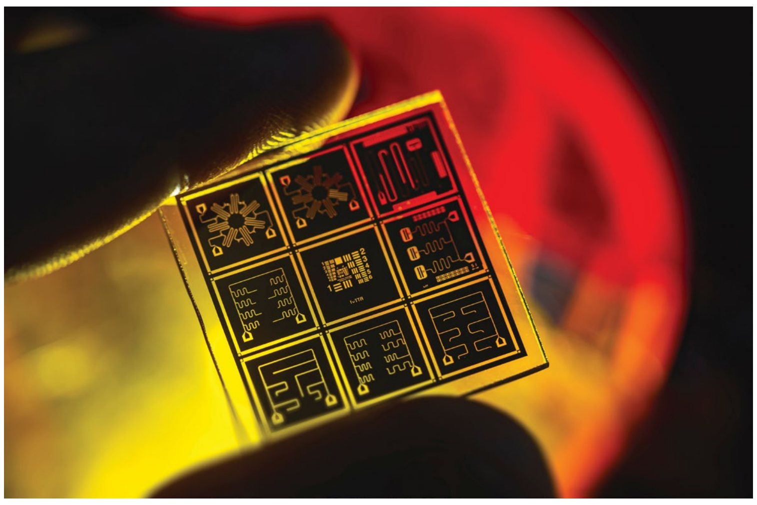
Wentzcovitch hopes that renewed connections in Rwanda will bolster the international partnerships borne out of USAfrI, while fostering new ones. Meanwhile, Martin reflects on the decades of partnerships — and friendships — that led to the Innovation Fund project.

“It's the most rewarding thing I've ever done,” he says.

Liz Boatman is a staff writer for APS News.

New Budget Caps Dampen Outlook for Science Spending Surge

BY MITCH AMBROSE



A quantum chip in a University of Maryland lab — research with funding from the National Science Foundation. Credit: University of Maryland

As a result of new spending caps set by Congress, science agencies will likely struggle to secure significant budget increases for the next two fiscal years.

To resolve a standoff over raising the federal debt limit, President Biden signed legislation in June that will hold discretionary spending on non-defense programs roughly flat for fiscal year 2024, which begins on Oct. 1. This cap will rise by about 1% for the year after, well below the current rate of inflation.

Since most science agencies are funded from the non-defense budget, any increases they receive will largely have to be offset by cutting other programs. Even defense research agencies may be constrained: The legislation only allows for a 3% overall increase to the defense budget for the upcoming year and a 1% increase the year after.

The caps mean that Congress will almost certainly undershoot the targets it set for science budgets last year through the CHIPS and Science Act. The act recommends Congress roughly double the budgets of the National Science Foundation and the National Institute of Standards and Technology over five years, and increase the budget for the Department of Energy's Office of Science roughly 50%. Instead, the House is proposing to hold the DOE Office of Science budget flat at $8.1 billion for fiscal year 2024.

Some lawmakers from both parties have criticized the spending caps, vowing to push for extra spending. Senate Majority Leader Chuck Schumer (D-NY) noted that the caps do not prevent Congress from approving supplementary or emergency funding for "issues of national importance."

But House Speaker Kevin McCarthy (R-CA) has said he won't support measures designed to circumvent the caps. McCarthy was a key architect of the caps, seeking to fulfill House Republicans' pledge to constrain federal spending. House Republicans have also taken aim at spending legislation approved by the previous Congress, seeking, for instance, to rescind parts of the energy technology development initiatives launched by the Inflation Reduction Act and the Infrastructure Investment and Jobs Act — though the Democrat-controlled Senate is unlikely to agree to unwind these acts.

Congress probably won't be able to finalize agencies' budgets before the next fiscal year begins on Oct. 1, a deadline it almost always misses. However, a new dynamic is at play this year: The spending cap legislation includes a provision that will automatically cut both defense and non-defense budgets by 1% if Congress does not reach an agreement by Jan. 1, 2024. This may motivate Congress to negotiate quickly, but it could also inspire representatives who want to decrease federal spending to try to scuttle any agreement, triggering the automatic cuts.

Mitch Ambrose is Director of FYI, a trusted source of science policy news published by the American Institute of Physics since 1989. Sign up for emails at aip.org/fyi.

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densed matter physicists can offer understanding of the properties of quantum matter, while atomic, molecular, and optical physicists have techniques to control and manipulate quantum matter. Oberthaler is working to bring in more cosmologists and astrophysicists, who can help identify the simulations that are most relevant to studying the universe.

These simulations also expand theorists' horizons. "It requires us to import mathematics that's been never really been used before in physics," says Maciejko. "Usually, when we run out of mathematical language to describe the physics, that means we've touched upon something fundamentally new that causes us to broaden our language." For his work, that math is algebraic geometry.

These are simplified models that may or may not reflect our actual universe. But Maciejko thinks understanding them could spark a deeper intuition about some of physics' most arcane questions. "Einstein discovered relativity by thinking about clocks on trains, which are not things we're actually really interested in," he says. He hopes that these quantum simulations might inspire fundamental breakthroughs in a similar way.

Sophia Chen is a writer based in Columbus, Ohio.

Enrollment continued from page 1

gineering departments and colleges, engineering physics programs are most commonly housed in physics departments. In general, they offer a similarly strong curriculum in the fundamentals, but with deeper theory content and a more scientific approach.

When Beloit's physics department was first mulling over the idea of developing an engineering physics program, the department's longstanding "3-2" dual-degree engineering program — where students spend three years at Beloit and two years at a partner engineering school, eventually earning two degrees — was growing in popularity, although it wasn't ideal for everyone, Scharringhausen says.

"So the thought was, could we make Beloit even more attractive to students who have an engineering interest, if there's an option where they can stay here the whole four years?" she says. Athletes could play for Beloit longer; students could avoid the extra year of tuition.

The key was finding a way to introduce engineering-specific courses to support the new major, while keeping upfront costs low — and that meant making use of existing resources and not bringing in new faculty. With a makerspace on campus, the college had already invested in several design and build capabilities, like CAD software and 3D printers, says Scharringhausen.

For the physics faculty, the hardest part was managing the added teaching load. To meet the challenge, the program coupled half-size engineering courses with existing physics courses, says Scharringhausen. "We pair classical mechanics with a statics course, and we pair electricity and magnetism with an advanced circuits course." In the engineering add-on courses, students do a hands-on design and build project.

The department also lets physics majors use engineering courses to fulfill in-major electives, which helps boost enrollment in the new courses and balance out teaching loads for the department's three faculty. Using this approach, Scharringhausen said the department didn't have to make much of an appeal to Beloit's administration.

The engineering physics major rolled out two years ago. So far, so good, she says: While enrollment is down college-wide, the numbers in physics have held steady. "We've been getting a lot of interest," says Scharringhausen. "I think students like the idea of having another option."

At the University of Maine, engineering physics is also a popular choice in the department of physics and astronomy, says recent department chair John Thompson. Launched in 1938, UMaine's engineering physics program was one of the first in the country.

"Engineering physics is a very versatile degree," says Thompson.

Unlike Beloit, the University of Maine also has engineering programs, housed in a separate college. UMaine's engineering physics students take a set of physics courses with physics majors, and then they select an engineering concentration — a partially prescribed set of courses taken through the engineering college.

Thompson says that collaborating with engineering faculty has been good for the department. "Because we teach the introductory physics courses that are gateway courses for the engineering students, we have a good relationship with the engineering college," he says.

And even though some would-be engineering students might ultimately choose engineering physics, Thompson says the numbers are small, so there hasn't been "tension" with the engineering college.

UMaine's engineering physics program has ABET accreditation, a necessity for their graduates to be considered true 'engineers,' professionally speaking.

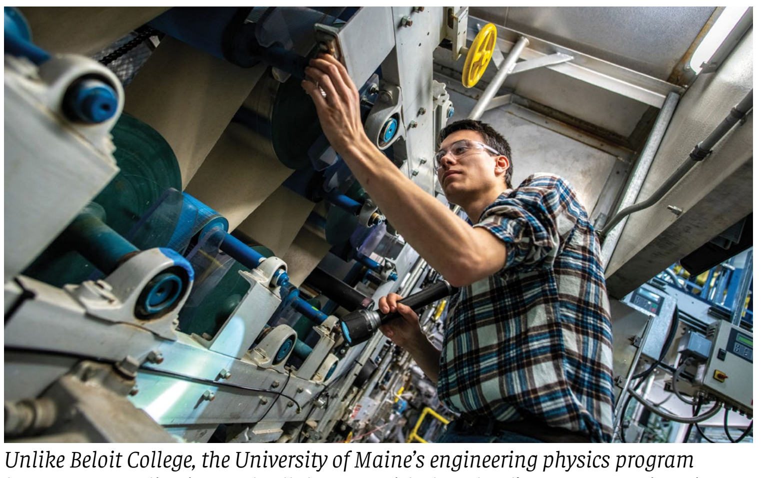
Thompson says that maintaining ABET accreditation for the engineering physics program "gives us some guidelines for what we [the faculty] need to be doing," he says. "The accreditation process is there to make sure that your program is continuously improving, that you're paying attention to what students want and what the engineering profession needs."

But not all engineering physics programs are designed to yield 'engineers,' so not all schools pursue ABET accreditation, which can be costly and time-consuming. Beloit, like many other small schools, has no intention of pursuing ABET accreditation for its new engineering physics program, says Scharringhausen.

Plus, Thompson adds, prospective students who come to UMaine for its engineering physics program don't necessarily choose it because it's accredited. "I think they're just excited about what our programs offer," says Thompson. So, while accreditation bolsters their program, he doesn't think it's a must-have for all new programs.

And both schools have looked beyond engineering physics to improve department culture. Several years ago, as growing numbers of first-generation college students were enrolling in UMaine's physics department, the faculty felt compelled to adapt. "That's one of the things that the university overall and our department is trying to pay attention to — how to get these students acclimated to college life," Thompson says.

To make its early curriculum shine, the department studied other schools for inspiration. Following the University of Colorado's lead, and starting with support from an NSF Math-Science Partnership award, the physics and astronomy department now uses undergraduate 'learning assistants' in two introductory and three sophomore-level courses. In lectures, they "go up and down the aisles and help students think about the questions, help guide them," says Thompson. "The students also learn that [the learning assistants] are people they can go to for help outside of class. And I think it builds community in the department."



Unlike Beloit College, the University of Maine's engineering physics program has ABET accreditation and collaborates with the school's separate engineering college. Credit: University of Maine

Still, the pandemic impacted both student retention and enrollment, especially in the physics and engineering majors, says Thompson. And last year, the state made community college free for everyone. These factors have lowered the size of recent incoming classes, he says.

Thompson is hopeful that, in a few years, as students begin to move through the community college programs, enrollment will climb back up — from about 70 undergraduates now to roughly 100, where it used to be.

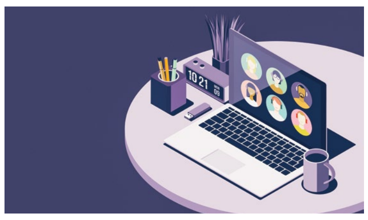
At Beloit, Scharringhausen is seeking to build stronger ties with local industry partners, to help students see more connections between the department's programs and eventual careers. She hopes this will help keep the department's program numbers strong, even in the face of the 'enrollment cliff' projected to hit colleges in 2025.

"My philosophy is, the world needs all different kinds of engineers," says Scharringhausen. "We need engineers that have had different educational paths, because then they bring to a company or a project different skills and strengths and knowledge."

Liz Boatman is a staff writer for APS News.

To future-proof your physics department, visit the APS EP3 guide at ep3guide.org.

APS Satellite Sites Increased Virtual March Meeting Attendance by Nearly 20%



During the virtual 2023 March Meeting, attendance by international scientists increased by nearly 20% — 250 people — compared to last year, a result of growing attendance at the meeting's satellite sites.

The satellite sites program, piloted in 2022, allows physicists around the world to gather at a local institute or university to participate in the virtual March Meeting. Attendees can access online meeting content while enjoying elements of an in-person conference, such as networking and presenting scientific talks and posters.

In 2022, APS sponsored four satellite sites in South Africa, Rwanda, and India (Bangalore and Mumbai). Those sites engaged hundreds of physicists in virtual "watch sessions," group discussions, and — in Bangalore — a five-day, in-person event.

This year, in addition to the 2022 sites in Rwanda and South Africa, satellite events were held at the South American Institute for Fundamental Research (SAIFR) in São Paulo, Brazil, and the SESAME facility outside of Amman, Jordan.

Foote continued from page 2

butions gathered dust, the well-connected and highly educated Tyndall measured the gases' absorption of heat with a spectrophotometer and publicized his results. Did he know about Foote's work, or even plagiarize it? Historians are at odds. Tyndall was on the editorial board of the *Philosophical Magazine*, which republished the paper by Elisha Foote that was printed alongside Eunice's, and Tyndall was known to believe women were less intellectually capable than men. Still, others argue that Tyndall set up his experiments in a manner totally independent of Foote's results, and there's no record of Tyndall mentioning either Foote in any records or correspondence.

Modern experts do agree, however, that Foote's experiment only measured warming from visible radiation and not infrared radiation, which we now know emanates from Earth to cause the greenhouse effect. Tyndall's more state-of-the-art experiments did.

In 2011, retired petroleum geologist Ray Sorenson, an avid collector of historical science books, happened across the summary of Foote's work in *The Annual of Scientific Discovery*. He published a paper noting her role as a climate pioneer, kicking off a cascade of appreciations. A retrospective obituary published in 2020 in *The New York Times* called her experiment "ingenious."

Reed had recognized this innovation decades earlier. "The work she did publish reveals her interest in scientific problems of large dimensions ... [and] shows that she had the attributes of a good research scientist," she wrote of Foote. "Whatever the reasons, her abandonment of scientific investigation resulted in a real loss to science of a gifted research mind."

Tess Joosse is a science journalist based in Madison, Wisconsin.

Hartle continued from page 2

wide-ranging interests," says Gary Horowitz, a theoretician at UCSB and a former postdoc of Hartle. "People often referred to him as 'a man with no boundaries.'"

The description also alluded to Hartle's collaboration with Hawking on the no-boundary wave function of the universe. "Jim used to say that physics had always been divided between the laws of motion and the initial conditions," Horowitz says. "Why couldn't they be the same?" In 1983, Hawking and Hartle proposed an alluring possibility: The wave function can describe a particle's complete quantum history — could it also describe the quantum history of the whole universe from the beginning?

Hartle and Murray Gell-Mann, longtime friends and colleagues, at the Sante Fe Institute in 2011. Credit: Copyright 2023 www.insightfoto.com

Conventionally, this was impossible. The truth of the universe's beginning was supposed to be hidden behind an incalculably dense singularity. Hartle and Hawking found a workaround: A 'no-boundary' universe that began without a singularity had a wave function that could be solved.

Hawking and Hartle proposed an alluring possibility: The wave function can describe a particle's complete quantum history — could it also describe the quantum history of the whole universe from the beginning?

It was a heady idea with disconcerting implications, including the breakdown of time at the beginning. Many did not agree with their conclusions. Gell-Mann frequently ribbed Hartle, asking why he wasn't rich if he knew the wave function of the universe. But the idea's ambition was influential. "People understood that it made sense to think about the universe as a closed system, with just quantum mechanics," Craig says.

Over the next few decades, Hartle continued his work on interpretations of quantum mechanics with Gell-Mann, often together at the Santa Fe Institute. At the time foundational questions about quantum mechanics were unpopular. "Jim was patient enough and farsighted enough to say, 'We really have to understand quantum mechanics at a very deep level,'" says Sean Carroll, a theorist at Johns Hopkins University.

At 65, Hartle retired — so that he could focus on doing more physics. In a 2015 essay, "The Observer Strikes Back," Hartle and Hertog grappled with the tricky detail that observers are more likely to exist in some universes than others. Hartle's work was welcomed by many philosophers. "Jim's work is a rich vein to mine for how to think correctly about these ideas," says Jenann Ismael, a philosopher of physics also at JHU.

Hartle also distilled his approach in an idiosyncratic textbook, *Gravity: An Introduction to Einstein's General Relativity*, in which he eschewed the typical math-first formula to focus on physical intuitions about nature. "He gave these absolutely beautiful lectures," Craig says. "His chalkboards would be works of art; his explanations would be crystal clear."

A fan of the arts, Hartle enjoyed the philosophically tinged works of Borges, Gogol, and Kafka. He also traveled widely, to Myanmar, Bhutan, and even Antarctica, twice. When, in early 2022, Hartle was diagnosed with Alzheimer's, he went to work memorializing his colleagues in a series of recollections.

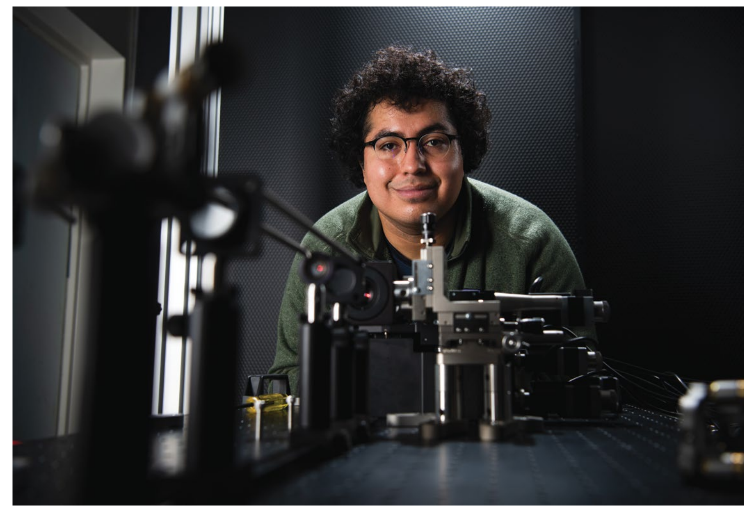
Colleagues remembered Hartle for his gentle demeanor. "It was just amazing just how kind and thoughtful he was," Horowitz says. When dealing with big egos and prickly tempers, "somehow he was very good at not letting it get under his skin," says his wife, Mary Jo. According to Craig, Hartle's attitude helped shape the culture of the general relativity community. "People would really ask constructive questions at conferences and approach each other with respect," Craig says. "I think that's part of Jim's legacy."

Hartle was legendary for amusing dinner toasts. In one video shared on Twitter, he delighted an audience by paraphrasing Mark Twain. "The road to good health consists of eating what you don't want, drinking what you don't like, and doing what you don't like," Hartle said, wielding his wine glass like a conductor's baton. "I have to tell you that this evening, we are not on the road to good health." Cue laughter.

Daniel Garisto is a writer based in New York.

APS Industry Mentorship Program Bolsters the Career of an Aspiring Quantum Scientist

BY TAWANDA W. JOHNSON



Enrique Segura Carrillo

In 2018, Enrique Segura Carrillo knew he wanted a physics career in industry — but he needed help getting there.

"I needed a mentor who . . . understood how the marketplace works — how to convert research experiences in the labs to a resume that is attractive to industry," said Segura Carrillo, a graduate student in physics at the University of Colorado, Boulder, who also conducts research at Los Alamos National Laboratory and JILA.

For support, he turned to APS's Industry Mentoring Program (IMPact). The program, started in 2015, connects students and early-career physicists with industrial physicists. Over three or four months, the industrial physicists advise mentees on resumes, conferences, projects, and more.

The program is the brainchild of Matthew Thompson, vice president of Systems Engineering at Zap Energy, who also previously chaired APS's Committee on Careers and Professional Development and APS's Forum on Industrial and Applied Physics.

Through IMPact, Thompson and Segura Carrillo, who wants to become a quantum computer scientist, connected in 2018.

"He gave me feedback about my personal statement, about how to make the most of my time [during a fellowship] at SLAC National Accelerator Laboratory, and how to approach the next steps of heading to a master's program to prepare for a future PhD application process," recalled Segura Carrillo.

While working toward his master's degree, which he earned in 2021, Segura Carrillo obtained real industry experience at The Aerospace Corporation, where he interned in the company's Physical Sciences Laboratories.

That year, Segura Carrillo connected with John Teufel, group leader at the National Institute of Standards and Technology in Boulder, who helped him apply for his PhD at the University of Colorado, Boulder.

"John took the time to guide me through the process," Segura Carrillo said. "Once I arrived at CU-Boulder, he made sure that we met at least twice a semester. For my qualifying exam, he helped me build a great technical talk."

Teufel said he was excited that Segura Carrillo had been accepted into the program and is slated to graduate in 2026.

"His dream was to work in quantum science, and he knew that dream depended on him being accepted to a good PhD program," said Teufel. "It's always rewarding to see things work out for those who put their blood, sweat, and tears into making it happen."

Teufel and Segura Carrillo said their experience has been a good one, and both offered tips for mentor/mentee relationships.

"I would recommend coming in with a clear picture of who your mentor is," said Segura Carrillo. "I wanted a career in industrial physics, and specifically in quantum information sciences, so I needed my mentor to be somewhere on that spectrum."

Teufel added that mentorship shouldn't be one-sided. "In my experience, mentoring is not about one person answering questions for the other," he said. "Instead, it is a platform where questions can be discussed, and progress can be made together."

Tawanda W. Johnson is the Senior Public Relations Manager at APS.

To support APS's efforts to help students and early-career scientists build rewarding careers, consider donating at aps.org/about/support.

THE BACK PAGE

The World is Coming for US Science Talent

Science's best and brightest must jump through hoops to study and work in the United States. Without common-sense immigration reform, they will look elsewhere — and the US will lose out.

BY MOUMITA DAS

A few decades ago, I was a quiet girl from West Bengal, India. Even before I knew what physics was, I marveled at the thread it stitched through the natural world — an insect that could walk on water; a rainbow that shimmered on the surface of an oily puddle.

Today, I am a theoretical physicist in Rochester, New York, and my specialty is cells and tissues. My team has bolstered scientists' understanding of the cytoskeleton, the scaffolding that holds cells together, and the cartilage that cushions joints. This research, which has received millions of dollars in funding from the US government and private foundations, could shape the development of new materials — imagine a prosthetic limb that heals its own wounds.

But here's the thing: I'm far from unique. For decades, STEM immigrants in the US like me have built great businesses, invented new technologies, and conducted crucial research. In 2019, immigrants made up 19% of the total STEM workforce, including 45% of workers with PhDs. Immigrants founded more than half of the US's privately-held billion-dollar startups. They represent an outsized proportion of Nobel Prize winners in science: Of Americans who won the prize in physics, chemistry, or medicine between 1901 and 2022, more than 1 in 3 were immigrants.

My own subfield has many brilliant immigrants. M. Cristina Marchetti, an Italian-born physicist at the University of California, Santa Barbara, has uncovered secrets of active matter — groups of self-propelled particles, like cells in a colony or birds in a flock — and has mentored countless scientists, including me. Manu Prakash, an Indian-born bioengineer at Stanford, has gone far beyond his work on cells to create easy-to-build tools, including a $1 paper microscope, that has made science accessible to people around the world.

Like Drs. Marchetti and Prakash, many international scientists in the US graduated from American institutions, and many want to stay. The US would be wise to let them. College enrollment is stumbling at US universities, even as the need for STEM workers is projected to grow more than twice as fast as the need for non-STEM workers.

The success of many immigrants in science obscures the difficult paths we took to get here. In theory, the path goes like this: Foreign students attend US universities on student visas. If their employers sponsor them after they graduate, they can become temporary residents, then permanent residents (with a coveted green card), and then, if all goes well, citizens.

In reality, America's immigration bureaucracy is a thorny tangle. According to an APS survey of international members, nearly 3 in 4 respondents reported challenges getting a visa. Delays were the biggest obstacle, with 1 in 4 respondents reporting waits between two months and a year.

That's been my experience. In my early 30s, while I was a postdoc in the US, I was offered a job at Rochester Institute of Technology, but my visa stipulated I had to return to India for two years before I could take the job. To avoid this, I needed a waiver that required written permission from three levels of government in India. Faced with unreachable contacts and a bureaucratic nightmare, I was forced to delay my start at RIT by a year.

Some visas have created more nightmarish scenarios. For example, students from some countries can obtain only single-entry visas. If they leave the US, they have no guarantee they'll be able to return — like my mentee from Myanmar, who has not seen her family in five years.

Other rules make no sense. For example, to apply for F-1 study visas, students must prove they intend to leave the US after school. This begs two questions: Why must students pretend they don't dream of staying and working here, and why must the US pretend it doesn't need them?

But perhaps the greatest challenges are faced by temporary residents, whose visas usually depend on their jobs. At universities, a gap in funding — a constant in cash-strapped academia — can force a postdoc out of the country. A layoff during a recession can upend a scientist's life. Some scientists even endure exploitative workplaces or unfulfilling roles, too afraid to risk their visas as they wait for permanent residency.

And the wait for permanent residency, depending on where a scientist originates, may be long — especially for immigrants from the Global South. The US caps the number of green cards it gives to applicants from any one country, a problem for people from populous nations like India, which send enormous numbers of scientists to the US. The cap has created a huge backlog: Many Indians must wait years or even decades to become permanent residents — including one of my brilliant colleagues, who won a prestigious CAREER Award from the National Science Foundation, but who expects to wait years for her green card.

What happens when labyrinthine rules make the US less attractive to STEM immigrants? These folks search elsewhere, and many countries look enticing. The United Kingdom, Australia, and Canada are projected to attract growing numbers of international students. These and other countries, like Japan and Germany, are changing their laws to make it easier for skilled immigrants to study and stay. Consider a Canadian program announced in June: Some temporary residents in the US will be eligible to come to Canada on open work visas. That's serious.

My colleagues and I have witnessed this trend ourselves. For example, a highly qualified Iranian student recently turned down a spot in my colleague's research group, heading instead to the UK. I'm not surprised: Nearly 90% of international students say they want to pursue degrees in countries where they can stay and work after school, according to an APS survey.

Meanwhile, some graduates return to their home countries, including China. It makes no sense that we educate students, only to send them and their newfound knowledge away — sometimes into the waiting arms of the US's technological competitors.

For now, the US remains a magnet for the world's brightest scientific minds. But as innovation accelerates and countries jostle for technological dominance, the US must not be complacent.

These issues are complicated, but the solutions don't have to be. For one, the US ought to stop making students feign disinterest in staying. Let them declare their intent to study and pursue a career in the US after graduation. Also, the US should exempt from green card caps those immigrants with advanced STEM degrees from US schools and good job offers. And the nation must give international STEM students and scientists an easier path to permanent residency, without hopscotching endlessly between temporary visas.

Some laws, if passed, would accomplish this. For example, the Keep STEM Talent Act, originally introduced in Congress a few years ago with APS's help, would exempt STEM PhD-earners with US job offers from green card caps. APS is still working to build support for this bill (and you can take action to support it, too).

For the US to maintain its global standing in science and technology, we need more of everything — more investment in STEM education in the US, more funding for American research, and more STEM workers, including immigrants. After all, international scientists *want* to work in the United States. They want to build new businesses, invent transformative technologies, and solve great scientific mysteries, right here in American labs, companies, and schools.

For the nation's sake, let's make it easier for them to get here — and easier to stay.

Moumita Das is a professor of physics at the Rochester Institute of Technology, where she studies soft matter and biological physics.

To learn about APS's advocacy efforts on immigration and more, or to take action, visit aps.org/policy.

Octopus Research continued from page 1

Meshulam contacted Reiter to begin collaborating three years ago, after she read a paper of his on camouflage in cuttlefish. "I looked at this paper and thought, 'This is the best,'" she says. "I like emergent phenomena. In an octopus, 100,000 chromatophores collectively coordinate to give rise to macroscopic behavior."

Collaborations between physicists and life scientists have become increasingly common, as has research in biological physics, which stretches from the mechanics of DNA to the study of animal behavior. In 2022, the National Academies released the first-ever decadal survey of biological physics, a signal of the field's maturity. In March 2023, APS launched *PRX Life*, the first interdisciplinary journal focused exclusively on quantitative biological research. Writing in *APS News* in April, William Bialek of Princeton University argues that core physics curricula should incorporate more biological concepts. "Physics reaches far beyond the world of inclined planes, isolated atoms, and ideal gases, to life itself," writes Bialek, a pioneer of the field.

Physicists bring a new angle to biology research, says Reiter. "I find physicists' emphasis on general principles refreshing," he says. "Biologists put a lot of emphasis on the nitty-gritty details."

By contrast, physicists tend to look at how a behavior might occur across many organisms, an approach Meshulam describes with an analogy. A tornado is different from a whirlpool that forms as a bathtub drains — the former is gas and dust, the latter water — but the Navier-Stokes equation describes both. Similarly, Meshulam searches for principles that apply to different organisms, regardless of their biological mechanisms.

But physicists can have their own biases. "They love power laws," Reiter says, referring to a physicist's propensity to search for specific mathematical relationships in organisms. "From my perspective, sometimes it's useful, and sometimes it's not."

It can be challenging to communicate with biologists, "but you learn so much," says Meshulam. She's found, for example, that biologists and physicists may use different terminology to describe similar concepts. Physicists predict the likelihood of a specific electron spin state using the concept of an "effective field," which describes the forces that act on the particle in a crystal. Meshulam found the same concept in biology, called "conditional probability," which describes the likelihood of an outcome based on previous events. She has used this to predict a neuron's state from the activity of those around it. Finding related ideas has helped her focus on the "essence" rather than the "lingo" of science, she says.

These collaborations are changing what qualifies as fundamental science in physics. "We need new math and physics to understand how biology works," she says. Living systems inhabit a distinct regime, beyond the frameworks of particle and condensed matter physics. Quantum mechanical activity, as in photosynthesis, directly affects macroscopic activity, such as a flower blooming.

"The exciting and terrifying thing about this field is that we don't even know the right questions to ask," says Meshulam. "We need to figure out not just how to calculate something, but what we should calculate." It's a fruitful time to join the field.

Sophia Chen is a writer based in Columbus, Ohio.