APS News

A Publication of the American Physical Society | aps.org/apsnews | December 2022 | Volume 31 | Number 11

Sixty Years After, Physicists Model Electromagnetic Pulse of a Once-Secret Nuclear Test

At an APS meeting on plasma physics, physicists presented simulations of Starfish Prime, a high-altitude nuclear test in 1962.

BY LIZ BOATMAN

Left: Starfish Prime lit up the night sky over Hawaii, nearly 900 miles away. Center and right: After the blast, a nuclear "aurora" formed, caused by beta particles, emitted by radioactive materials, moving along Earth's magnetic field. Credit: U.S. Government/Public domain (July 9, 1962)

On the night of July 9, 1962, a brilliant flash lit the sky above Hawaii. Lights on some streets went dark, and inter-island communications from Kauai were severed. A red, aurora-like glow haunted the southwesterly skyline for hours.

The flash marked the detonation of a thermonuclear warhead 250 miles above Earth's surface, in the ionosphere, the outermost portion of Earth's atmosphere where several thousand satellites orbit today. The nuclear explosion that set the sky aglow that night was a classified U.S. government experiment known as Starfish Prime.

It wasn't until 2006 that key data from the experiment was declassified. Since then, scientists have developed computer models that simulate the effects of high-altitude nuclear explosions, in part to better inform U.S. defense and readiness. This October, at the 2022 APS Division of Plasma Physics' meeting in Spokane, Washington, a team of computational physicists from Law-

Starfish continued on page 5

Undergrads Awarded for Work on Slime Mold and Black Holes

The 2022 Apker Award has gone to students in biophysics and astrophysics.

BY LIZ BOATMAN

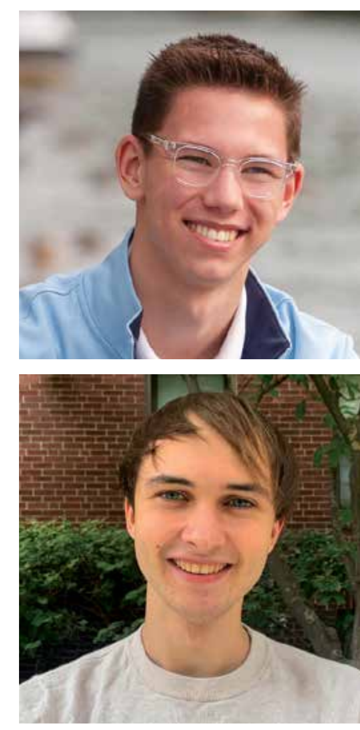
Each year, the American Physical Society recognizes undergraduate achievements in physics with the LeRoy Apker Award. This year's recipients are Matthew Cufari, a senior at Syracuse University, and Adam Dionne, now in his first year of a doctoral program at Harvard University, for work he completed as a student at Williams College.

Dionne investigated nutrient transport in slime mold, while Cufari built a model to explain the origin of a periodic burst of light emitted from a distant galaxy.

Dionne spent many hours in the lab, bent over Petri dishes as he cultured his organism, Physarum polycephalum — feeding it oat flakes, slime mold's favorite meal. He observed spatial patterns in nutrient distribution in the slime mold, which he then modeled using principles of network theory.

"Physarum can do things like

Apker continued on page 5



Matthew Cufari (top) and Adam Dionne, recipients of the Apker Award.

Physicist in Brazil Translates Physics Lessons into Portuguese and Spanish for High Schoolers

With support from the APS Innovation Fund, Nathan Berkovits' team in São Paulo hopes to train teachers across Latin America.

BY LIZ BOATMAN

Facilitators work with Brazilian high school teachers in a Perimeter Institute physics training in June 2022. Here, the teachers, acting as students, build a physical model of a black box. Credit: Nathan Berkovits

In 1994, physicist Nathan Berkovits, a Massachusetts native with a doctorate from the University of California, Berkeley, packed up his life in the U.S. and moved to São Paulo, Brazil. Now, nearly three decades later, and with the support of the APS Innovation Fund, he's tackled a new challenge: sharing physics with Spanish- and Portuguese-speaking high schoolers.

Before the move, Berkovits had visited the region with his first wife, a Brazilian physicist studying in the U.S., and grown fond of the country's

Brazil continued on page 3

Physicists Can Help Combat Global Threat of Nuclear Weapons, Say Experts at Nuclear Physics Meeting

Plenary speakers at an APS meeting on nuclear physics discussed the past, present, and future of nuclear weapons.

BY SOPHIA CHEN

Alan Robock tells one story often. Addressing a virtual audience over Zoom, he repeated it — ostensibly a success story of politicians listening to scientists — at the Fall 2022 Meeting of the APS Division of Nuclear Physics.

As the story goes, Robock was part of a group of U.S. and Soviet scientists in the 1980s who predicted the consequences of nuclear war using scientific models. The work introduced the public to the concept of nuclear winter. If countries were to use nuclear weapons again in war, the models predicted, the weapons would not only directly kill millions, but also cause firestorms whose smoke would block sunlight. The resulting climate change would trigger famine and death around the world.

Politicians responded to these sobering predictions, as well as broader geopolitical shifts. "The arms race ended," said Robock, a climatologist now at Rutgers University. President Ronald Reagan and Soviet leader Mikhail Gorbachev cited the research as a motivator for the shift. The number of nuclear weapons peaked in 1986, with about 65,000 worldwide. In 2022, nine countries possess 12,720, according to Nagasaki University's Research Center for Nuclear Weapons Abolition.

In a U.S. test in Sept. 2019, an unarmed ballistic missile called Trident II D5 is launched from the submarine USS Nebraska off the coast of San Diego. Credit: U.S. Navy photo/Released (Flickr)

But a worrisome new chapter has begun. Since Russia invaded Ukraine in February 2022, President Vladimir Putin has made veiled statements — for example, that Russia has "more modern [weapons] than the weapons NATO countries have" — that the U.S. government has interpreted as threats to deploy nuclear weapons.

Physicists have an important role to play in technology development and policymaking related to nuclear weapons, expressed Robock, along with three other speakers during the meeting's plenary sessions on nuclear threat and mitigation. Robock encouraged meeting attendees to join the Physicists Coalition for Nuclear Threat Reduction. This group, formed in 2020 with a grant through the APS Innovation Fund, advocates for government policies that reduce nuclear threats.

And nuclear physics research can help promote nonproliferation, as Bethany Goldblum of Lawrence Berkeley National Laboratory dis-

Nuclear weapons continued on page 2

This APS News issue is a bit shorter than previous ones. Our efforts to make APS News sleeker and smarter continue. Want more stories, including some not featured in print? Visit aps.org/apsnews.

Nuclear weapons continued from page 1

cussed in her talk. For example, some researchers are investigating the use of antineutrinos to monitor nuclear material. As radioactive material like uranium undergoes fission, it releases antineutrinos, which can signal how much material is inside a reactor. If a bad actor removed this material from a nuclear reactor, an antineutrino detector could flag it.

Still, the world faces grave nuclear risks, Robock explained. Stockpiles are so large that, if a Hiroshima-sized bomb had dropped every two hours from the end of World War II until today, it would still not have used up today's global arsenal, he said.

Nuclear security expert Steve Fetter of the University of Maryland, who co-founded the Physicists Coalition, gave an overview of the state of nuclear weapons in the world. He focused mainly on the U.S. and Russia, which together control more than 90 percent of the world's stockpile. Both countries have weapons for three different types of deployment — intercontinental ballistic missiles (ICBMs), launched via rockets, some of which can reach anywhere on the planet; submarine-launched ballistic missiles, which can launch nuclear weapons with similar range from underwater; and bombers, or airplanes that can carry and deploy nuclear weapons. Russia's strategy relies on more intercontinental ballistic missiles, whereas the U.S. relies on more submarine-based ones. Both countries have around 1,000 nuclear weapons that can be launched within minutes, said Fetter.

[Nuclear] stockpiles are so large that, if a Hiroshima-sized bomb had dropped every two hours from the end of World War II until today, it would still not have used up today's global arsenal, Robock said.

Fetter also discussed developments in nuclear weaponry. The U.S. government plans to spend $1.3 trillion to replace and upgrade its arsenal starting in 2030. "Even by the standards of the U.S. Department of Defense, this is a lot of money," he said.

Russia has invested in new nuclear weapon technology, too. In 2018, Putin announced a new ICBM called Sarmat with a range of 18,000 kilometers. Sarmat "could be launched to attack the United States from the South Pole to avoid U.S. missile defenses," said Fetter.

Russia is also developing a missile called Burevestnik that not only carries a nuclear weapon but runs on nuclear power. "Just saying the words 'flying nuclear reactor' probably conveys why this is not the best idea," Fetter said about the system, which cannot carry radiation shielding. In 2019, Russia's nuclear energy agency reported a radiation accident that some experts believe was caused by a test of this missile's prototype. Seven people were killed.

Robock presented contemporary versions of his nuclear winter models. Working with climate, ocean, and crop modelers, Robock's team predicted the consequences of a nuclear war involving the U.S., NATO, and Russia, as well as one between India and Pakistan, two countries with smaller nuclear capabilities.

From a scientific standpoint, these models have unique constraints: not a lot of data exists to validate their accuracy. In addition to using information from the Hiroshima and Nagasaki nuclear bombings of World War II, researchers also look to climate events with potential analogs — for example, wildfires in Australia and Canada in the last decade.

In their study, published in *Nature Food*, Robock and his colleagues found that a war between India and Pakistan could kill more than 2 billion people, and a U.S. and NATO war against Russia could kill over 5 billion. They also found that about 20 times more people would die from starvation than directly from nuclear war. (Some researchers who have modeled possible scenarios have predicted far less severe global impacts.)

"So what do you do with this information?" Robock asked. "The most natural reaction is to try to forget it. As Mark Twain said, 'Denial ain't just a river in Egypt.'"

But he also sought to give listeners a sense of agency. "My reaction is to try and do something about it," said Robock. In 2017, the United Nations passed a treaty to ban nuclear weapons, and 68 countries have ratified it, although the U.S. and Russia have not. He quoted Beatrice Fihn, whose organization, the International Campaign to Abolish Nuclear Weapons, won the Nobel Peace Prize in 2017: "The story of nuclear weapons will have an ending, and it is up to us what that ending will be."

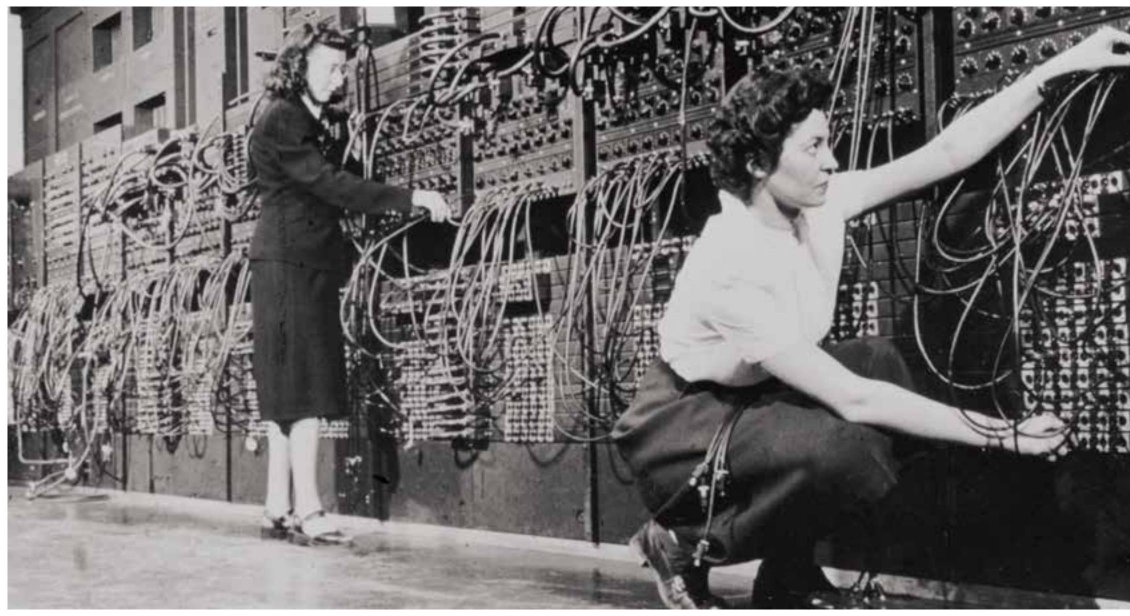
Sophia Chen is a writer based in Columbus, Ohio.

THIS MONTH IN PHYSICS HISTORY

December 1945: The ENIAC Computer Runs its First, Top-Secret Program

Six young women programmed the world's first modern electronic computer.

BY TESS JOOSSE



Marlyn Wescoff (left) and Ruth Lichterman were two of the ENIAC's first programmers. Credit: U.S. National Archives Education Updates

In December 1945, a secret sat behind a heavy door at the University of Pennsylvania's Moore School of Electrical Engineering. Eighty feet long, made of hulking black metal, and weighing 30 tons, "it was just a monstrous thing," recalled Betty Snyder Holberton a half century later. She and five other young mathematicians, Kathleen McNulty (later Mauchly Antonelli), Jean Jennings (Bartik), Marlyn Wescoff (Meltzer), Frances Bilas (Spence), and Ruth Lichterman (Teitelbaum), were the secret's keepers, tasked with figuring out how it ticked and putting it to use.

That secret was the Electronic Numerical Integrator and Computer, or ENIAC, the world's first programmable modern computer. Financed by the United States Army, designed by physicist John Mauchly and engineer J. Presper Eckert, and programmed by the six women, the ENIAC was first put to work on December 10, 1945, solving a math problem from the Army's Los Alamos Laboratory. The program likely involved ignition calculations for the hydrogen bomb, but remains classified to this day.

However, the computer's existence wasn't hidden for long. The ENIAC was unveiled to the public on February 15, 1946, in a splashy demonstration held at the Moore School. "Electronic Computer Figures Like a Flash," read a headline in *The New York Times*. The program the ENIAC ran in two hours, ballistic trajectory calculations, "would have kept busy 100 trained men for a whole year," the article declared.

In reality, the calculations would have been the purview of 100 trained women. And the six who programmed the ENIAC weren't mentioned in the press, nor at the demonstration. "No attendee congratulated the women. Because no guest knew what they had done. In the midst of the announcements and the introductions of Army officers, Moore School deans, and ENIAC inventors, the Programmers had been left out," writes Kathy Kleiman in *Proving Ground: The Untold Story of the Six Women Who Programmed the World's First Modern Computer*. "On probably no other day of my life have I experienced such thrilling highs and such depressing lows," Jennings Bartik later said.

Four years earlier, in 1942, the Army sent out notice that it was looking for women mathematics majors to work at the Moore School. Women had been working as "computers," the term at the time for people who do calculations, since the late 19th century, says Janet Abbate, author of *Recoding Gender: Women's Changing Participation in Computing* and a historian at Virginia Tech. "It was work that required a mathematical education but was a repetitive and dead-end job, so it didn't appeal to educated men," she explains. The new opportunity at the Moore School involved the war effort, and across the U.S., women were following Rosie the Riveter's lead and joining the workforce to help in the fight.

"No attendee congratulated the women. Because no guest knew what they had done. In the midst of the announcements and the introductions of Army officers, Moore School deans, and ENIAC inventors, the Programmers had been left out," writes Kathy Kleiman.

Nearly a hundred women, including the six who would later program the ENIAC, were hired as computers at the school for the Army's Ballistics Research Laboratory.

For a salary of about $1,620 per year ($27,000 today), they calculated ballistics trajectories for artillery used by the military. A gunner on the battlefield needed to know the precise angle to position their weapon based on that day's conditions, but each measurement required a complex differential equation. With pencil, paper, and heavy desktop calculators that were the size of modern microwave ovens, the computers toiled over the problems, inputting possible values for variables like temperature, humidity, wind, and missile weight. "It was really very complicated, and it required an awful lot of calculating," McNulty Mauchly Antonelli said in a 1997 interview included in the documentary "The Computers: The Remarkable Story of the ENIAC Programmers."

But the work was vulnerable to error, and one trajectory took 40 hours to calculate by hand. In 1943, with the war raging overseas, the Army agreed to fund an idea from Mauchly to create an electronic, programmable, digital calculator. He, Eckert, and a team of engineers built the ENIAC using 18,000 vacuum

History continued on page 4

APSNews

Series II, Vol. 31, No. 11
December 2022

APS News is published 11 times per year by the American Physical Society, One Physics Ellipse, College Park, MD 20740-3844, (301) 209-3200. It contains news of the Society's units, events, initiatives, and people; opinions; and related information.

Subscriptions: *APS News* is a membership publication. To become an APS member, visit aps.org/membership/join. For address changes, please email membership@aps.org with your old and new addresses; if possible, include a mailing label from a recent issue. Postmaster: Send changes to the APS mailing address above (please address to "*APS News*, Membership Department").

We welcome letters to the editor. You can reach us by email at letters@aps.org, or by mail at the address above (please address to "Editor, *APS News*"). Include your mailing address (if mailed), and email. If we publish a letter, we may edit for length and clarity.

Coden: ANWSEN ISSN: 1058-8132

Brazil continued from page 1

culture. But he also realized there might be physics opportunities in Brazil that the U.S. lacked. “I like the idea of being at a place where I can do things that weren’t done before,” he says.

Now a full professor at the Instituto de Física Teórica of São Paulo State University, a research institute, he says “the scientific opportunities are almost the same.” He has graduate students and grants from the São Paulo research funding agency, and his salary affords him a comfortable quality of life, he says.

But in diverse São Paulo, the experience for many Brazilians isn’t the same. “The difference between rich and poor is something that you never get used to,” says Berkovits.

These wealth disparities impact schools. This is because students’ socioeconomic backgrounds influence their education outcomes, particularly in Brazil: According to the Organization for Economic Cooperation and Development (OECD), for every 10 socioeconomically advantaged students who score at or above reading proficiency in Brazil, only about 5 disadvantaged students do — a greater disparity than for most OECD countries measured.

Math is no different. “In Brazil and South America,” Berkovits says, “many of the public high school students have difficulty with mathematics,” which can hinder their education in physics. Through the Programme for International Student Assessment (PISA), which measures math, science, and reading abilities of 15-year-olds in 79 countries, the OECD most recently placed Brazil among the lowest performing in math and science. Nearly half of 15-year-olds in Brazil today score below minimum mathematical proficiency for their grade level.

And outreach efforts that “have existed for a hundred years in the U.S. and Europe” — for example, university professors visiting high schools — are rare in Brazil, especially in public schools, which enroll most students, he says.

“In Latin America, there is a huge

> “It’s not hard to get students interested in black holes,” Berkovits added. “But most don’t know the math — they don’t have the background to understand what people are talking about.”

Brazil continued on page 4

APS Letter on Access to Reproductive Health Care

APS leaders address the overturning of Roe v. Wade.

Statue at the Supreme Court.

On Oct. 13, APS leadership published a letter to members on the Supreme Court’s decision in June to overturn the constitutional right to abortion in the United States, a right that had stood for nearly 50 years. Here, the letter is reproduced in full.

The recent U.S. Supreme Court ruling on Dobbs v. Jackson Women’s Health Organization affects the lives of many across the nation, including physics professionals and students, by eliminating the constitutional right to an abortion. About half of U.S. states are expected to or have already enacted bans on abortion or other gestational limits. While respecting that individuals have differing views on abortion, as a scientific organization, we feel compelled to acknowledge the impact that recent changes in access to reproductive health care have on all people, including women in physics. Research shows that access to legalized abortion leads to increases in educational attainment and improvements in employment outcomes. These effects are greater for women of color and women with lower socioeconomic status, as well as students and early-career scientists who may lack the financial resources needed to fulfill parental responsibilities.

As a member-driven society, APS is committed to listening to members about the impact of the Dobbs decision and considering how this should inform the actions of the Society. The APS statement on Protection Against Discrimination declares that “the protection of the rights of all people...will guide the Society in the conduct of its affairs.” Understanding what actions might help begins with hearing from those most affected by the recent changes in access to reproductive health care and involving them in devising practices and policies. We invite APS members to contact the CSWP at women@aps.org to share their experiences, to comment about the impacts of the Dobbs decision on members of the physics community, and to identify opportunities for action. We also encourage members to engage in local or national advocacy in their personal capacity.

This is an important moment to reflect on the APS Statement on the Status of Women in Physics. This statement “urges [APS] members, physics leaders, and policymakers to take action to improve recruitment, retention, and treatment of women in physics at all levels of education and employment.” In the U.S., only about 22% of undergraduate degrees and about 20% of doctoral degrees in physics are awarded to women. At stake are the “health and future achievements of our discipline.”

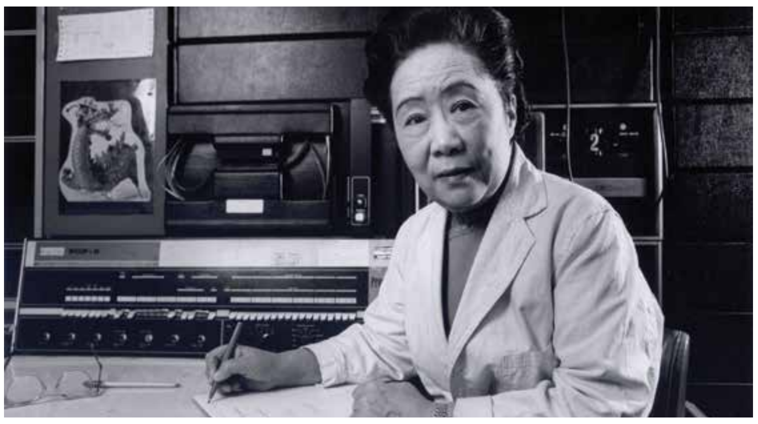
APS has invested substantially in promoting the participation and success of women in physics, through its Conferences for Undergraduate Women in Physics (CUWIP), longstanding Climate Site Visit Program and grants for Women in Physics groups, among other programs and initiatives. Many APS meetings offer Meeting Caregiver Grants and provide access to lactation rooms. APS Governmental Affairs advocates for legislation consistent with our policy statements, most recently in the CHIPS Act, which included language to broaden participation and address sexual harassment.

We stand fully behind the APS statements highlighted in this letter and remain committed to realizing the vision they articulate. We encourage members to become involved in APS initiatives that support women in physics.

For sources and signers, visit go.aps.org/dobbs.

Global Event Honors Trailblazing Nuclear Physicist Chien-Shiung Wu

BY DAVID BARNSTONE



Chien-Shiung Wu *Credit: University Archives, Rare Book & Manuscript Library, Columbia University Libraries*

Chien-Shiung Wu (1912-1997) is widely regarded as one of the most influential scientists of the 20th century, having disproved what was, until the late 1950s, considered a fundamental law of physics — the conservation of parity in weak interactions. Wu’s meticulous experiments verified the theory that earned her male colleagues the 1957 Nobel Prize in Physics.

On Sept. 24, APS and the Chinese Physical Society commemorated the 110th anniversary of her birth at an event organized by Nanjing University Alumni Association of the United States. Among the speakers at the C.S. Wu Global Online Symposium were 2021 APS President Sylvester James “Jim” Gates, Jr. and APS Vice President Young-Kee Kim.

“[Madame Wu] made many contributions to our society which remain critical today,” said Kim. “Her election and achievements as [the first female] president of APS helped to ensure that all physicists, independent of race, nationality, and gender are welcome in our community.” Kim noted that during Wu’s presidential year in 1975, she met with U.S. President Gerald Ford and urged him to establish the Office of Science and Technology Policy.

While Wu is revered today, as her granddaughter Jada Yuan wrote in *The Washington Post* last year, “she had walked unnoticed between her laboratory at Columbia University and the nearby rent-stabilized faculty apartment she shared with my grandfather, who was a particle physicist, and my father, who would become a nuclear physicist.”

“Yet despite her small stature, she was a true giant in physics and was an intellectual powerhouse,” said Kim. “Her scientific pursuits challenged the status quo.”

David Barnstone is APS Head of Integrated Marketing Communications for Research and Publications.

APS Board Executive Committee Endorses Statement on Protests in Iran

On Oct. 13, the APS Board Executive Committee unanimously endorsed the statement, by the Executive Committee of the International Human Rights Network of Academies and Scholarly Societies, on recent protests in Iran. The statement calls upon Iranian authorities “to cease unnecessary use of force in response to popular demonstrations and to ensure the release of students and others who have been arbitrarily detained.” It also urges authorities to “uphold the rights to freedom of expression and assembly in the country and to refrain from further attacks on educational institutions.”

Read the full statement at go.aps.org/IHRN.

Brazil continued from page 3

A university professor gives a lecture on special relativity, using high school-level mathematics, to high school students in São Paulo. Credit: Nathan Berkovits

disparity between public and private schools," Berkovits said in an interview with *APS News* in 2021. "Public schools are way behind."

"It's not hard to get students interested in black holes," he added. "But most don't know the math — they don't have the background to understand what people are talking about."

A few years ago, Berkovits spotted a chance to help. In 2012, the São Paulo-based physics institute that Berkovits now directs, the ICTP South American Institute for Fundamental Research (ICTP-SAIFR), partnered with the influential Perimeter Institute in Canada. The Perimeter Institute, a physics research center, had long invested in programs for high school students. Its physicists worked with teachers to develop an enormous collection of high school-level physics lessons on topics like dark matter and relativity. As a partner institution, ICTP-SAIFR could use these materials.

Berkovits realized that, if the materials could be translated into Portuguese, they could be shared with public high school teachers and students in São Paulo — and perhaps equip more young people from disadvantaged backgrounds to pursue physics. So Berkovits recruited a team of local teachers, including Ana Luiza Serio and Lucas David, to help him launch training workshops for other high school teachers and a Saturday lecture series for high school students.

The effort made an impact, says Berkovits. In Brazil, to be admitted to an undergraduate program, students must pass a subject test. The students who participated in the lecture series and received the outreach lessons "were essentially able to pass this exam because they took these courses," he says.

The promising results in São Paulo encouraged Berkovits to scale up the project. But to move beyond the borders of Brazil, the materials would need to be translated into Spanish, the national language of nearly every other country in Latin America.

Seeking to fund the Spanish translation work, Berkovits applied to, and received a grant from, the APS Innovation Fund in 2020. Since then, his team has translated into Spanish all 18 volumes of lessons developed by the Perimeter Institute.

"The next step is, of course, to spread [the lessons] to different classrooms," he says.

Navigating the COVID-19 pandemic, Berkovits was forced to keep the earliest implementation workshops online. Despite these limits, the workshops inspired a unique spin-off project: His team partnered with teachers from La Paz, Bolivia, and the city's Max Schreier Planetarium to create a joint workshop on cosmology, he says.

With pandemic travel restrictions easing, the team will hold their first in-person teacher workshop this fall. "We have about ten people coming from different countries in Latin America," says Berkovits.

"For [the teachers], it's exciting because now they have material that they can actually talk with confidence about, that the students find interesting," he says.

Despite the success stories, Berkovits says big challenges remain, particularly in funding — "paying the costs for high school teachers to be able to come to our workshops."

For now, "the funding is enough for these workshops [in São Paulo], but it's not enough to send people to other countries." For example, if his team wanted to create a base in another South American city, they'd need funding from that city. "That's a challenge," he says.

Still, Berkovits is thinking carefully about the future. "The main problem is getting the students from the public high schools involved in science," he says. "That's something that's slowly changing, but that's the main hope — that eventually, the pool of potential physicists will be much bigger."

Liz Boatman is a staff writer for APS News.

APS Science Trust Project Trains Members to Curb the Spread of Misinformation

BY TAWANDA W. JOHNSON

Science misinformation is on the rise, but APS's Science Trust Project aims to combat it by teaching members to meaningfully contend with misinformation in their own lives.

The project, which began last year, trains members in science communication skills, both online and offline, professional and personal — and participants learn from each other, too. The goal is for members, equipped with new skills, to help stop the spread of misinformation.

Shannon Swilley Greco, a science education program leader at Princeton Plasma Physics Laboratory, attended last year's virtual, four-week training to learn to better navigate tense conversations with family and friends about science issues, including vaccines and climate change.

In those conversations, she'd start with "positive engagement," said Swilley Greco. "But after they started asking difficult questions about climate change, it began to get a little hostile, so I needed some new techniques to engage with them in a positive way to keep the conversations respectful."

One of her takeaways from the training: "It's not about winning an argument. You have to play the long game. Rather than convincing someone in that particular moment that they are wrong, you should ask questions such as, 'Well, why do you think that?'"

Swilley Greco said she hopes the training helps participants engage in "a more positive way" with people around them.

"Everybody comes to a discussion with their own background and expertise. Let's lose the term 'arguing' and move toward engagement," she said.

Combating misinformation is hard. The Science Trust project helps scientists get better at it. Credit: Maria Petrish/Adobe

Jackie Acres, a Ph.D. candidate in biophysics at Portland State University, said she joined the training out of concern for some people's disregard for data. She recalled an experience in which she and others were speaking to a career scientist about the COVID-19 vaccine, and some people in the group responded, "Well, my thoughts are just as good as your thoughts" about the vaccine.

She added that people should respect the expertise of others. "If you're a mechanic who understands everything about cars, I'm not going to tell you how they work," she said.

Acres said the training taught her the importance of reflective listening. "It helped me to validate what people are feeling," she said. "I learned to try to hear what their issues are and see if there is something we can agree on. Most people just want to be heard."

The Science Trust Project is being supported by a $66,000 grant through the American Institute of Physics' Venture Fund, as well as a $100,000 grant from the Kavli Foundation.

"We are very grateful for the amount of support and interest we have received," said Claudia Fracchiolla, APS Head of Public Engagement and a leader of the Science Trust Project.

Fracchiolla said she's excited about the project's upcoming activities. "We are having a modified in-person workshop at the APS Annual Leadership Meeting to get the Society's division leaders involved in the project," she said.

The team is also launching a group on Slack, a messaging tool, for people to learn more about combating misinformation and to share resources with the community.

"We are really looking forward to growing this initiative," she added.

To learn about upcoming workshops, visit go.aps.org/sciencetrust.

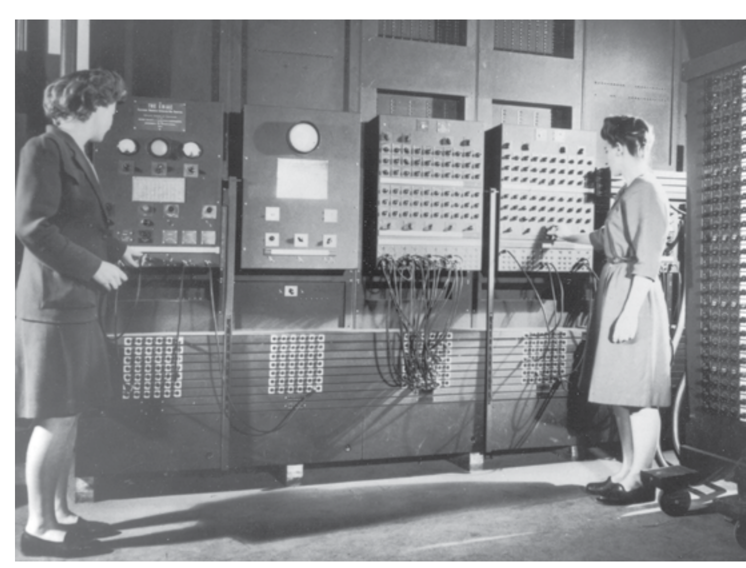
Tawanda W. Johnson is the Senior Public Relations Manager at APS.

History continued from page 2

tubes, 10,000 capacitors, and 6,000 switches across 40 nine-foot-tall panels that stretched around three walls of a huge room.

The device was finished in summer 1945, but it needed to be told what to do — it needed "programming." ENIAC team leader Herman Goldstine later wrote in his book *The Computer: from Pascal to von Neumann* that "six of the best computers" were summoned and selected for the job. There was one hiccup: They didn't have the security clearance to see the classified machine at first, so they had to learn the mechanics of the ENIAC from tangled diagrams. They broke up the differential equation into many small steps and figured out how to set up the operations in parallel across the cables, switches, and panels of the machine. "The ENIAC was a son of a bitch to program," Jennings Bartik said in an interview included in "The Computers." But their experience calculating longhand paired with their new knowledge of the machine's components proved valuable. "We learned to diagnose troubles as well as, if not better than, the engineer," Jennings Bartik said.

The war ended in September before the group had the ballistics calculations up and running, but the Army brass gave the go-ahead for scientists from Los Alamos, which had just been publicly revealed as the birthplace of the atomic bombs dropped on Japan, to run a calculation on the ENIAC. In November, the six computers — now programmers — were finally allowed to see the behemoth to help the Los Alamos physicists load their secret problem onto the machine. The women had no idea what the program was for, only that it was a complicated first test for the computer. The ENIAC service log marked the occasion of the calculation's first run on December 10, reading "Problem A—12/10/45," followed by "Machine tested—OK."



Betty Jean Jennings (left) and Frances Bilas operate ENIAC's main control panel. Credit: U.S. Army photo; archives of the ARL Technical Library

After the ENIAC's successful run of the Los Alamos calculations and the February 1946 unveiling, many of the programmers continued working with the computer. Several went on to have long careers in technology, including Jennings Bartik, who programmed subsequent computers BINAC and UNIVAC I, and Snyder Holberton, who created the first program for sorting large data files and worked in computing until the 1980s. Thanks to the work of Kleiman, who sought them out after seeing an unnamed photograph of the women with the ENIAC, the programmers' contributions were rediscovered and reappraised towards the end of the twentieth century. In 1997, all six were inducted into the Women in Technology International Hall of Fame, and the last of the ENIAC programmers, Bilas Spence, passed away in 2012. And though the six weren't recognized publicly in ENIAC's heyday, Abbate, the historian, said they made an impression on the women who followed in their footsteps.

"Women who started programming in the 1950s recalled female programmers being common," she says. "The early programmers may have been invisible to the wider world, but they were visible to other women in the field."

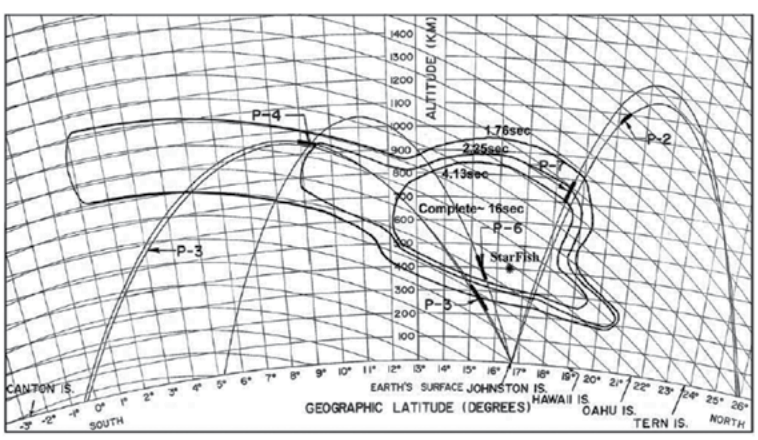
Tess Joosse is a science journalist based in Madison, Wisconsin.

Starfish continued from page 1

rence Livermore National Laboratory presented the first model to simulate the electromagnetic pulse from Starfish Prime from first principles — an achievement made possible by access to world-leading supercomputers.

Starfish Prime was one of a flurry of nuclear experiments in the 1950s and early 1960s, when the Cold War between the U.S. and the Soviet Union was raging. "We were doing all sorts of nuclear explosions in the atmosphere" and even some underwater, says Dan Winske, a physicist now retired from the Los Alamos National Laboratory in New Mexico.

One of the questions the U.S. government sought to answer was how a thermonuclear explosion would impact the nation's fledgling satellite infrastructure. But modeling such a blast was difficult: Back then, a physicist trying to predict the effects "could probably only do a one-dimensional calculation," says Winske. "The models weren't very good. It was all very crude. … They had no idea what was going to happen, in some sense."



Trajectories of military rockets launched in tandem with the Starfish Prime warhead, to record magnetic field data. Physicists later used this data to simulate the blast. Credit: Dyal, P. (2006). Particle and field measurements of the Starfish diamagnetic cavity, J. Geophys. Res., 111, A12211, doi:10.1029/2006JA011827.

So in the summer of 1962, the U.S. government detonated a real high-altitude warhead. The Starfish Prime rocket was launched from a remote outcrop called Johnston Island, dredged from a coral atoll and barely large enough for a runway and a handful of military buildings. The nearest landmass of any significance is the Hawaiian islands, about 900 miles away.

Chasing the warhead skyward were smaller rockets, outfitted with magnetometers, sensors attuned to the magnetic field. Below, U.S. military vessels stood by, waiting to record transmitted data to magnetic tapes. Soviet ships prowled the waters nearby, keeping a watchful eye.

The detonation ejected a huge plume of high-energy electrons — beta particles — upward, while energizing a massive swath of the atmosphere below, in a region that physicists refer to as the x-ray ionization patch.

Those beta particles can "become trapped in the Earth's field, and they're deadly for satellites," says David Larson, a computational physicist at Lawrence Livermore. Of the 24 satellites in orbit in 1962, Starfish Prime damaged at least one-third.

The blast blew out a huge bubble of plasma, producing a giant, short-lived cavity in the Earth's ionosphere. The planet's magnetic field was completely expelled for nearly half a minute.

The blast also emitted an incredibly strong electromagnetic pulse, or EMP. "The signal from the EMP propagates down to the ground," says Larson. "It couples into long conductors like power lines," which is why Starfish Prime triggered street light blackouts in Hawaii.

In 1963, a little more than a year after the blast and just months after the Cuban Missile Crisis, the U.S. and Soviet Union agreed to ban above-ground nuclear testing. The Starfish Prime magnetic tapes are now some of the only data ever recorded from a real high-altitude nuclear test.

In the decades after, thousands of scientists spent millions of hours developing the physics and computational models to interpret high-altitude phenomena, like those observed in Starfish Prime. But mysteries remained — especially surrounding the EMP emitted, which was far larger than physicists had theorized.

When the U.S. government shelved the testing program, Palmer Dyal, the scientist who led the recording of Starfish Prime's magnetic field data, shelved the box of magnetic tapes, too — in his garage.

And there the tapes sat for four decades.

Then, in the early 2000s, the U.S. Defense Threat Reduction Agency asked Dyal if he would analyze the recordings. In 2006, Dyal published the first magnetic field data from a once-classified high-altitude nuclear explosion ever shared publicly.

With access to world-leading supercomputing capabilities, Larson's team of computational physicists at Lawrence Livermore saw an opportunity. In 2017, they began the four-year process of developing a code that could simulate a large-scale EMP — specifically, a portion of the pulse known as E3, caused by distortions in the Earth's magnetic field. "When that field wiggles, it produces an electromotive force that can generate voltages in long loops of wire," like power grids, says Mikhail Belyaev, who presented the team's work at the DPP meeting.

When the U.S. government shelved the testing program, Palmer Dyal, the scientist who led the recording of Starfish Prime's magnetic field data, shelved the box of magnetic tapes, too — in his garage. And there the tapes sat for four decades.

The team validated the code, named TOPANGA, against the declassified Starfish Prime data. Because the x-ray ionization patch from the detonation spanned more than 5,000 miles and the blast occurred hundreds of miles above Earth's surface, Larson's team had to design a simulation that would capture a vast volume of atmosphere.

The team also needed to simulate nearly two minutes of EMP behavior in increments smaller than a millisecond. Even on a 10,000-core supercomputer, each simulation took two or three days.

To fully capture the EMP behavior, Belyaev says, "you have to simulate the entire system, not just a small part of it."

TOPANGA isn't the first model developed to simulate the Starfish Prime EMP, but it is the first model that can three-dimensionally reproduce the magnetometer measurements recorded in 1962 from first principles — including kinetic modeling of ions, an inertialess fluid of electrons, and even ionosphere gas chemistry.

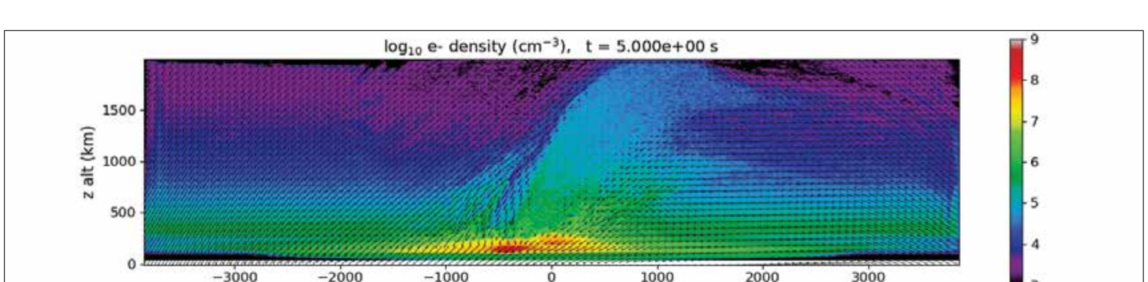
The E3 portion of the EMP, it turns out, exhibits two types of behavior, dubbed E3a and E3b. E3a travels around the x-ray ionization patch to reach the Earth's surface, a longer bypass that diminishes the pulse's intensity. E3b moves straight through the patch, striking the planet directly.

The Lawrence Livermore team's simulation also produces powerful visualizations. "You can see the curvature of the Earth … the magnetic bubble forming. You can really picture what's happening," says Belyaev.

Sixty years after the last warhead was detonated in the atmosphere, TOPANGA paves the way for a new kind of high-altitude nuclear test — one safely confined to the simulated atmosphere of a supercomputer.

In the future, the TOPANGA team plans to expand their modeling to other sources of EMPs, such as geomagnetic storms. Research into global EMP events can tell scientists how an EMP propagates from space, through the ionosphere and to the ground. This is important for safeguarding critical civilian infrastructure, like power grids, from the destructive effects of EMPs, both natural and manmade.

Liz Boatman is a staff writer for APS News.



Five seconds after detonation in the TOPANGA simulation, x-rays have ionized a massive patch of atmosphere (yellow-orange-red). A plume of beta particles reach the ionosphere, where satellites are susceptible. Credit: Mikhail Belyaev/Lawrence Livermore National Laboratory

Apker continued from page 1

solve a maze or create this optimal distribution network," says Dionne, even though it has no nervous system and its transport network is "very decentralized and simple." He worked with Henrik Ronellenfitsch, then an assistant professor at Williams, to develop a theory underpinning the organism's behaviors. The duo partnered with assistant professor Katharine Jensen for the experimental portion.

"I could start to see how the model came together in a way that demonstrated how this organism, Physarum, really organized itself," says Dionne.

Cufari, meanwhile, was studying a galactic nucleus, known as ASASSN-14ko, in a distant region of the sky. Other researchers had reported on a periodic burst of light from ASASSN-14ko, emitted every 114 days. They speculated that the source could be a large star gravitationally tethered to a black hole at the galaxy's center, emitting the flare every time the star looped around and passed close to the black hole.

But they couldn't explain how a star could have been captured in an orbit tight enough to give rise to the short periodicity of 114 days. So Cufari and his project advisor, assistant professor Eric Coughlin, set out to develop a model that would explain, and then simulate, how this could happen. The duo ultimately demonstrated that the black hole likely captured the large star from a nearby binary star system, in a process known as the Hills mechanism.

At some points during the project, their model didn't seem to work. "It was often difficult to tell if the model couldn't explain the origin of ASASSN-14ko, or a piece just needed to be reconsidered," Cufari says.

Despite the challenges, Cufari's calculations were spot on. "[When] you work on a model for months that yields predictions in magnificent agreement with observation — it's really amazing," he says.

Although maze-solving slime mold and hungry black holes seem unrelated, both projects relied on computer simulations, which the students mastered thanks to their undergraduate computer science courses.

"It's really easy to lose sight of how revolutionary [computers] truly are," says Dionne. "Seeing how the cutting edge of research uses them to understand systems … was really inspiring."

Both students credit their research with making physics feel relevant to the real world. Cufari says he learned how investments in the optical systems of telescopes have impacted a range of technologies, like instruments used in medicine to diagnose and treat disease. And Dionne underscores that "whimsical" slime mold can do more than solve mazes — it can inform our understanding of decentralized distribution in large networks, which has implications for modern systems like power grids, he says.

So what's next for the two physicists?

Cufari, who once thought he would be a physician or lawyer, now plans to pursue a career in science because of "the type of problem solving that goes into physics research — the open-ended questions," he says. He's also drawn to the field's applications — for example, to engineering for clean energy — and the role physicists can play in "pushing technology forward, making life more equitable, more accessible for everyone, and improving the world that we have today."

Cufari is applying to graduate programs to further his interests in plasma astrophysics, in the hopes of becoming a research scientist or professor, he says.

Dionne, in his first semester at Harvard, is already focused on "trying to find a way to do research that is both meaningful to me and [that helps] out other people." For him, science communication is key. Physicists have "a role to play, an onus to communicate … with the public in a way that they can understand," he says. Part of this onus for physicists includes "restoring trust" that the public has lost in recent years, by becoming better communicators.

Physicists have "a role to play, an onus to communicate … with the public in a way that they can understand," Dionne says.

Beyond that, Dionne says he's still charting his course, in part because, as a first-generation college student turned first-generation graduate student, "I didn't really know that a Ph.D. was an option for my life until I was in college."

For now, "I'm just trying to become the best scientist I can," he says, "because it's what I enjoy and [it's] a really meaningful career to pursue."

Liz Boatman is a staff writer for APS News.

THE BACK PAGE

Graduate Students Should Be Paid Living Wages

To invest in science, we need to invest in tomorrow's scientists. Let's start by paying them wages that meet the cost of living.

BY JACQUELINE ACRES

What, exactly, is a graduate student?

The answer was not always clear-cut to the U.S. government, which for decades debated whether graduate students are strictly students, or whether they are also *employees*.

In 2016, the U.S. National Labor Relations Board voted that graduate students who teach and aid research are indeed employees [1]. This reaffirmed what many knew all along — that graduate students provide enormous value to universities as employees, not just as students.

So why are graduate students still so underpaid?

Graduate Students are Vital University Employees

Some universities argue that their relationship with graduate students is solely educational, because students' labor — through teaching or research, for example — helps them earn degrees.

But this overlooks graduate students' economic and scientific contributions to their schools. For faculty to be successful, they must have students capable of researching, and who can demonstrate competency in their field. In addition to aiding in meaningful research, graduate students teach, often as a requirement — and they spend many hours doing so, often far more than the university expects. Data is scarce, but according to a 2015 survey from Georgetown University, more than 75% of graduate students worked *at least* 30 hours per week. In my experience, students work 30 to 70 hours per week and treat this as a year-long, full-time job.

For these contributions, graduate students across disciplines should receive at least a living wage, but many do not. In 2020, a national survey of 3,000 graduate students found that 1 in 4 endured housing or food insecurity. According to recent crowdsourced data, 98 percent of institutions and departments in the biological sciences do not guarantee that graduate students receive salaries that exceed their cost of living. And a 2019 survey from the American Chemical Society found that more than 27 percent of graduate students reported that their funding was not adequate — a number that rose more than 6 percentage points from 2013.

Physics is no different. According to data from the American Institute of Physics' Statistical Research Center, first-year doctoral students who earned their bachelor's degrees in 2019 and 2020 in physics earn $21,900 to $30,000 annually (25th to 75th percentile) from teaching assistantships, the most common type of support (Fig. 1). The cost of living in these institutions' cities frequently exceeds these salaries. (Students are pushing back, often through strikes.)

Some graduate students earn fellowships to supplement their income, but many do not. Some work second jobs, but many universities prohibit this. And graduate students usually lack access to employer-sponsored, tax-advantaged retirement plans, like 401(k)s or 403(b)s, impacting students' far futures. For all of this, students pay a price: Scientists have known for decades that low or no pay is linked to worse health outcomes, both physical and mental.

Like so many graduate students, I have faced these financial stressors firsthand.

A Current Graduate Student's Perspective

I'm Jackie Acres. I'm a doctoral candidate in applied physics at Portland State University, and I expect to defend my dissertation this February. Even now, so close to the finish line, that sentence comes as a shock. I've spent my life seeking opportunities to learn, but I did not realize how much a Ph.D. would challenge me.

My path was unconventional. After I earned my master's degree in biomedical engineering in 2010, I took several years off to stay at home with my daughter, Lyra.

My life changed when I got divorced and decided to go back to school. Graduate school scared me: I would live for years with low pay, and if I did not earn my degree, I would have nothing to show for that time. The prospect of failure, particularly with a then-first-grader, was frightening.

How frightening? PSU's acceptance offer made no promise of pay at all, and if I were to receive a stipend, I could earn, at most, $24,000 a year, before taxes and without benefits — but MIT's living wage calculator indicates that a household with an adult and child in my area needs to earn $79,000 before taxes to cover basic costs of living. The discrepancy is stark, not least because, according to rent.com, the average rent for a one-bedroom apartment in Portland is $1,622 per month, nearly $19,500 a year.

But I dove in. At Portland State University, I found Dr. Jay Nadeau, whose work in biophysics fascinated me: Dr. Nadeau uses digital holographic microscopy to look for life on other planets. She also makes sure graduate students are paid and secures the funding to do so. On paper, the program seemed like a great fit.

Getting through the program, though, was a different ball game. My first year in, rumors abounded about the program shutting down. Although I received funding as a research assistant through Dr. Nadeau's grant, I feared that the situation could change, or that I would struggle to pursue a career in academia after school. I began to doubt that my degree, if I earned it, would be useful.

> "Some graduate students earn fellowships to supplement their income, but many do not. Some work second jobs, but many universities prohibit this. ... [And] scientists have known for decades that low or no pay is linked to worse health outcomes, both physical and mental."

To assuage my fears, I started my own tutoring business and took on as many clients as I could. I worked in the lab for Dr. Nadeau, one of few professors at the school to pay their students through grants, and ran my business in my off-hours to generate extra income.

I completed my required coursework in two years, passed my comprehensive exams, and am working on my dissertation. I am the first author on two publications, and I won a fellowship through the Oregon Space Grant Consortium. I have also maintained my tutoring business and raised my daughter, encouraging her to pursue her interests.

I am proud of all this, but financial insecurity has also made this experience deeply difficult. I am a divorced mother in my late thirties; career pivots are risky, and pay matters. In many ways, I have been lucky — I earned income through my business, and Dr. Nadeau let me work at my own pace — but I do not want others to go through similar struggles.

Graduate Student Pay is an Equity Issue

The consequences of underpayment do not hurt everyone equally. Graduate programs that do not pay students living wages will push away bright minds who come from less wealthy or marginalized backgrounds. Higher education is already unaffordable to low-income families; years of financial insecurity await many of them if they become graduate students.

If indeed diversity, equity, and inclusion are central to our vision of physics's future, then science institutions must look beyond those who have traditionally had access to more resources. To support scientists of diverse backgrounds or non-traditional career paths like mine, we must advocate for stronger financial support for graduate students, who are invaluable employees for universities.

Paying graduate students fairly would also be better for science. We need aspiring scientists to focus on discovery, problem-solving, and innovation, not on whether they will make their next rent payment on time.

In the last few years, I have become a strong advocate for equitable pay for graduate students. In December 2020, I was elected Secretary of the APS Forum on Graduate Student Affairs (FGSA), and I participated in the 2022 Congressional Visit Day, where I could advocate for more funding in education. Now, through the APS Student Ambassadors Program, I have worked with other graduate students to bring attention to graduate student pay.

Through this involvement, I have learned more about what could help solve these challenges. Our student ambassador group has drafted a white paper on this issue, to discuss with APS leadership, and we're proposing a focus session at the 2023 APS March Meeting, hosted by FGSA, to raise awareness of graduate student underpayment. We are urging APS to publish guidelines that advocate for living-wage-minimum pay for graduate students. This issue is also woven into the fabric of federal research funding, which is why we urge agencies, like the National Science Foundation and the National Institutes of Health, to allocate more funding to graduate students.

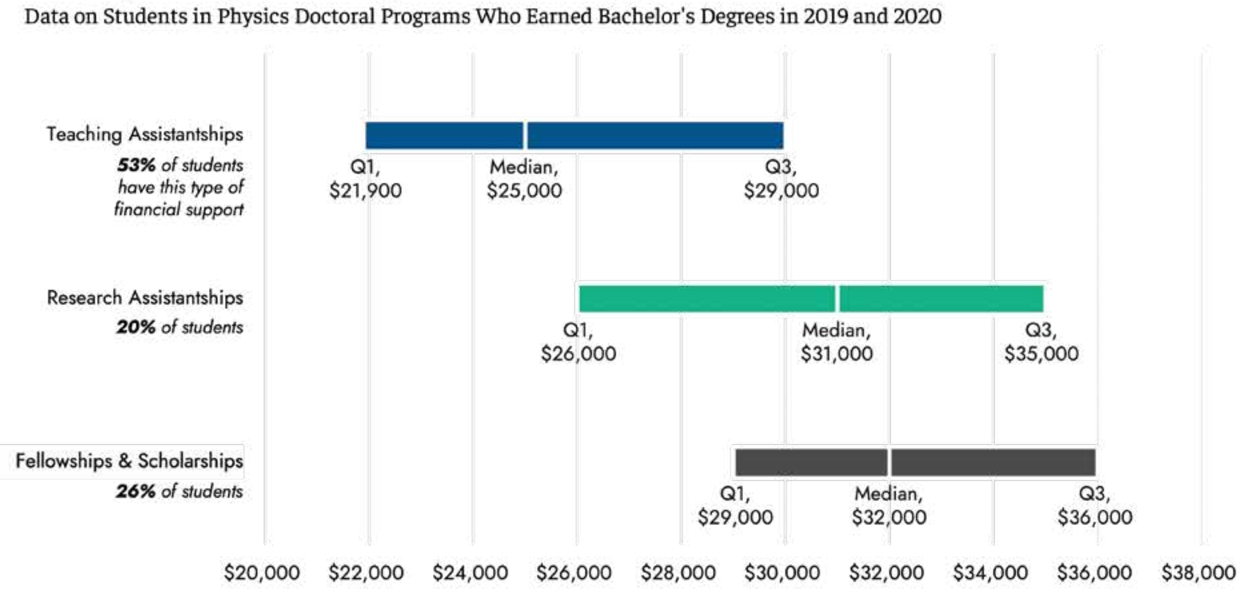
If you are interested in sharing your own story, or helping our team in our advocacy efforts, please join us. Together, we can work to ensure that graduate students, no matter their background, are paid livable wages — not only for their contributions to universities, but to science, which needs every penny.

Jacqueline Acres is a doctoral candidate in applied physics at Portland State University in Oregon and an APS Student Ambassador. To learn more about the APS Student Ambassadors program, visit https://go.aps.org/studentambassadors.

[1] The National Labor Relations Board's decision applied to graduate students at private universities; student assistants' rights at public universities are governed by state law.

Fig. 1: Typical Stipends and Types of Financial Support for First-Year Physics Graduate Students

Data on Students in Physics Doctoral Programs Who Earned Bachelor's Degrees in 2019 and 2020



Note: Boxes show 25th to 75th percentile of first-year stipends for students enrolled in full-time physics or astronomy doctoral programs in the U.S. Data does not take into account the number of hours that graduate students are contracted to work. Data on self-funded students, who make up 1% of doctoral students in this group, are not shown.
Credit: Data graciously provided by the American Institute of Physics' Statistical Research Center (SRC). To learn more about the SRC, visit aip.org/statistics.