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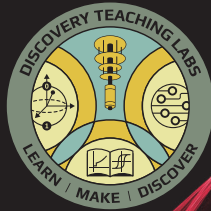
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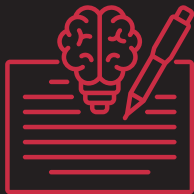


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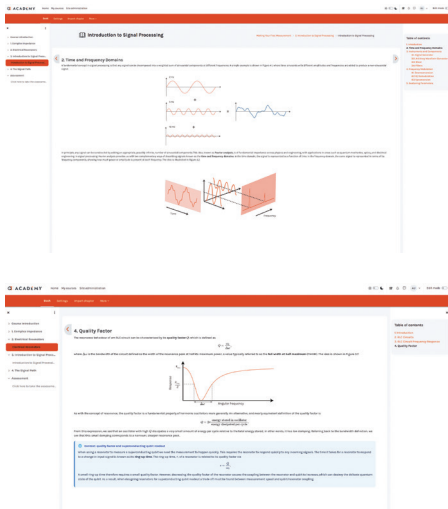
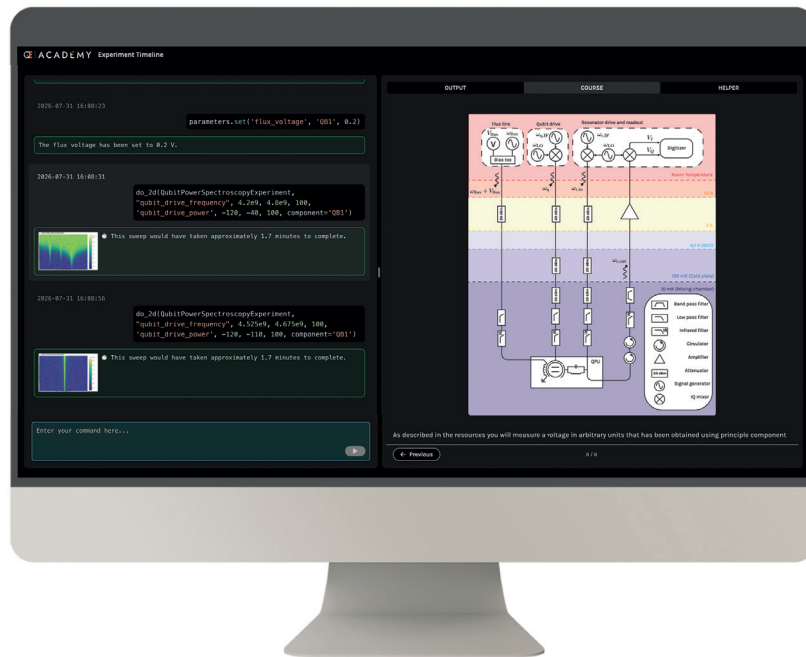
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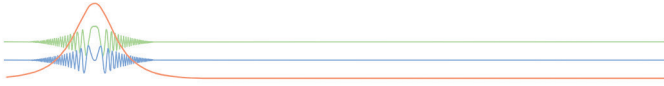
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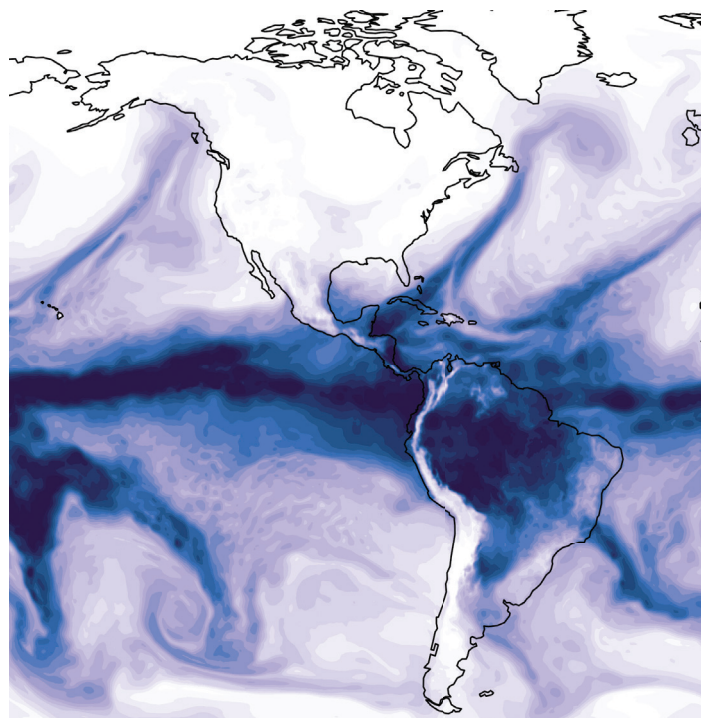
Trevor Owens

As higher-education programs compete for a shrinking pool of students, departments must better communicate the value that a physics major brings.

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Rivers in the sky

**Serena R. Scholz and
Juan M. Lora**

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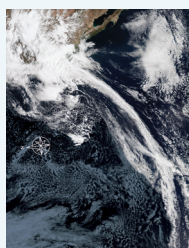
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ON THE COVER

An atmospheric river—a long, flowing band of concentrated water vapor—formed an arc on 20 February 2017 that stretched from Hawaii to the western coast of the US. The system delivered record-breaking daily rainfall to parts of California during an already wet year, and it caused floods, landslides, and debris flows. See the Quick Study by Serena R. Scholz and Juan M. Lora on **page 44** to learn about the formation of atmospheric rivers and their global impacts under a changing climate.

(Image by Jesse Allen, NASA Earth Observatory, using *Suomi NPP VIIRS* data; compass rose adapted from iStock.com/Anton Porkin.)

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TO READ ABOUT THE AIR AND SPACE MUSEUM'S REVAMPING, TURN TO PAGE 22

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Ultrabright laser brings details of proteins into focus

For nearly a century, scientists have known that phase shifting an electron beam could radically improve electron microscopy. They've finally found a reliable way to do it.

By **Laura Fattaruso**

Probing flash-frozen biological samples with an electron beam has been a game changer for researchers examining the details of biological structures. The technique—cryogenic electron microscopy, known as cryo-EM—has exploded in popularity in the past 15 years. It earned some of its inventors the 2017 Nobel Prize in Chemistry and was used in 2020 to analyze the structure of the COVID-19 virus's spike protein (see the 2020 *PT* story “World's physics instruments turn their focus to COVID-19”), an achievement that enabled development of targeted vaccines.

Still, most proteins in the human body are too small to be effectively imaged with cryo-EM. The primary challenge is that biological materials refract electrons only weakly, so the images are inherently low contrast.

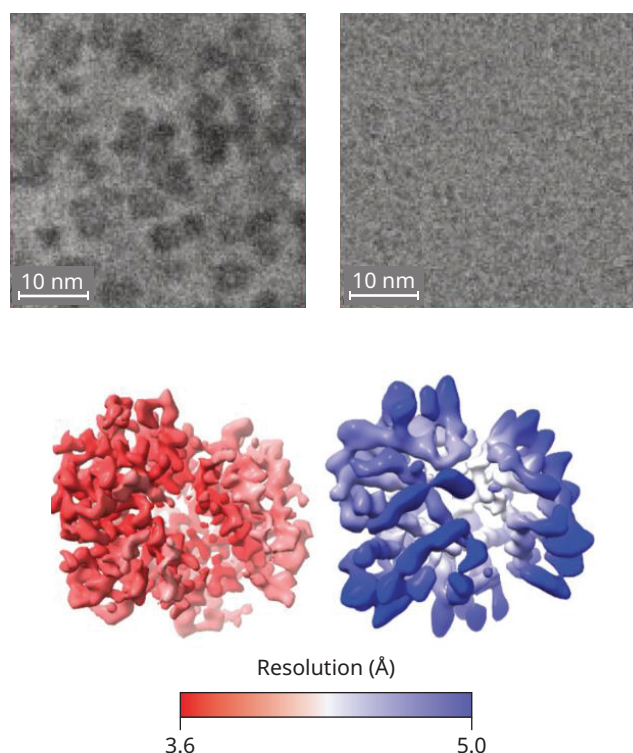
And because electron beams damage biological samples, lengthening exposure times isn't a viable solution.

A new advance by a team led by physicist Holger Müller at the University of California, Berkeley, improves the resolution of cryo-EM and offers promise for clearer images of the cellular world. The researchers use the highest-intensity continuous-wave laser ever demonstrated—about 400 GW/cm², 100 million times as bright as the Sun's surface—to phase shift the electron beam.¹ That phase shift produces cryo-EM images with heightened contrast and produces higher-resolution models of proteins, such as the hemoglobin molecule shown in figure 1.

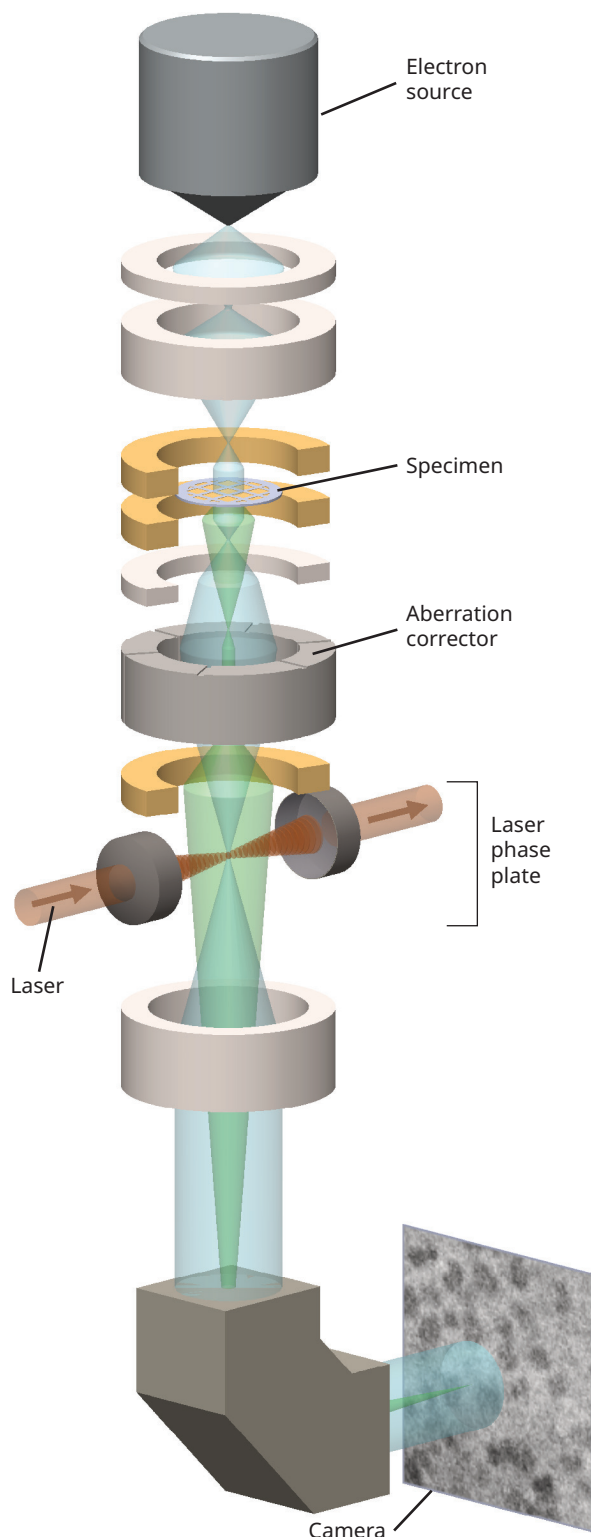
Fuzzy details

In typical cryo-EM, a combination of strategies is used to extract useful information from low-contrast images. One counterintuitive tactic is to collect intentionally defocused images to create contrast. Consider a blurry photocopy of a book page on which each line of text appears as a fuzzy gray line. Details of individual words and letters are sacrificed, but the lines stand out more. Without defocusing, cryo-EM images have essentially no contrast. (For more on the methodology of cryo-EM, see Bob Glaeser's 2008 *PT* article, “Cryo-electron microscopy of biological nanostructures.”) Researchers using cryo-EM collect up to hundreds of thousands of defocused images of molecules and then process them with algorithms that analyze proteins' shapes and orientations to produce a single structural model.

Though biological samples also produce weak scattering and low contrast in light-based microscopy, an



▶ **Figure 1.** A micrograph of hemoglobins collected with a laser phase plate-fitted electron microscope (**top left**) has better contrast than one collected without the plate (**top right**). Thousands of protein images are analyzed to produce a structural model of hemoglobin. The higher-contrast images yield a structural model (**bottom left**) that captures more details of hemoglobin's shape than does a model produced from lower-contrast images (**bottom right**). (Figure adapted from ref. 1.)



▲ **Figure 2.** By adding an ultrabright laser to an electron microscope, researchers improved the contrast of biological images collected with the microscope and were able to see more details in the structure of small proteins. (Figure adapted from ref. 1.)

effective technique to deal with that problem was deduced in the 1930s: Phase shift the direct light—the portion that has not been diffracted while passing through the sample—by 90°. The phase-shifted light waves produce constructive and destructive interference with the scattered waves, which enhances the contrast of the subsequent image without the need for defocusing. (Frits Zernike was awarded the 1953 Nobel Prize in Physics for the phase-contrast method.) Though it was quickly recognized that the same approach could benefit electron microscopy, phase shifting electrons has not been as straightforward as phase shifting light.

Before turning to lasers, researchers had explored other methods to phase shift electron beams and improve cryo-EM contrast. The most successful phase-shifting approach has been the Volta phase plate, a heated thin film of amorphous carbon. Interaction between the plate and the unscattered electron beam produces a voltage potential that phase shifts the beam. Though the Volta phase plate has succeeded at producing some of the best cryo-EM images to date, it also causes signal loss and has thus not yielded consistent improvements in resolution.

Laser focus

Müller and colleagues proposed in 2010 that passing the electron beam through a powerful laser, called the laser phase plate and illustrated in figure 2, might do the trick.² Despite its name, there is no physical plate involved in the laser phase plate. Electrons entering the electric field of the laser experience a repulsive potential that shifts the phase of the electron wave function by an amount that is predictably related to the laser's power and wavelength. To create a continuous-wave laser with the necessary 80 kW power, the researchers would need to bounce it back and forth between two curved mirrors about 10 000 times. The mirrors form a resonant cavity that amplifies the laser power with each traverse. The cavity also focuses the beam down to a diameter of about 7 μm , the width of a red blood cell, to yield the intensity of 400 GW/cm².

In early attempts, the mirrors got too hot and started to change shape when the laser power reached about 10 kW. The researchers changed the mirror material to a titania silicate glass with a low thermal expansion coefficient and achieved about 30 kW. To further improve the laser power, the researchers had to secure the mirrors so that the distance between them would remain at an exact multiple of half the laser wavelength.

Finally, around 2020, the laser was working as needed, and the team began collecting cryo-EM images. Though the contrast looked much better, the postprocessing resolution didn't seem to improve. "We had a microscope



▲ **Figure 3.** Holger Müller in front of the laser phase plate–fitted electron microscope. (Photo courtesy of Robert Sanders/UC Berkeley.)

that produced gorgeous-looking images. We were so happy,” says Müller. “But then you feed the images into the computer and say, ‘Tell me what’s the resolution from these images,’ and the computer says that it’s about the same as without the laser.”

To add the laser to the microscope, the researchers also had to add two more electron lenses, but those were introducing aberrations that negated the improvements from the laser. By upgrading to a state-of-the-art electron microscope that has an electron beam with a narrower energy spread and an aberration corrector, the benefits of the laser phase plate finally came into view.

The next phase

For their first analysis of images from the laser phase plate–fitted microscope, which is shown in figure 3, Müller and colleagues used otherwise standard procedures for collecting cryo-EM images, including defocusing, so they could directly compare images collected with and without the plate. With a diameter of about 55 Å, hemoglobin molecules are on the smaller end of molecules that can be imaged with cryo-EM. By using the laser phase plate, the researchers enhanced the resolution of the molecule’s structural model—the

largest improvement was from 4.46 Å down to 3.09 Å. The heightened contrast from the laser phase plate also means that defocusing should no longer be necessary for future data collection. The team plans to collect in-focus images that should reveal even finer details of protein structures.

The laser phase plate “makes a much larger pool of proteins available to study by cryo-EM, which is important because the majority of proteins in human cells are very small,” says Mohammed Kaplan, a microbiologist at the University of Chicago. He says the method should be especially useful for cryoelectron tomography, in which intact cells are imaged at multiple angles to produce 3D volumes that show proteins in their cellular environment.

Another benefit of the laser phase plate is that frames collected at the beginning of a sample analysis should become more useful. When cryo-EM samples are prepared, they are plunged into liquid ethane to shock-freeze them. That creates a vitreous phase of ice that locks tension into the sample. Energy deposited by the electron beam releases the tension, and samples start to move erratically. As a result, the amount of noise in the earliest frames is high, and the images are discarded. The improved signal-to-noise ratio of the new technique, however, should make the early frames usable.

Müller got the funding to upgrade his lab’s electron microscope from the nonprofit research organization Biohub and has worked with researchers there to develop another version of the laser phase plate. That one, built at Biohub’s imaging lab, uses two crossing lasers at half power each and also significantly improves resolution, the researchers report in a *bioRxiv* preprint.³ Both research teams are working with Thermo Fisher Scientific to commercialize the technology. Any ultimate product would probably require that researchers have a state-of-the-art electron microscope similar to the ones in Müller’s lab and at Biohub.

Beyond its value for cryo-EM, the ultrabright laser could have other uses. Müller’s lab is looking into using it as an optical trap that is compatible with a wider range of molecules than are current trapping methods. **PT**

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1. P. N. Petrov et al., “Laser phase plate improves structure determination of small proteins by cryo-EM,” *Science* **393**, 195 (2026).
2. H. Müller et al., “Design of an electron microscope phase plate using a focused continuous-wave laser,” *New J. Phys.* **12**, 073011 (2010).
3. Y. Yu et al., “A crossed laser phase plate for cryoEM,” <https://www.biorxiv.org/content/10.64898/2026.06.05.730245v1>.

Life beyond stellar death for an unusual exoplanet

Researchers have characterized the atmosphere of a massive gas planet closely orbiting a white dwarf to better understand how it survived the shutdown of its star.

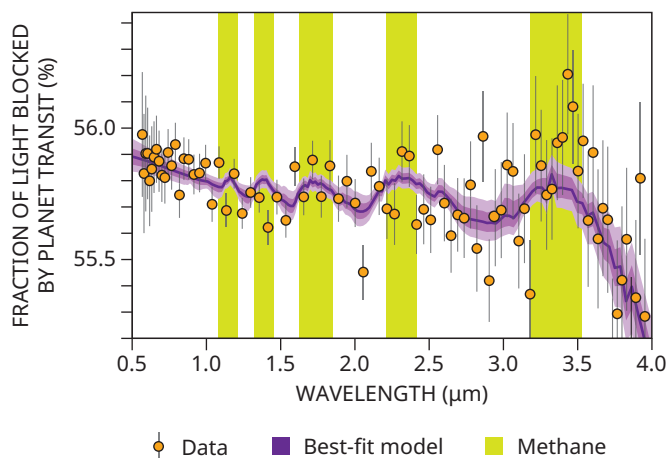
By Sarah Wells

By all accounts, the gas giant exoplanet WD 1856+534 b is an oddity. The planet is extremely large, more than 10 times as massive as Jupiter. And it orbits its star, a white dwarf that is smaller than it by about a factor of seven, at a distance only $\frac{1}{100}$ of that between Earth and the Sun. Typically, a planet orbiting its star so closely would be destroyed as the star expanded into a red giant before shutting down, cooling, and condensing into a white dwarf. So, wondered Ryan MacDonald from the University of St Andrews in Scotland and colleagues, how did it survive?

The research team developed two competing hypotheses.¹ The first proposes that the exoplanet initially orbited at a much farther and safer distance from the red giant but that two additional stars in the system pulled it closer to the white dwarf after the end of the star's life. The second borrows a model from binary stars and proposes that WD 1856+534 b survived inside the red giant's swelling hydrogen envelope because of aerodynamic drag. That process would create enough kinetic energy to expel the star's gas envelope and leave the exoplanet orbiting the red giant's exposed core. In that scenario, the researchers expected that WD 1856+534 b's atmosphere would become relatively rich in hydrogen through accretion from the red giant and that, as a result, it would have comparatively less carbon and nitrogen.

To determine which scenario was more likely, MacDonald and colleagues used transmission spectroscopy to analyze IR and red-light (0.55–5.5 μm) spectral data collected by the *James Webb Space Telescope*. When the exoplanet transits in front of the white dwarf, its atmosphere absorbs some of the light from the star. From the spectrum of the transmitted light, shown in the figure, the researchers could extract the atmosphere's chemical composition. The transit data also enabled them to determine the planet's temperature and mass.

The researchers found that the exoplanet was much hotter (roughly 400 K) than expected for a giant planet of its age and that its atmosphere contained a high percentage of methane. Based on cooling models for planets of that size, they determined that WD



▲ The transmission spectrum of exoplanet WD 1856+534 b provides insight into how the planet survived its star's transition to a white dwarf. The data points show the spectrum measured by the *James Webb Space Telescope*, and the curve represents the best-fit model. The presence of the methane absorption peaks (green) suggests that the planet migrated inward after the white dwarf formed. (Image adapted from ref. 1.)

1856+534 b had undergone a period of reheating after its star had become a white dwarf. That history and the abundant carbon are strong signals that the exoplanet started its life much farther from the star and that tidal interactions heated it as it migrated in to its current position.

Although WD 1856+534 b's system is different from our own, the work still offers potential insight into what may happen to Jupiter, Uranus, and Neptune billions of years in the future when our sun exhausts its fuel and evolves into a white dwarf. Similar to WD 1856+534 b, the outer planets may then find their orbits affected by gravitational interactions that heat them up and send them inward. In the meantime, MacDonald says he hopes to find a rocky planet orbiting a white dwarf, which could teach scientists more about the potential future of Mars or even Earth. **PT**

Reference

1. R. J. MacDonald et al., "Aerosols and hydrocarbons in the atmosphere of a white dwarf planet," *Nature* 655, 76 (2026).

Ghost imaging delivers high resolution with a limited x-ray dose

A new version of a technique that images samples with the help of light that never reaches them brings researchers closer to the goal of reducing radiation exposure in medical imaging.

By Sarah Wells

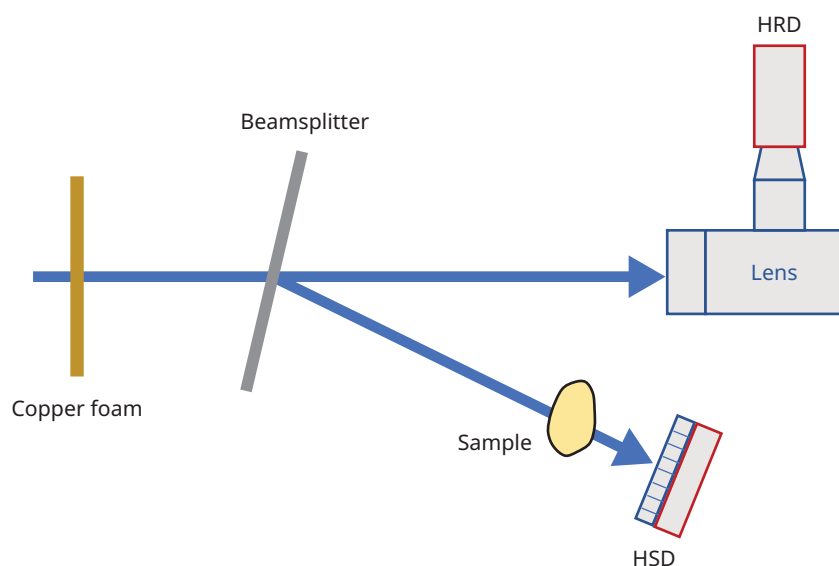
X-ray imaging with high spatial resolution is widely used in both scientific and clinical applications to look inside samples non-invasively. But although it allows users to quickly assess a fractured bone or the atomic structure of a crystal, such imaging can cause significant cellular damage to biological samples when they are extensively subjected to its ionizing radiation. Now Tiqiao Xiao of the Chinese Academy of Sciences in Shanghai and colleagues have adapted a technique called ghost imaging, most of whose x rays never interact with the sample.

Scanning nonbiological samples, the researchers achieved resolution on par with what's needed for biomedical applications while exposing samples to a fraction of the x-ray photons typically required in radiology.¹

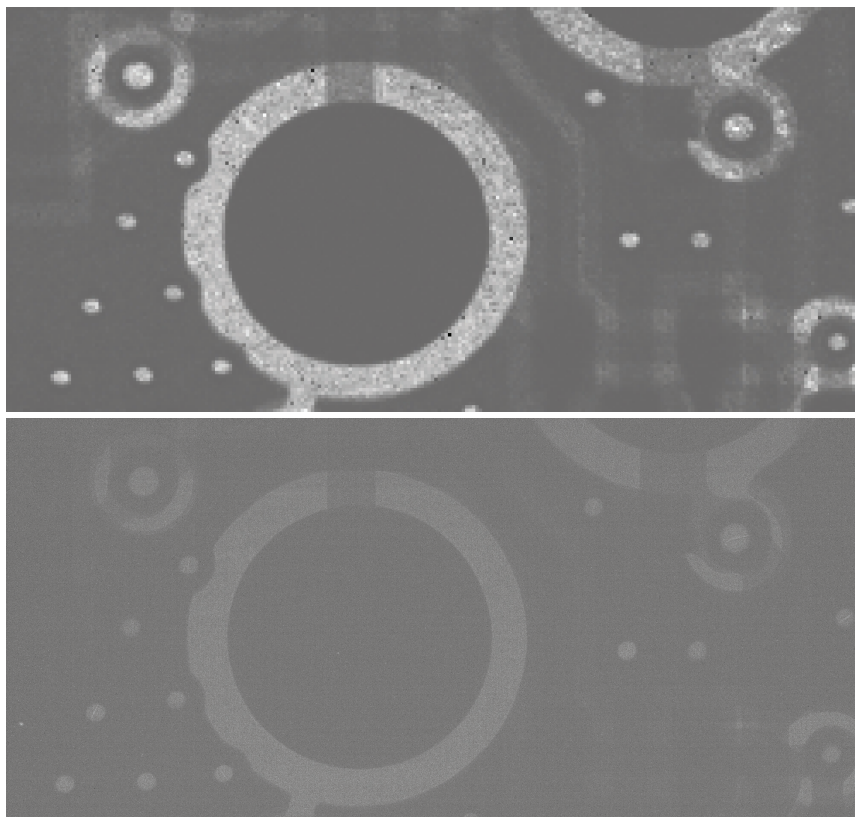
Ghost imaging was first experimentally demonstrated in 2016. As shown in figure 1, in Xiao and colleagues' setup, an x-ray beam is imprinted with a unique pattern before it's split to create a ghost, or reference, beam that never directly interacts with a sample and an object beam that does. Measurements of the spatial features of the reference beam are matched with mea-

surements of photon intensities of the object beam to gradually reconstruct an image of the sample.

A major challenge is that unlike radiological imaging, ghost imaging requires multiple scans of the sample, which can add to the total photon count even if the per-scan exposure is relatively low. To achieve high resolution while minimizing the number of scans, Xiao and colleagues installed a crystal beamsplitter and detectors tailored to each of the split beams. At the Shanghai Synchrotron Radiation Facility, the researchers passed an x-ray beam through a 300- μm -thick copper foam sheet to encode it with a speckle pattern and then split the beam with the crystal.



◀ **Figure 1.** The x-ray imaging technique implemented by Tiqiao Xiao and colleagues uses copper foam to imprint a beam with a speckle pattern before splitting it into two components: a ghost, or reference, beam that never directly interacts with a sample and an object beam that does. By correlating measurements taken by specialized—high spatial resolution (HRD) and high photon sensitivity (HSD)—detectors at the end of the beams' paths, the team can reconstruct an image. (Image adapted from ref. 1.)



▲ **Figure 2.** A circuit board is imaged with both a new x-ray ghost imaging technique (**top**) and conventional x-ray imaging (**bottom**). The new method required less than 0.5% of the photons of the conventional method to achieve the same resolution. (Images courtesy of Tiqiao Xiao, Shanghai Advanced Research Institute, Chinese Academy of Sciences.)

The reference beam traveled directly to a high spatial resolution detector, while the object beam passed through a sample before reaching a detector with high photon sensitivity.

To compare the image quality of the new method, dubbed ultra-low-light megapixel x-ray ghost imaging (UMXGI), with that of traditional x-ray imaging, the researchers used both techniques to reproduce a circuit board. They looked at the contrast-to-noise ratio—a measure of how much an object stands out from the background noise in an image—and the number of photons needed to visualize certain microstructures. The images are shown in figure 2. The team consistently found that UMXGI achieved the same image quality as the traditional method

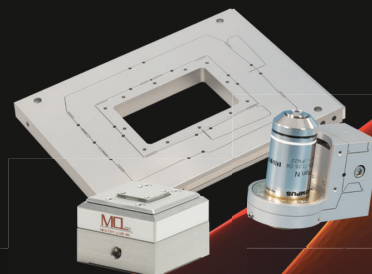
with 0.48% of the number of photons interacting with the sample compared with traditional radiological imaging.

UMXGI is not ready to be used on biological samples because they generally have less predictable structures and require a higher contrast-to-noise ratio than was achieved by the recent experiment. The next steps toward that milestone, Xiao says, include transitioning to a laboratory-scale x-ray source, like an x-ray tube. The team also plans to investigate the use of advanced image-reconstruction algorithms to improve overall image quality. **PT**

Reference

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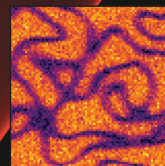


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The US is losing appeal for international students

Uncertainties in funding and visas are complicating international students' US experiences and leading some to go elsewhere.

By **Toni Feder**

Federal research funding in the US is on the rocks. Visas to study and work in the country have become more restrictive and harder to get. Universities have doubled down in cautiousness about how many graduate students they admit. Given the instability and uncertainty, it's no surprise that international students—who, for nearly two decades, have made up about 44% of the physics PhD student population in the US—are thinking twice before opting to pursue their PhDs in the country. (For more on funding, visas, and university admissions, see the 2025 *PT* story “Rapid-fire changes in federal funding stoke uncertainty in US universities.”)

The University of Illinois Urbana-Champaign saw a decrease this year of more than 17% in international applications for PhD spots in physics, says Lance Cooper, the department's graduate coordinator. For students from China and India, he says, the drops were 26% and 27%, respectively. (Bangladesh was among the few countries for which the number of applicants rose.) For comparison, domestic applications increased by nearly 10%. At the University of Maryland in College Park, applications for the physics PhD program went from 1000 last year to 850 this year, a drop “attributable entirely to fewer inter-

national students applying,” says physics chair Steven Rolston.

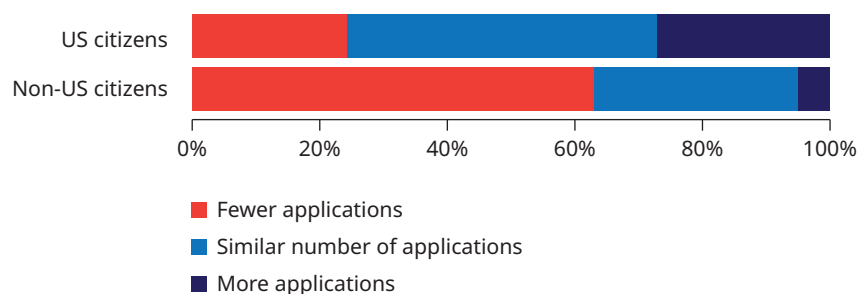
Such snapshots dovetail with the results of a survey conducted this past spring by the statistical research team at the American Institute of Physics (AIP, which publishes *Physics Today*). According to the group's 4 June report, more than 60% of US PhD-granting physics and astronomy programs received fewer applications from international students for this fall than for a year earlier; for US student applications, about half of departments saw little change and the rest were split roughly evenly between increases and decreases (see the chart below).

Depending on their nationality,

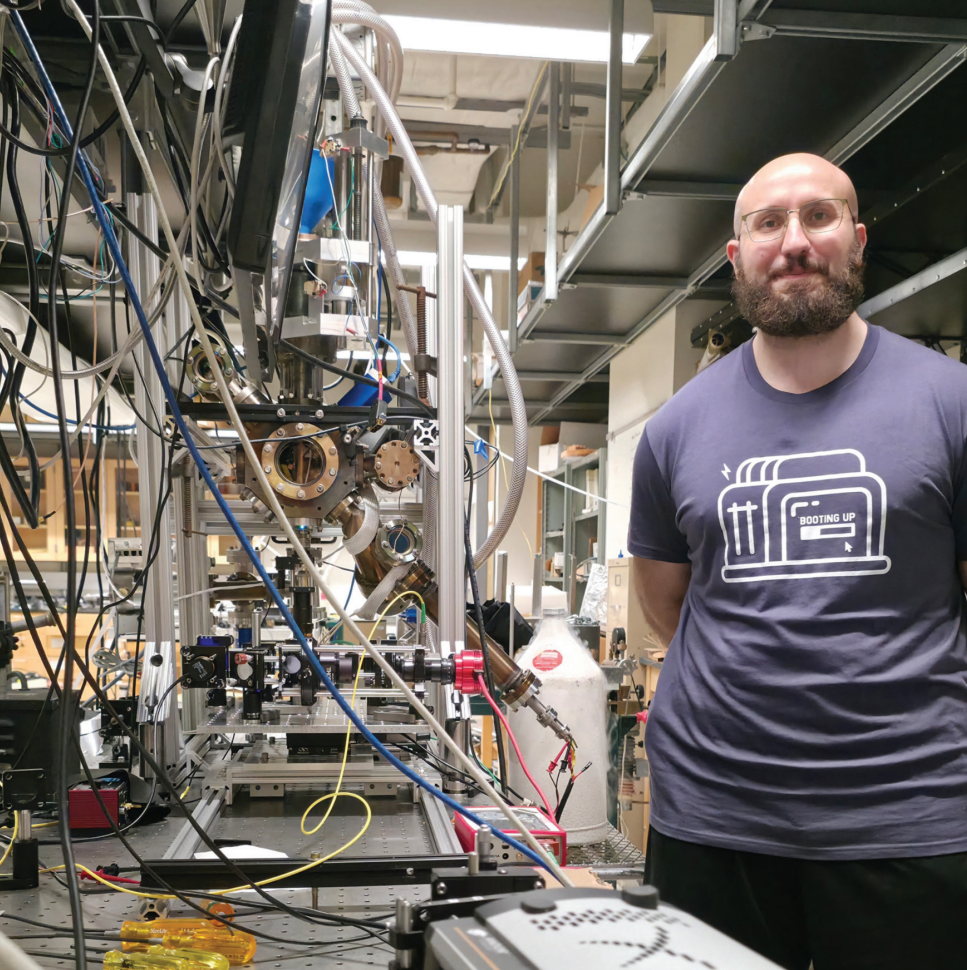
students who come—or try to come—from abroad may find themselves in unexpectedly precarious positions. The experience has become infused with anxiety and uncertainty. To ensure their futures, PhD candidates are accelerating their PhDs, skipping visits home, picking up master's degrees in case they are forced to exit the country before completing their doctoral degrees, or pursuing their studies in other countries.

Frustrations

Abdullah Alhag arrived in the US from Libya in 2014. He double majored in physics and computer science at the Ohio State University and then worked for three years



▲ More than 60% of the 81 US PhD-granting physics and astronomy departments that responded to a survey by the American Institute of Physics reported that they had received fewer applications from international students in fall 2026 than they had in 2025. The bars show the percentages of departments that reported a decrease, no significant change, and an increase in the numbers of applicants. (Bar chart adapted from P. Mulvey, T. Owens, and S. Nicholson, *Federal Funding and Visa Uncertainty Shape Fall 2026 Graduate Admissions in Physics and Astronomy*, American Institute of Physics, 2026.)



▲ Abdullah Alhag, a PhD candidate from Libya, in the lab at the Ohio State University. His PhD research has focused on the interactions of atomic qubits with 2D materials for quantum information science. He says that he no longer feels welcome in the US and plans to pursue his career abroad. (Photo courtesy of Abdullah Alhag.)

before starting his physics PhD at OSU. After President Trump returned to office, Alhag tried to finish faster because “the States has started to feel like a prison for people from countries under a complete travel ban.” (The ban relevant to him was implemented in June 2025.) He plans to finish his experiments investigating atomic qubit interactions with 2D materials at OSU and then write and defend his thesis remotely from outside the US.

Alhag notes that his professional connections are in the US and that entering a new job market will be a challenge in the current economic climate; he says he may pursue a postdoctoral position in Europe or elsewhere. For now, he says, although he feels safe, he worries about getting on a plane to go to a conference, even domestically: “Once they see my passport...”

A dual Russian–European citizen worked in the US finance sector before starting their physics PhD at a major US university in 2020. (Many international students who were interviewed for this article requested anonymity out of fear of retaliation, including the endangerment of possible future applications for a US visa.) The student had entered the US without incident multiple times. But in 2022, instead of the usual two weeks to renew their visa, they were stranded in Europe for a year and a half. The process is “like an administrative black hole,” they say. “I suspect the hassles are because I have Russian citizenship.” Finally, they were allowed back into the US. But when they returned to Europe for a family matter in 2024, they were pulled back into the vagaries of the visa

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process. After more than a year in limbo, they filed a writ of mandamus to require the government to give them a decision on the visa. Within two weeks, they say, they got their visa. They returned to the US in late 2025.

A theoretician, the Russian-European student was able to continue their PhD work from afar. To get by financially—including paying rent in the US—they did whatever their department came up with: “I worked with the communications department, I graded,” they say. “It would have been impossible without the support of my university.” In the current environment, they say, they are less inclined than before to pursue a career in the US.

After applying for a US visa multiple times, a student finally gained entry late last year to pursue a physics PhD at a university that had accepted them for fall 2024. Shortly after they arrived, new rules came into play for people from a host of countries, including the student’s home country of Nigeria. It would no longer be possible to reenter if they left the US. Not knowing when they’d see their spouse and child, who are in the UK, caused “mental stress,” they say. “I couldn’t concentrate.” Still, the student plans to stay to complete their PhD in computational nanoscience.

A German national wanted to study AI with a specific mentor in the US but was denied a visa. The student is now working on their PhD at a UK university. A student from Iran had their sights set on a PhD in theoretical physics at a US university. The school deferred admission twice, in 2024 and 2025, while the student tried to get a US visa. As the student’s hopes faded that the visa would be granted, they decided to study in Canada. The delays and denials from the US “caused mental and emotional

pressure,” the student says. The US suspension in January 2026 of visa issuance to Iranian nationals has created an additional professional barrier, the student says: “I cannot travel to any scientific event in the US just because of my nationality.”

Mitigations

Many other international graduate students and aspiring graduate students face related challenges. US universities and faculty members help where they can. They commonly defer admissions. They provide points of contact. They advise against leaving the country for conferences or visits home. They come up with responsibilities that students can carry out remotely to continue collecting a paycheck if they do get stuck outside the country.

When students who are advanced in their PhD studies have been stranded outside the US, as sometimes happens for those who go home to China, for example, universities have arranged for them to complete their dissertations and defend remotely. “If someone is in their fourth or fifth year, we would come up with ways for them to finish their PhD,” says Cooper. “But if they get stuck back in their home country in their first year, I don’t know if we could do anything.” Cooper says that he has contacted state representatives for help obtaining visas and contributed personal funds to help a prospective student with a writ of mandamus. The student was denied entry.

“A flood of international students has been applying for master’s degrees,” says Cooper. The degrees are insurance to avoid being left empty-handed if students can’t stay to finish their PhDs. A federal rule, set to take effect in mid-September, that will cap stays for international students is likely to exacerbate that trend—and discour-

age PhD students from coming to the US, he adds. Betty Wilkins, graduate program coordinator at Virginia Tech, says that physics PhD candidates who came in with physics master’s degrees are picking up master’s degrees in computer science and other fields.

Wilkins says she has seen an uptick in applications from international students who did their undergraduate studies in the US. Students who are already in the US have a visa, notes Cooper. “I have discussions with them about when they should go home to renew. These discussions never happened 5 or 10 years ago.” Students are “trying to read the tea leaves,” he says.

At the other end of the physics degree pipeline, graduates are increasingly leaving the US to put their skills to use. According to a 3 August report from the AIP statistics team, the percentage of international PhDs who were outside the country in the year after receiving their degree jumped from 16% in 2024 to 29% in 2025; that is the largest one-year increase in people leaving the US since 2006, which is as far back as the AIP researchers have checked. For US citizens, the percentage who were not in the country a year after receiving their degrees rose from 10% in 2024 to 12% in 2025.

The June AIP report on graduate admissions concludes that “departments generally are not anticipating restoring previous levels of international recruitment in the 2027 cycle, and a notable share remain uncertain about future admissions plans altogether.” The findings suggest, the report says, that “current funding and immigration-related uncertainties are likely reshaping graduate admissions strategies and the future talent pipeline for physics and astronomy, and likely all physical science disciplines, in the U.S.”

PT

Study of Danish academics reveals child penalty

Academics in the child-friendly nation face career disadvantages, such as lower employment rates, after becoming parents.

By **Jenessa Duncombe**

Welcoming a new child into the world is often described as a life-changing event for parents. New research suggests that it also could be an inflection point in parents' academic careers, particularly in the careers of women.

Researchers analyzing the careers of academics in Denmark found evidence of child penalties—"differential effects of parenthood on women's and men's likelihood of staying in academia, and having tenure"—despite the country's paid parental leave and subsidized childcare. In their preprint, which was posted earlier this year and has been submitted to a peer-reviewed journal, the researchers found that mothers leaving academia account for about 70% of Denmark's academic-employment gender gap.

"What surprised us was that the penalties persist well beyond the period of parental leave," says study coauthor Sofie Cairo, an economist at Copenhagen Business School. "This suggests that the challenge is not only time away from work immediately after birth but the longer-term difficulty of combining research with the ongoing responsibilities of caring for young children."

The study is part of a growing body of literature by economists quantifying child penalties, such as lost earnings or work-hour reductions, in a variety of careers. A study from 2019, for example, concluded that Danish women with children experience a persistent earnings penalty of 20% in the 20 years after their first child. Similar studies have been conducted in many countries around the world.

Denmark as a case study

One difficulty in child penalty research is obtaining information on when workers become parents. To make up for missing birth history, some researchers have assumed that workers have children after a certain number of years of marriage. Other researchers have surveyed workers directly about when they welcomed children.

"Our setting in a Scandinavian country allows us to actually overcome some of the empirical challenges



▲ (Photo by iStock.com/dragana991.)

that our colleagues in the past have faced," says study coauthor Valentina Tartari, an economist of science at the Stockholm School of Economics. Tartari and her colleagues had access to Danish academics' entire parenthood history via the country's administrative book-keeping. Denmark's population registers contain contemporary demographic, labor, family, and education information tagged by personal tax numbers. The registers include the year, age, and career stage that an academic became a parent. The data can be anonymized for studies like Tartari's.

Examining the child penalty in a country with strong family policies is a particularly useful case study because the child penalty may be lower than in countries with fewer family-oriented policies, says Tartari. Danish policies supporting maternity leave date back to the early 20th century, and paternity leave in the country was introduced in the 1980s. Today, Danish parents generally receive a combined 48 weeks of paid parental leave after birth, and they have access to low-cost childcare starting when the child is about six months old until they reach school age.

As in many other countries, women in academia are

underrepresented in top positions in Denmark. In 2022, about 25% of full professors in Denmark were women. In the US, 36% of full professors in the 2022–23 academic year were women, according to a survey by CUPA-HR, an association of human resources professionals in higher education. Research has shown that many women are driven out of STEM fields. (See Jennifer Blue, Adrienne Traxler, and Ximena Cid's 2018 *PT* article, "Gender matters.") In 2024, about 15% of physics and 17% of astronomy full professors in the US were women, according to the statistical research team at the American Institute of Physics (which publishes *Physics Today*).

Job outcomes

For the latest study, Denmark's national statistical authority assisted Tartari, Cairo, and their coauthors in matching individuals in the national population registers with academic publishing metrics from Elsevier's Scopus database and responses from a Danish academic survey conducted in 2017. The anonymized dataset—which Tartari has been working on for more than 10 years—comprises more than 13 000 academics who were enrolled in a PhD program from 1996 to 2017 and had children.

Tartari and colleagues examined, by gender, the academic career trajectories of academics who enrolled in a PhD program and subsequently became parents. Individuals included those who were single and those who were coupled with same- or opposite-sex partners. Then, the researchers took an event-study approach, a common economics modeling method that estimates an event's impact on subsequent outcomes. For example, the birth of a first child constitutes an event, and a parent's academic employment and tenure are outcomes.

The researchers found that the careers of men and women progressed similarly until the birth of their first child. Then, the average trajectories diverged. The researchers modeled the trajectories that mothers' careers would have taken had they not had children. Mothers' likelihood of being employed in academia eight years after they became parents was 29% lower than the likelihood if they hadn't had children. The mothers who stayed in academia were 23% less likely to obtain tenure eight years after having their first child than had they not become parents. Mothers who left academia mostly chose work outside of research, according to the Danish registers, and on average took a 12% pay cut.

Fathers, on average, were 14% less likely to have academic employment eight years after the birth of their first child than if they hadn't had children. Fathers, however, had the same likelihood of receiving tenure than had they not become parents, and they did not experience a drop in earnings.

Fathers' likelihood of receiving tenure dropped for those who took parental leave compared with those who did not take it. That and similar findings related to taking leave, the researchers write, is "consistent with the idea that time away from research and greater childcare involvement carry substantial career costs, regardless of the caregiver's gender."

Dissecting the child penalty

The researchers found that child penalties remained stubbornly entrenched even in the face of interventions. The penalty stayed consistent despite a mother's access to a retired grandmother or a partner who took parental leave. But one factor that lessened women's child penalties was their academic employment status when they became parents. If women secured a job in academia before having their first child, the child penalty on tenure decreased.

In the 2017 survey of Danish faculty and doctoral students, mothers and fathers reported different caregiving behaviors. Respondents who were mothers were five times as likely as fathers to be the primary parent for sick care, doctor visits, and nighttime care. For instance, 55% of mothers said that they would take care of a child during the night all or most of the time, compared with 11% of fathers. "We know from a long sociological tradition that parenthood is a moment where gender roles and the specialization in households become more relevant," says Tartari.

The study's findings do not capture the breadth of parents' personal experiences and family structures. Analyzing the career impacts of parenthood for same-sex couples only or single parents only was not possible due to the small sample sizes, Tartari says. She says that she frequently hears from men who say that they are more involved in raising their children than other fathers and that the study's findings do not resonate with them. But the average effects described in the study are still important, she says, particularly for shaping academic department policy pertaining to tenure and employment.

Petra Moser, an economist at New York University who provided feedback on an early manuscript of the study, says that the research complements a 2025 analysis of more than 80 000 scientists who worked in the US in the mid 1950s. In that work, Moser and Scott Kim, a University of Pennsylvania graduate student at the time, found that the scientific careers of women were significantly more affected by having children than those of men. "Comparing [the Denmark study's] results with ours suggests that unfortunately not much has changed since the 1950s, or at least not as much as we had hoped," says Moser.

PT

Q&A: Anna Quider advises the STEM community on federal policy

A love of science and ease in communicating led her to start a consulting firm that aims to broaden opportunities in science and technology.

By **Toni Feder**



▲ Anna Quider (Photo courtesy of Anna Quider.)

While working on her PhD in astronomy at the University of Cambridge, Anna Quider realized that although she loved knowing and promoting science, discovering something like a new stellar population wasn't motivating for her; she would be happy to be "the champion for the person who is making those discoveries." She earned her PhD in 2011, ditched her plans to pursue an academic career, and pivoted to science policy.

In 2023, she launched her consultancy, the Quider Group, through which she advises research and higher-education organizations on science policy, congressional and agency engagement, grantsmanship, and advocacy.

Quider says that she remains "deeply connected" to the physics community. She is a fellow of the American Physical Society (APS) and of the American Association for the Advancement of

Science (AAAS); both organizations have recognized her contributions to science policy and her mentoring of early-career physicists.

The following interview has been edited for length and clarity.

Why did you go into science?

In eighth grade, my Earth sciences teacher wrote on the board that the universe was expanding. I could think of nothing else: How is it expanding? Is it stretching? Or is it rigid? I was always curious about a lot of things, so my ending up in science was not surprising. Early on, I was convinced I would be an astronomy professor.

How did you U-turn from your early plan to stay in academia?

What started opening my eyes was winning the Marshall Scholarship from the British government to do graduate studies at Cambridge. The scholarship has a policy component, and I had the opportunity to meet with elected leaders in the UK and to visit Scotland, Northern Ireland, and Ireland. Crucially, I started going to talks at Cambridge's new Centre for Science and Policy, and members of Parliament said they needed scientists to bring their expertise to policymaking.

At the same time, although my research was going well, I was realizing that sitting at a computer all day, every day, and wrestling with data was not how I wanted to spend my time. I'm better at talking to people than I am at talking to machines.

I started thinking, What are the things that I am uniquely good at? What do I value? It kept coming back to, I really like communicating, I like complexity, I like systems thinking.

I like knowing science, and I like promoting science, but I discovered in grad school that I am not motivated by discovery. That got me thinking about how I could become part of the enabling environment.

What were your next steps?

I became an APS Congressional Fellow and worked for a member of Congress for a year advising on science, technology, innovation, telecommunications, and education. Then I worked for nearly two years in the State Department on an AAAS Science & Technology Policy Fellowship. Those experiences showed me that science policy is a way to serve the scientific enterprise at a systems level and introduced me to the government relations profession.

I joined Northern Illinois University as federal relations director and later as an assistant vice president.

What did your work at Northern Illinois University entail?

I founded the DC office for the university, and I managed its federal portfolio. I maintained and managed our relationships with the state's congressional delegation. I advised the institution on federal policy issues. My role was also about creating opportunities for expertise within the institution to make its way into the policymaking process—for example, by setting up opportunities for faculty experts to weigh in with committees and other congressional staff who make decisions.

Part of the work relates to science and technology policy funding and how that connects with opportunities on campus. But it also involves other federal policies that affect institutions, such as those on immigration, athletics, tax, and labor.

While at the university, I was also very involved in crafting the science portion of the CHIPS and Science Act. [The 2022 law authorizes roughly \$280 billion for domestic semiconductor research and manufacturing and for other investments in science and technology.]

How did you contribute to the CHIPS and Science Act?

One of my major contributions was leading the effort to include a new higher-education designation: emerging research institutions, or ERIs, which are higher-education institutions that spend less than \$50 million annually on federally sponsored STEM research. Among higher-education institutions in the US, about 175 are not ERIs. But those 175 receive 93% of federal research dollars despite educating less than half the students—and only about one-third of low-income and minority students attend a research-active campus.

Why did you switch to consulting?

I had been doing effectively the same job for eight and a half years. Having that hyperfocus on science and technology policy [while working on the CHIPS and Science Act] made me realize that I wanted to get closer to my roots in science and technology. It was important to me that I focus on increasing access to opportunity; by offering multiple services under one contract, I make strategic federal engagement more accessible to more organizations. I also wanted a job that would let me have work-life balance—I have a young daughter.

How did you make the switch?

You see a problem, you see an opportunity. That's what entrepreneurship is. If the solution doesn't exist, you build one. That's why I started my firm in January 2023. It's been great.

The funny thing was that earlier, when I was at the State Department, I had managed a global entrepreneurship program. At the time, as I sat through entrepreneurship trainings, I told myself, “Being an entrepreneur is brutal. I’m never doing that.” I ate my words.

Tell me about your firm.

I work with higher-education institutions and other research-focused organizations. My clients are mostly ERIs. I help them strategize and get what they need from the federal government, with a focus on science and technology.

I also do paid speaking to keep clients informed about what’s happening in the federal government in areas that matter to them. For example, I am hired by boards to give quarterly updates on federal policy priority areas. Science policy fellowships hire me to run trainings on policymaking. And I do grantsmanship trainings and advise on national scholarships and student opportunity programs.

For some clients, my work has a strategic component. For others, it’s more focused on government relations. They may want support navigating a congressio-

nal process or advancing a priority of theirs through the legislative or appropriations process. Some clients want a little bit of everything.

How has demand changed since the new administration came in?

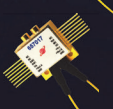
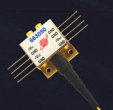
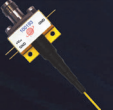
My clients need more real-time interpretation of federal policy and funding developments and more support anticipating what could be coming next. Some clients have decided to put building toward long-term federal policy or funding goals on the back burner. Their immediate priority is navigating uncertainty from the federal government, including research funding levels, grants administration policy changes, and reduction in basic-needs assistance for students.

How do you use your physics in your work?

I do a fair bit of data analysis. I’m not daunted by complex problems; I understand that they can be broken down. And I use my physics background to tap into a network of other highly motivated, technical people. Finally, people sometimes have more respect for “Dr. Quider” than they do for “Anna.”

PT

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Air and Space Museum celebrates 50 years with revamped galleries

By **Faith Simmons**

A half century after opening its doors, the Smithsonian's National Air and Space Museum in Washington, DC, unveiled five reimagined galleries on 1 July. "It became clear a decade ago that significant work was needed to bring this museum into the 21st century," director Christopher Browne said during a press tour. The institution has received roughly \$1 billion in public and private funding, and most of the renovations were ready in time for the country's semiquincentennial. The museum's eight-year-long revitalization of all 20 of its galleries will be complete when the last two displays open this fall.

Among the first things visitors see when they enter the building is a full-scale model of the *Hubble Space Telescope* in the *RTX Living in the Space Age Hall* exhibit, which features exhibits on rocket innovation, missile development, and the people who worked on space technology. Another gallery features artifacts that put aviation at the center of World War II and helped make the US a superpower. A third explores questions about the universe and includes a stack of hard drives containing black hole data from an Event Horizon Telescope site in Hawaii. Multimedia and in-

The *Jay I. Kislak World War II in the Air* gallery features a bronze statue of the Tuskegee Airmen, the first Black military aviators in the US. Above them hangs a North American P-51D Mustang, which had more victories than any other Allied fighter because of its speed and agility. (Photo by Daniel Soñé, Smithsonian's National Air and Space Museum.)



▲ The *RTX Living in the Space Age Hall* exhibit covers space technology and infrastructure from the mid 20th century to the present and the impact they have on daily life. The hall includes a model of the *Hubble Space Telescope* (back right), a training version of the Minuteman III missile (center), and the backup Skylab Orbital Workshop (left), the largest component of the US's first space station. (Photo by Mark Avino, Smithsonian's National Air and Space Museum.)





◀ **(Top)** Visitors to the museum can sit inside a model of the Cessna Skyhawk and manipulate airplane controls to move the ailerons, elevator, and rudder. Beneath the single-engine plane is a walk-in wind tunnel for guests to test the effect of lift and drag on different wing shapes. To the right is a buoyancy demonstration in which visitors fill a balloon with hot air and watch it rise. (Photo by Daniel Soñé, Smithsonian's National Air and Space Museum.)

(Middle) The U.S. National Science Foundation *Discovering Our Universe* gallery is organized by questions that include "What do we learn from starlight?" and "How did the telescope change astronomy?" Multimedia stations around the exhibit hall share how more-precise instruments have allowed researchers to better understand the universe. (Photo by Michael Persaud, Smithsonian's National Air and Space Museum.)



(Bottom) The *Flight and the Arts Center* explores the relationship between creativity and the experience of flying. Catherine Stewart's *Katherine Johnson Dress* is on display in the left case. (Photo by Michael Persaud, Smithsonian's National Air and Space Museum.)

teractive tools focus on the people who worked with the instruments on display. For instance, one presentation spotlights astronomer Vera Rubin and the image tube spectrograph she used to find evidence of dark matter.

The museum's most hands-on exhibition, which contains nearly 50 interactive stations, focuses on how aircraft and spacecraft fly. Visitors, for example, can sit in a full-scale Cessna Skyhawk, test wing shapes in a wind tunnel, or pilot a drone. The museum's art collection, which is in a renovated space, features works by more than 50 artists. Included are the Norman Rockwell painting *Man on the Moon (Portrait of an Astronaut)* and Catherine Stewart's *Katherine Johnson Dress*, a tribute to the NASA mathematician whose work was vital to early spaceflights. (To read more about Johnson, see the 2017 *PT* article "What it took to be a NASA computer.") The dress features embroidered equations from a paper on lunar orbit that Johnson coauthored.

PT



US caps length of student visas

By **Lindsay McKenzie** and **Jacob Taylor**

Starting on 15 September, the US will admit student visa holders for a fixed period that is tied to their program's length but capped at four years, and it will add restrictions on when and whether visa holders can change their majors or programs.

The federal rule laying out the new immigration regulations was published by the Department of Homeland Security in July. The four-year limit applies to F (student) and J (exchange visitor) visas. The rule does away with the duration-of-status system, which had allowed student visa holders to remain in the US for the duration of their time as a student.

Universities and scientific organizations warn that the change creates new administrative hurdles for international students and that it may deter them from choosing to study in the US. (For more on the uncertainty facing international students in US physics and astronomy departments, see "The US is losing appeal for international students" on page 14.) Under the rule, students who need more time to complete their program will have to either apply for a formal extension of stay from US Citizenship and Immigration Services or leave the country and apply for a new visa before returning.

DHS says that the new rule closes an immigration loophole by restoring federal oversight of immigration decisions that had been delegated to university officials. "For decades, foreign students have been admitted into the U.S. indefinitely, allowing thousands to abuse our immigration system by perpetually enrolling in courses to avoid having to leave the U.S.," DHS Secretary Markwayne Mullin said in a statement.

DHS proposed eliminating the duration-of-status rule during President Trump's first term, but the proposal was withdrawn during the Biden administration. During the public comment period for the new rule, many universities, medical schools, scientific societies, immigration advocates, and lawyers argued that the proposal would disproportionately affect doctoral students, researchers, and physicians in training, whose programs routinely exceed four years.

In its response to the comments, DHS said that the four-year cap is "intended as a law enforcement and screening tool to assess whether a student is maintaining normal academic progress and eligibility for F-1 status," rather than as a mechanism to force students to finish within four years.

In a 2025 report, the statistical research team at the American Institute of Physics (which publishes *Physics Today* and *FYI*) found that about 97% of international students in physics and astronomy take more than four years to complete their PhDs; the median duration for all students, domestic and international, is six years. The median time to complete a research doctorate across all disciplines is 5.7 years, according to NSF's 2024 Survey of Earned Doctorates.

The new rule prevents international undergraduate stu-

dents from changing programs or switching majors during their first year, and graduate students on a student visa are prohibited from changing programs or switching majors. International students who complete a degree in the US will not be allowed to pursue another degree in the US at the same or lower education level.

White House science vision puts individuals before institutions

By **Lindsay McKenzie**

The US research enterprise has become too centered on established research institutions, according to a report issued by the White House Office of Science and Technology Policy in July.

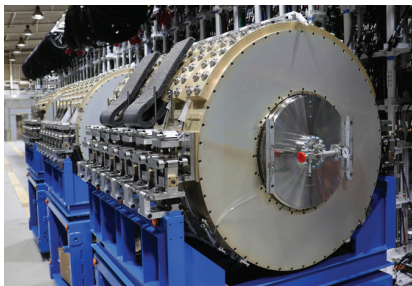
Authored by OSTP Director Michael Kratsios, *Science: A New Golden Age* is written as an update to Vannevar Bush's landmark 1945 report, *Science: The Endless Frontier*. Kratsios argues that today's scientific landscape is shaped by AI, global competition, and large private-sector investment and therefore requires a fundamental redesign of how the federal government funds research.

Key recommendations in the report include prioritizing individual scientists over "a narrow set of legacy institutions," with greater federal support for startups, independent research organizations, nonprofits, industry, and NSF's recently launched X-Labs program, which aims to support research teams from a wide variety of organizations and allow those teams to operate with broad independence. Kratsios also frames NSF's Graduate Research Fellowship Program as a success story that should be expanded.

In the report, Kratsios argues that traditional peer review tends to disadvantage bold ideas from individual researchers. He recommends the use of experimental funding approaches, including letting technical reviewers at federal agencies recommend "unconventional proposals that may not pass consensus-driven review panels." That "golden ticket" model is being piloted at NSF's Directorate for Technology, Innovation and Partnerships. The report also issues a new call to "rein in indirect cost recovery that supports administrative bloat, redirecting that money to real scientific infrastructure."

As a supplement to the report, Kratsios and White House Office of Management and Budget Director Russell Vought published a memorandum on the Trump administration's R&D budget priorities for fiscal year 2028. The memo instructs science agencies to incorporate the priorities into their forthcoming budget requests and to develop implementation plans within 90 days for a series of "R&D priority practices." **PT**

For more from *FYI*, the science policy news service at AIP, visit <https://aip.org/fyi>.



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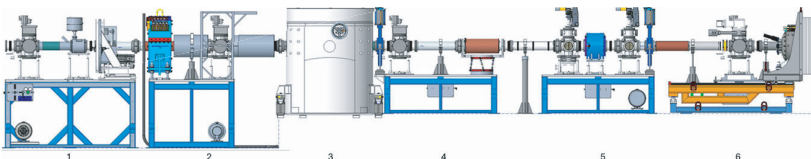
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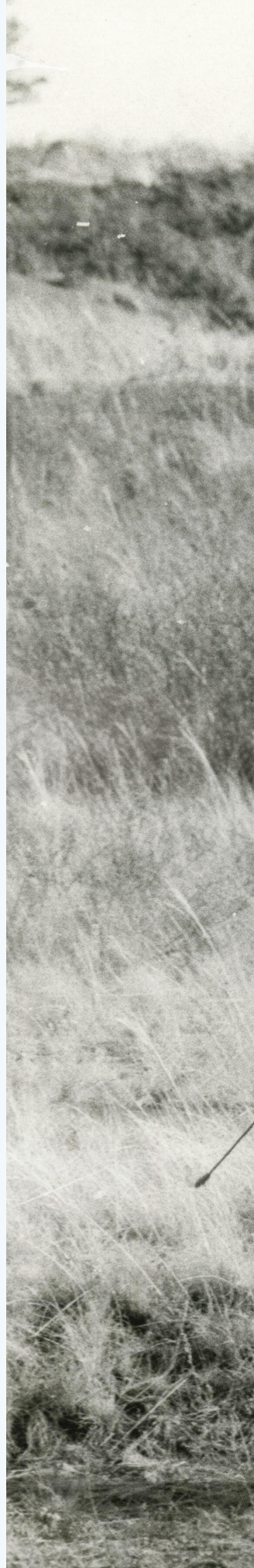
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How Soviet and US scientists helped end the Cold War nuclear arms race

**Frank N. von Hippel, Roald Z.
Sagdeev, and Thomas B. Cochran**

Three physicists give a firsthand
account of disarmament efforts in
the 1980s and 1990s.





◀ Soviet physicist Evgeny Velikhov (left) with US physicist Thomas Cochran in Kazakhstan in 1986. (Photo from Colaimages/Alamy.)

Significant changes in global policy are generally achieved only after long-fought struggles by coalitions of key players and advocates. In the case of nuclear arms control, scientists—especially physicists—have made important contributions both to the public debate and as government advisers. The three of us had the good fortune to participate in such an opening 40 years ago. We are sharing our story here in the hope of encouraging our fellow scientists to be alert to opportunities to network and brainstorm internationally about global problems.

The freeze movement

Our engagement in international dialogue about nuclear arms control began in the early 1980s. At that time, Cold War tensions were at the highest they had been since the Cuban Missile Crisis in 1962. The Reagan administration came into office in 1981 convinced that the Soviet Union was seeking the capability to fight and win a nuclear war, and it backed the development of a new generation of ballistic and cruise missiles accurate enough to destroy a large fraction of the Soviet strategic nuclear forces.

The administration's rhetoric about nuclear war-fighting provoked the rise of a mass movement in the US calling for a freeze in the nuclear arms race. (See the January 1983 *PT* article "The freeze and the counterforce race," by Harold Feiveson and Frank von Hippel.) That movement arguably peaked on 12 June 1982, when a huge, exuberant crowd of protesters with banners marched in New York City from the United Nations headquarters to Central Park, where approximately 1 million activists gathered to hear speeches.

Nine months later, Reagan shifted his focus and announced the Strategic Defense Initiative (SDI), a proposed space-based missile defense system that he claimed would make Soviet missiles "impotent and obsolete." He offered to share the technology with the Soviet Union. Critics ridiculed the initiative as a fantasy and labeled it Star Wars.

The Soviet government had already had internal debates over space-based ballistic-missile defense systems. In the late 1960s, one institute suggested shooting down incoming warheads with lasers or particle beams. And in the early 1980s, one of the bosses of the Soviet missile complex proposed placing interceptors in orbit like those proposed shortly thereafter by the Reagan administration (and now by the Trump administration).

Evgeny Velikhov, a fusion physicist who was one

of the vice presidents of the Academy of Sciences of the Soviet Union and later president of the Kurchatov Institute of Atomic Energy, had developed high-powered lasers and was invited by the Soviet leadership to participate in its reviews of the ballistic-missile defense proposals. Those reviews highlighted the systems' limitations and vulnerabilities. (For more on Velikhov's role, see his November 1989 *PT* article, "Science and scientists for a nuclear-weapon-free world.")

Velikhov and one of us (Sagdeev), at the time the director of the Space Research Institute of the Soviet Academy of Sciences, had benefited from dialogues on nuclear arms control with senior US physicists who had advised their government on nuclear weapons issues. The US National Academy of Sciences had recently created the Committee on International Security and Arms Control to engage with foreign counterparts.¹ Members included Richard Garwin, Marvin Goldberger, Wolfgang Panofsky, and Charles Townes.

In the wake of Reagan's SDI announcement, Velikhov organized the Committee of Soviet Scientists for Peace and Against the Nuclear Threat (CSS), a new body within the Soviet Academy that would engage with the US scientific community more broadly. Sagdeev, who initially served as Velikhov's deputy and succeeded him as chairman of the CSS, led several studies that recommended that the Soviet Union not attempt to emulate the SDI program. Instead, the studies proposed that the Soviet Union adopt a much less costly asymmetric strategy of countermeasures to neutralize any US space-based defense system.

The CSS also reached out to its counterparts in the US. Back in 1972, during the era of Cold War détente, the US and Soviet Union had ratified the Anti-Ballistic Missile (ABM) Treaty, which placed strict limits on the two countries' ballistic-missile defenses. The committee wrote an open letter to US scientists asking whether they had changed their opposition to ballistic-missile defense. Mathematician Jeremy Stone, director of the Federation of American Scientists, and one of us (von Hippel), the FAS chairman, wrote back,

We want the ABM Treaty strengthened rather than weakened. And we consider this Treaty to be the fulcrum on which new limitations on offensive weapons can, and must be, based. Without this Treaty, the arms race would soon speed up, and become still more dangerous than it is even today.²

That exchange launched a series of reciprocal visits that allowed the CSS and FAS to brainstorm about strategies for nuclear arms control.

Gorbachev's nuclear-testing moratorium

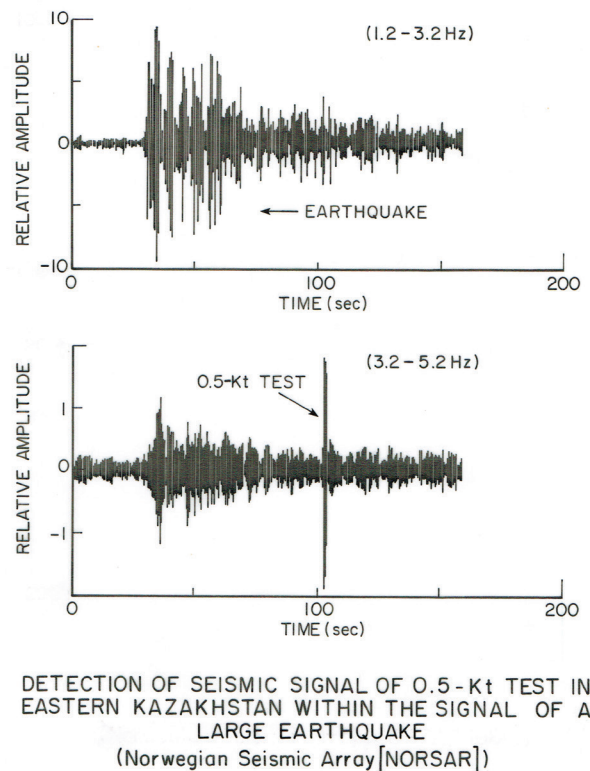
Velikhov was invited in December 1984 by the Central Committee of the Soviet Communist Party to accompany a young member, Mikhail Gorbachev, on a trip to the UK. After returning, Velikhov became a close adviser to Gorbachev, who became the leader of the Soviet Union in March 1985.

The first nuclear arms control initiative that Gorbachev announced was a unilateral moratorium on Soviet underground nuclear weapons tests starting on 6 August 1985, the 40th anniversary of the atomic bombing of Hiroshima. Although originally intended to last until the end of that year, it ended up being extended through 1986. It was an echo of Nikita Khrushchev's unilateral nuclear test moratorium of 1958, which Dwight D. Eisenhower joined five months later and which ultimately helped lead to the 1963 Partial Test Ban Treaty that banned nuclear tests everywhere except underground.

Underground testing was not prohibited in that treaty because of concerns from both sides. In the US, test-ban opponents made exaggerated claims that the Soviets could reduce the seismic signals of underground nuclear explosions by a factor of 300 by conducting them in huge, deep caverns. The Soviets, on the other hand, were paranoid about the US's demand for a large quota of annual on-site inspections at the locations of suspect seismic events in the Soviet Union.³

Even though Reagan was not interested in joining Gorbachev's underground-test moratorium, an international organization called the Parliamentarians for Global Action commissioned Charles Archambeau, a US expert on the seismic detection of underground nuclear tests, to design a system that could verify a bilateral moratorium if one were instituted. He proposed constructing clusters of seismic stations around the test sites.

Velikhov was thinking along similar lines. Two months after the Soviet testing moratorium began, while he was at a conference on nuclear arms control in Copenhagen on the occasion of the 100th anniversary of Niels Bohr's birth, Velikhov proposed to "organize a [nongovernmental] laboratory to detect nuclear explosions. We do not need anyone's permission to make it.... Let us turn for money to the



▲ Two seismograms taken by a Norwegian seismic array on 14 September 1979 illustrate the advantage of taking measurements above the normal frequency range used for studying earthquakes. The upper seismogram shows the signal from a distant earthquake in the 1.2- to 3.2-hertz frequency band. The lower seismogram, taken in the 3.2- to 5.2-hertz band, shows an event in Kazakhstan that was determined to be a small, 0.5-kiloton nuclear test. (Figure adapted from L. B. Loughran, ed., *Semiannual Technical Summary*, 1 April–30 September 1984, sci. rep. no. 1-84/85, NORSAR, November 1984, p. 62.)

individuals and organizations who are worried about the nuclear threat.”⁴

Von Hippel, who attended the conference, told Velikhov that he would try to find Western groups that might be interested in supporting the effort.

Another of us (Cochran) independently began developing a similar monitoring proposal. At a workshop in Moscow organized by Velikhov and von Hippel in May 1986, Cochran proposed that the Soviet Academy of Sciences and the Natural Resources Defense Council (NRDC), the US environmental group where he worked, establish jointly operated seismic stations around the two nations' nuclear test sites: the Semipalatinsk Test Site in northeastern Kazakhstan and the Nevada Test Site. After deliberating with his colleagues and seeking government approval over the weekend, Velikhov signed an agreement for



▲ US seismologists with seismometers on a granite outcrop about 200 kilometers from the Semipalatinsk Test Site in northeastern Kazakhstan to measure surface background noise. Permanent seismometers were placed in 100-meter-deep boreholes to isolate them from the surface noise.

collaboration with Adrian DeWind, the NRDC chair, who had accompanied Cochran to the workshop.

Archambeau, who also participated in the Moscow workshop, reached out to Jonathan Berger, a leading seismologist at the Scripps Institution of Oceanography at the University of California, San Diego, and he agreed to recruit a group of US seismologists for the collaboration. Mikhail Gokhberg, deputy director of the Soviet Academy's Institute of Physics of the Earth, recruited seismologists from his institute.

Berger and his team chose seismometers capable of recording higher-frequency signals so that they could distinguish earthquakes from chemical and nuclear explosions. DeWind's connections in the Reagan administration helped speed US government permissions to ship the seismometers to the Soviet Union and to set up seismic stations on federal land around the Nevada Test Site.⁵

The US and Soviet seismologists arrived with their equipment in Kazakhstan on 9 July 1986 and

began the process of setting up three seismic stations around the Semipalatinsk Test Site.⁶ Two years later, the NRDC was able to invite the Soviet seismologists to Nevada. The collaboration calibrated the seismic transmissivity of the rock under the test sites with nearby chemical explosions.

The Soviet display of openness had a dramatic impact in the US House of Representatives. Christopher Paine, a congressional staffer who attended the May 1985 workshop in Moscow, worked with then-Representative (and now Senator) Edward Markey (D-MA) on a measure that would have required the US to place a moratorium on nuclear tests with yields above 1 kiloton as long as the Soviet Union reciprocated. The measure passed the House in August 1986, but it took six years before enough support could be found in the Senate to force a stop to US nuclear testing. The moratorium legislation, which was signed into law by George H. W. Bush in October 1992, also required the executive branch to initiate

negotiations on a treaty banning all nuclear tests.

Negotiations in Geneva produced the Comprehensive Nuclear-Test-Ban Treaty in 1996. Although the treaty still has not entered into force—it has not yet been ratified by nine required states, including the US—it has been complied with since 1998 by all nuclear-armed countries other than North Korea. (Both Trump administrations have accused Russia and China of carrying out small nuclear tests, but they have not provided any evidence for Russian tests, and their seismic evidence for possible Chinese tests is ambiguous.)

Nuclear glasnost

Glasnost, or openness, was Gorbachev's policy to facilitate internal Soviet political reform. Starting with the 1986 Soviet test-site monitoring initiative, Velikhov used glasnost to promote international nuclear arms control.⁷ The next year, he partnered with Cochran and his group at the NRDC to bring a US delegation—including three members of the House, members of their staff, and two US journalists—to visit one of the newly established joint seismic monitoring stations in Kazakhstan.

After they returned to Moscow, Velikhov arranged a second site visit to a large Soviet phased-array radar under construction near Krasnoyarsk in Siberia.⁸ The US government had pointed out that the radar violated the ABM Treaty, which required that all early-warning radars be located on the periphery of the country and face outward. But the visitors saw that the radar was not hardened against nearby nuclear explosions and that the spacing of its receiver components meant that its wavelength was too long for battle management and that it indeed was an early-warning radar. Two years later, Soviet Minister of Foreign Affairs Eduard Shevardnadze—one of Gorbachev's reformist allies—acknowledged that the radar violated the ABM Treaty, and the government began tearing it down.

Immediately following the 1989 Black Sea Experiment discussed below, Velikhov took a similar US delegation, including Cochran, Paine, and von Hippel, to visit Ozersk, a closed plutonium production city in the Ural Mountains, to show that the Soviet Union was beginning to shut down its production reactors. (US plutonium production reactors had already been shut down by then because of safety concerns after the 1986 Chernobyl accident in Ukraine.) The visit started the two countries down a path to a 1994 bilateral Russian-US agreement to end plutonium production for weapons.⁹

Velikhov then took the same group to visit a laser director at the Soviet ballistic-missile defense test site at Sary Shagan in Kazakhstan. A Pentagon publication claimed that the facility was part of a clandestine Soviet counterpart to SDI.¹⁰ The visitors found, however, that it contained only low-powered lasers. As Velikhov related in his 1989 *PT* article, the operators stated that they had been unable to even detect a reflection from a satellite equipped with a retro-reflector. Velikhov gave his own account of those adventures in his 2012 memoir, *Strawberries from Chernobyl: My Seventy-Five Years in the Heart of Turbulent Russia*.

Warhead detection and dismantlement

Sagdeev, who took over from Velikhov as chairman of the CSS, and von Hippel at the FAS established in 1987 a joint study group on the detection and verified dismantlement of nuclear warheads. Von Hippel's interest was reinforced by testimony given at the 1988 ratification hearings for the Intermediate-Range Nuclear Forces Treaty, which eliminated all Soviet and US land-based missiles with ranges between 500 and 5500 kilometers. A Reagan administration official explained that the treaty did not provide for the destruction of the missile warheads because verifying that they had been destroyed would be too intrusive.

Sagdeev, on the other hand, was motivated by Soviet arms control concerns: US sea-launched cruise missiles could easily reach Moscow from the waters around Europe, so the Soviets wanted to include them in future arms control agreements limiting nuclear missiles and warheads. But US negotiators had rejected that proposal on the basis that it would be impossible to nonintrusively distinguish nuclear-armed cruise missiles from conventional ones. Sagdeev thus wanted to determine the ranges at which radiation detectors could identify the presence of warheads on ships.

Cochran and Velikhov agreed in 1988 to demonstrate the use of various types of radiation detectors for identifying the presence or absence of nuclear warheads on ships. With Gorbachev's backing, Velikhov was able to acquire for one day (5 July 1989) the use of the Soviet Black Sea Fleet's flagship, the nuclear-armed missile cruiser *Slava*. In what came to be known as the Black Sea Experiment, a helicopter with a neutron detector developed at the Kurchatov Institute strapped to its side successfully picked up neutrons from spontaneous fission of plutonium-240,



▲ During a detection test on 5 July 1989, a nuclear-armed cruise missile was loaded into one of the launchers of the Soviet missile cruiser *Slava* (top, pictured in 1983), and a neutron detector developed by Soviet physicists was carried by a helicopter (bottom left). The detector was able to pick up neutrons from spontaneous fission of plutonium-240, a minor isotope present in warheads, up to 70 meters away. Soviet physicists later shared that the system had been flown over US nuclear-armed ships. On board the *Slava* (bottom right), a Soviet experimental physicist (right) uses a liquid-nitrogen-cooled germanium-crystal scintillation counter to measure the gamma-ray spectrum from the cruise missile warhead. Steve Fetter and Thomas Cochran took similar measurements with a US-made counter.¹⁷ (*Slava* photo from Wikimedia Commons/ National Archives at College Park, MD, photo no. 6380582.)

a minor isotope present in the cruiser's warheads, from 70 meters away.

The joint FAS–CSS study group ultimately produced a 1990 book, *Reversing the Arms Race: How to Achieve and Verify Deep Reductions in the Nuclear Arsenal*, edited by von Hippel and Sagdeev, that proposed a nonintrusive approach to nuclear warhead dismantlement. Congress ordered the Department of Energy to do its own study of verified warhead dismantlement. The DOE report did not rebut the FAS–CSS approach but questioned the value of verifying warhead dismantlement given the uncertainty of the size of the Soviet stockpile.¹¹

That underlined the potential importance of nuclear archaeology—checking the veracity of declarations by the Soviet Union and the US of the quanti-

ties of plutonium and highly enriched uranium that they had produced. All the Soviet and most US plutonium had originated in graphite reactors. As part of the FAS–CSS study, Steve Fetter of the University of Maryland showed that neutron transmutation of trace elements in the graphite could be used to estimate the neutron fluence to which the graphite had been exposed and thereby the cumulative amount of plutonium the reactors had produced. That technique was tested and verified as accurate by Pacific Northwest National Laboratory, but it has not yet been incorporated into an arms control agreement.¹²

Many of the study group papers were also published in *Science and Global Security*, a joint US–Soviet journal originally proposed by Sagdeev in the 1980s and founded in 1989 by Harold Feiveson, who

edited the journal for 20 years, von Hippel, and Sagdeev. It continues to publish articles on the technical basis for nuclear arms control.

Workshops on eliminating nuclear warheads

Cochran and Paine at the NRDC, von Hippel at FAS, and Sergei Kortunov, a young, new-thinking official in the Soviet (and later Russian) foreign ministry, co-organized a series of international workshops from 1990 to 1993 with scientists from the weapons laboratories. The objective was to brainstorm about how to dispose of the nuclear material inside the excess warheads from the Cold War and downsize the nuclear weapons complexes.

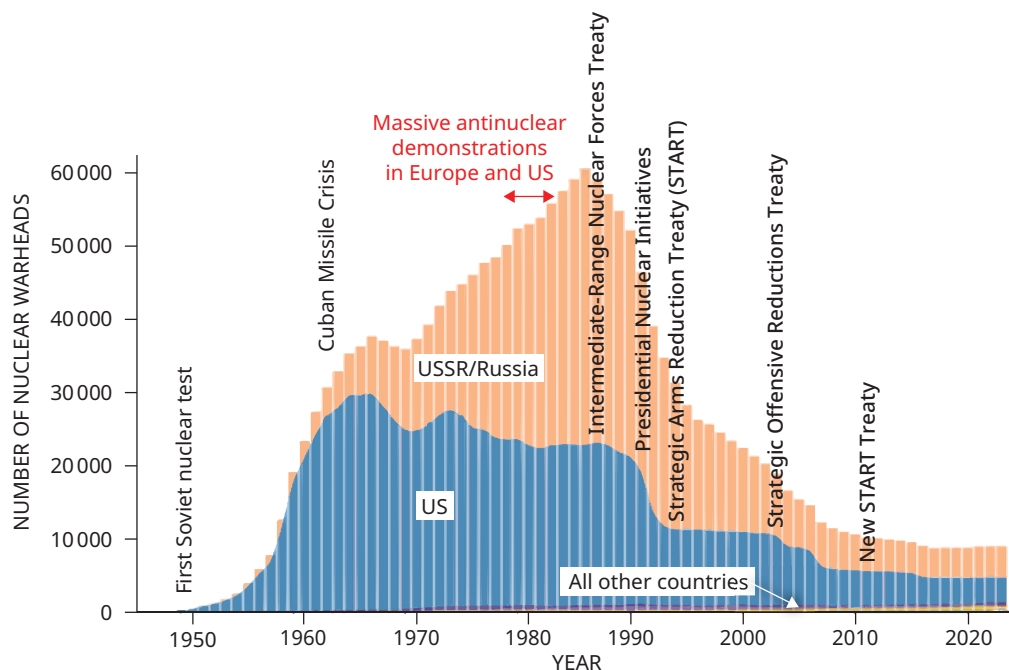
At the October 1991 workshop in Washington, DC, Thomas Neff, an MIT physicist who had written a book about uranium markets, approached Viktor Mikhailov, a weapons physicist who was serving as the Soviet Union's deputy minister of atomic energy and would soon become Russia's minister of atomic energy. Neff proposed that the Soviet Union, which was entering a deep economic depression, could dispose of the highly enriched uranium from its excess warheads by blending it down to low-enriched uranium that would be sold as fuel for nuclear power plants. In that way, the possibility of weapons-grade uranium being sold on the black market by desper-

ate nuclear workers would be forestalled. The idea made sense to Mikhailov, and Neff soon publicized it with an op-ed in *The New York Times*.¹³ Neff's idea drew support from key officials in the Clinton administration, including physicists Ernest Moniz and James Timbie, and in Congress, where it was championed especially by Pete Domenici, a Republican senator from New Mexico.¹⁴

The resulting “megatons-to-megawatts” deal blended down 500 tons of Soviet weapons-grade uranium from approximately 20 000 warheads to provide about half the fuel used by US nuclear power reactors over two decades, from 1993 to 2013. A related agreement, facilitated in large part by Paine—who arranged for Mikhailov to meet with key US senators—saw the US fund the construction of a secure storage facility for the plutonium recovered from the Soviet warheads.¹⁵ Both the proceeds from the nuclear fuel sales, which totaled roughly \$17 billion, and the secure storage facility may have forestalled the nightmare of loose nukes available on the black market.

The legacy

Gorbachev's pursuit of nuclear disarmament and his freeing of the captive nations of Eastern Europe ended the Cold War and made possible huge cuts in the global stockpile of nuclear weapons, which we—



◀ The world's estimated stock of nuclear warheads from 1945 to 2023. In the past three years, the global stockpile has probably increased by a few hundred warheads because of China's expansion of its nuclear arsenal. (Figure adapted from ref. 18.)

along with many others—helped facilitate. We offer this account because we hope similar opportunities will come to a younger generation of physicists, and we wanted to share what worked for us. We learned the importance of international workshops and seminars in exploring the possibilities of progress. We also learned that international demonstrations and visits to key facilities can attract much more public and government attention than writing papers.

Finally, we pass along the sage advice of Neff. “I think there are always opportunities,” he observed in an interview.

There are always people who see something that can be fixed. The average college graduate will probably have an opportunity in his or her life to do something that actually improves things.

But the trick is recognizing it.¹⁶

We hope a new generation of physicists will get involved in preventing a new three-way nuclear arms buildup between the US, China, and Russia. It is true that the current governments in Beijing, Moscow, and Washington have not welcomed ideas from independent scientists. But that may change: When Gorbachev took power in 1985, few predicted the reforms he would make in the Soviet Union. In the meantime, we encourage young scientists to join or help create international networks that can brainstorm how to deal with existential challenges. **PT**

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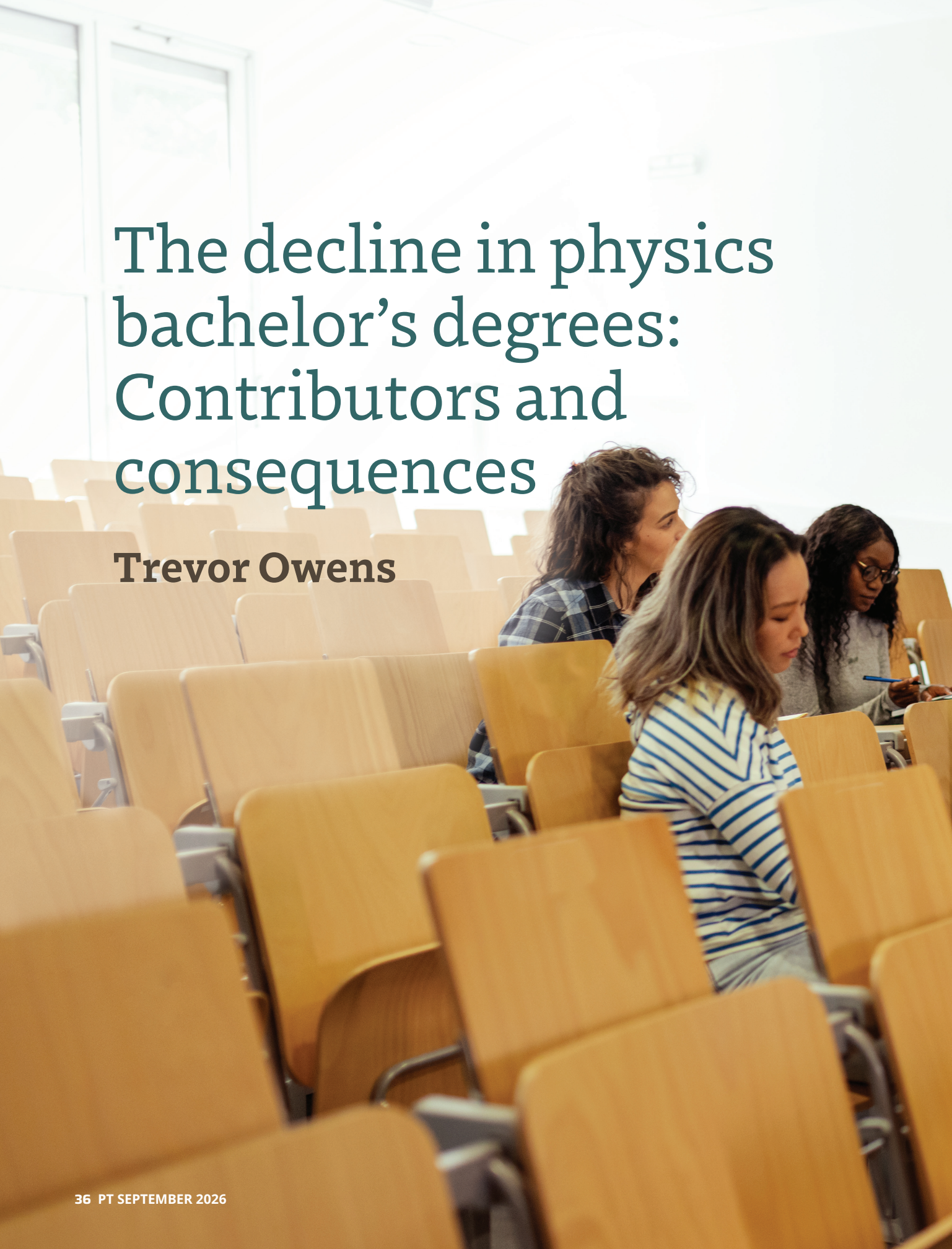


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The decline in physics bachelor's degrees: Contributors and consequences

Trevor Owens



As higher-education programs compete for a shrinking pool of students, departments must better communicate the value that a physics major brings.

The numbers are unnerving. After two decades of sustained growth, the number of physics bachelor's degrees awarded in the US declined from the years 2020 to 2024, according to a recent trend analysis from the research team at the American Institute of Physics (AIP, publisher of *Physics Today*).¹ Figure 1 shows the drop, which, the latest AIP data show, was followed by a slight increase in the 2024–25 academic year.² US physics departments awarded 8108 bachelor's degrees in the 2024–25 academic year—that's down 13% from the peak of 9296 degrees awarded in 2019–20.

As AIP's chief research officer, I have been asked by many people in the physics community to explain the multiyear decline. Is the decline a result of department closures? Is it unique to physics? Does the signal indicate a coming physics, or physics educator, workforce shortage? And what, if anything, should physics departments and the broader community do in response?

The goal of this article is to clarify what the enrollment and degree trends do—and do not—tell us about the current state and future of undergraduate physics education. Amid broad structural trends in higher education, physics departments will increasingly need to adapt and make institutional choices that remain firmly in their control.

Are department closures to blame?

The shuttering of physics departments in recent years has received considerable attention.³ That makes sense: An institution of higher education ending its physics bachelor's degree program is disruptive and upsetting for faculty and students. (You can expect to read more

on the situation in an upcoming issue of *PT*.) The visibility of the closures has led to the question of whether the recent decline in physics bachelor's degrees is primarily because of departments disappearing.

Indeed, the number of institutions awarding physics bachelor's degrees has declined. In the 2023–24 academic year, 723 US institutions offered physics bachelor's degrees—that's a net decline of 34 departments (4.5%) from five years earlier.¹

It is tempting to try to connect those closures to the broad decline in degree production. But the institutions that stopped awarding physics bachelor's degrees from 2019 to 2024 averaged 2.5 graduates per year. As a result, department closures account for no more than 10% of the overall decline since the 2019–20 peak.

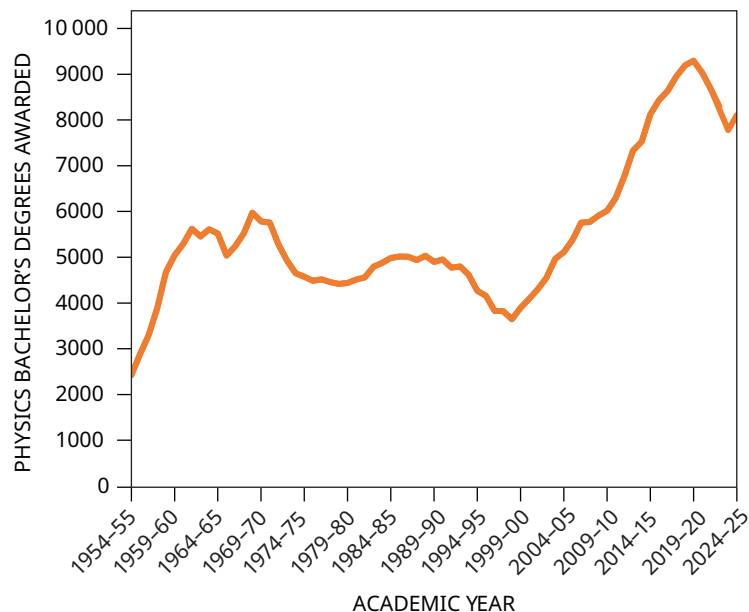
Although the closure of any physics program has substantial consequences for students, faculty, and communities, the trend of fewer bachelor's recipients appears to be driven by an overall decline in degree production at institutions across the physical sciences.

Is physics alone?

Interpreting the recent decline in the number of physics bachelor's degrees requires situating physics within the broader trends occurring in the sciences and higher education. The data show that the decline is not unique to physics.

Data from the Department of Education show similar or steeper declines across several physical science disciplines. In 2024, there were 12 590 people who received bachelor's degrees in chemistry, a 22% drop from the all-time peak in 2017. There were 4802 geoscience and Earth science degrees awarded in 2024, a

Figure 1. After peaking in 2019–20, the number of physics bachelor's recipients decreased for four consecutive years before rebounding slightly in 2024–25. Although the decrease is partly influenced by broad trends in higher education, departments can take actions to attract and retain students. (Data courtesy of the American Institute of Physics.)



Academic field	Drop in US bachelor's degree recipients, from recent peak to 2024
Physics	▼ 17% from 2020
Chemistry	▼ 22% from 2017
Geological and Earth sciences/geosciences	▼ 31% from 2018
Engineering	▼ 9% from 2020

▲ **Figure 2.** The numbers of students in the US who have been awarded a bachelor's degree in certain physical science fields and in engineering have dropped from their peaks of 6–9 years ago, according to the US Department of Education. The percentage decrease for physics differs slightly from that in figure 1 because of methodology differences. (Data courtesy of US Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System.)

31% decline from the all-time high in 2018. Taking all the physical science fields in the data, the number of awarded bachelor's degrees dropped from 33 150 in 2018 to 27 177 in 2024, a decline of about 18%.⁴ Figure 2 tabulates some of the drops in degree production.

Despite the trend in the physical sciences, overall STEM degree production has continued to increase. Much of that growth, however, has been driven by the dramatic expansion of computer science and information science bachelor's degrees, which more than doubled from 2014 to 2024. Outside of computing-related fields, many STEM disciplines have stagnated or declined. The biological and biomedical sciences have seen slight declines in 2023–24 compared with 2022–23, and the number of awarded engineering bachelor's degrees has dropped about 9% from an all-time peak of more than 130 000 in 2020. The broad shifts likely reflect a combination of demographic pressures, changing student perceptions of career pathways, and evolving patterns in undergraduate enrollment behavior.

The rise and fall of degree numbers in different STEM fields helps explain an apparent contradiction in recent reports on STEM education. NSF's *The State of U.S. Science and Engineering 2026* report noted a 17% increase in science and engineering bachelor's degrees from 2014 to 2024.⁵ That statement is accurate. The choice of a 10-year window, however, obscures important changes in the latter half of the period. Many disciplines, including several physical science fields, experienced degree growth during the first half of that period before enduring declines more recently. Much of the increase during the decade-long period reflects the extraordinary growth of computing-

related disciplines and, to a lesser extent, of other fields, such as psychology.

Will the situation improve?

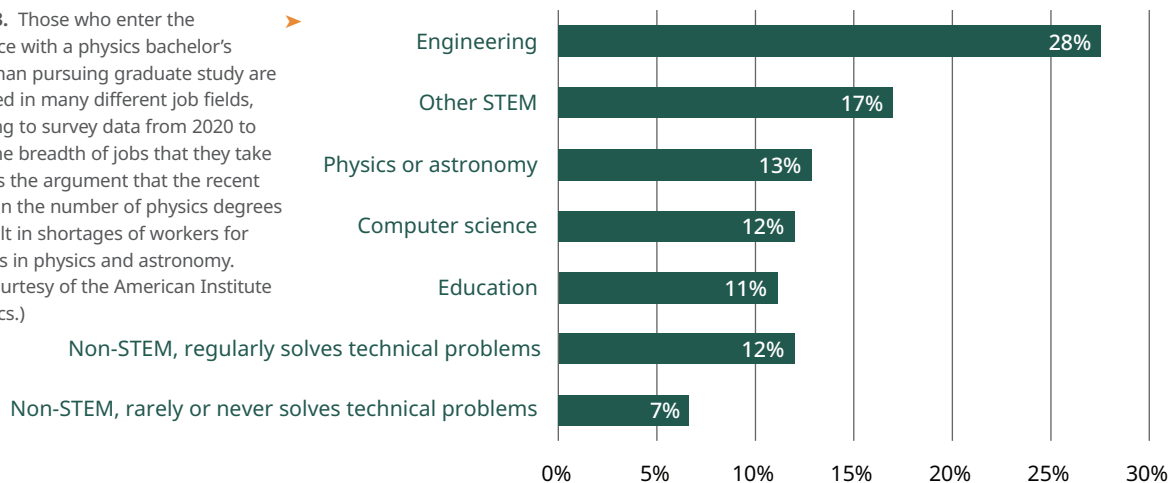
One way to get an early indication of future degree production is to analyze the enrollment patterns of current students. Unlike the Department of Education and NSF data, which describe only degrees that have already been awarded, AIP's annual Survey of Enrollments and Degrees also tracks the number of juniors and seniors in undergraduate physics programs. In those data, upper-level undergraduate enrollments appear to have bottomed out around the year 2022 and have since begun to rebound modestly. (Indeed, a recent report from AIP's research team describes that modest rebound.²) The increase in physics bachelor's degree production in 2024–25 could be a sign of stabilization, and the trend may continue over the next several years.

But short-term stabilization is different from long-term structural recovery. The number of US high school graduates has begun a decline after peaking in 2025. The US birth rate has not bounced back from declines that began at the start of the Great Recession in late 2007, and the number of graduates is projected to decline steadily through at least 2041. In higher education, the trend is widely referred to as the “demographic cliff.”

Additionally, undergraduate enrollment nationally has been mostly declining since 2011 as a smaller share of potential students has pursued four-year degrees.⁶ The trend is expected to intensify competition among colleges and universities for a shrinking pool of undergraduate students.

The demographic and enrollment pressures suggest

Figure 3. Those who enter the workforce with a physics bachelor's rather than pursuing graduate study are employed in many different job fields, according to survey data from 2020 to 2024. The breadth of jobs that they take weakens the argument that the recent decline in the number of physics degrees will result in shortages of workers for positions in physics and astronomy. (Data courtesy of the American Institute of Physics.)



that even if physics degree production rebounds modestly in the near term, departments will increasingly need to adapt: Compared with previous years, the higher-education environment today is more competitive and demographically constrained.

Will there be a shortage of physicists?

Scientific society leaders and physics department chairs frequently ask me whether the recent decline in physics bachelor's degree production is likely to lead to a shortage of physicists in the US. That question is more complex than it initially appears because physics graduates pursue a broad breadth of educational and career pathways.

AIP's studies of degree outcomes for physics students can help provide an answer. Conducted by the research team since the 1960s, those studies provide important context for understanding how physics graduates move through higher education and the workforce.

Among recent physics bachelor's degree recipients, roughly half enter graduate school, while the other half move directly to the workforce.⁷ Figure 3 shows that, of those entering the workforce in 2020–24, only 13% report working in positions they describe as physics or astronomy related. The predominant fields of employment are engineering (28%) and other STEM fields (17%), which include data science jobs and other technical occupations. Some 19% work in a non-STEM field. The data suggest that physics bachelor's degrees function less as narrow vocational credentials and more as broadly applicable preparation for analytical and technical work across many sectors of the economy.

At the doctoral level, about half of newly awarded physics PhDs initially take postdoctoral positions, most of which are in physics research environments. But for those who move directly to potentially permanent positions, most report employment outside core physics

roles and pathways.⁸ Among those who take potentially permanent positions, 20% report working in data science, 17% in engineering, and 11% in computer software.⁹ Those moving directly into the private-sector workforce report substantially higher incomes than those doing postdocs.⁸

Taken together, the employment outcomes complicate any single narrative about potential workforce shortages. Declining physics degree production does not necessarily translate directly into shortages of workers for narrowly defined physics jobs, particularly given the broad occupational distribution of physics graduates.

The employment findings also complicate simplistic pipeline models of physics education. The data make clear that physics education is not merely, or even primarily, about moving students from bachelor's degrees to graduate school, into postdoctoral training, and into academic research careers resembling those of their faculty mentors. Physics graduates already move into an exceptionally diverse number of scientific, technical, financial, and analytical professions. One of the central challenges facing the field is figuring out how to better communicate the value of those diverse career pathways and to prepare students for them more intentionally.

Acting where departments have agency

The forces shaping undergraduate enrollment are outside the control of individual departments. Physics faculty cannot reverse national demographic shifts or broad declines in undergraduate enrollment. Departments do, however, have substantial agency in shaping whether students who arrive interested in physics ultimately persist in the major.

A five-year longitudinal study published in 2024 by AIP examined persistence and attrition among undergraduate students who took an introductory physics

course at four large universities.¹⁰ The researchers found that physics departments were losing many students who initially were interested in majoring in physics. Among the 277 students who initially expressed interest in physics and were tracked from introductory coursework through degree completion, only about 38% ultimately graduated with a physics degree. Many of those students cited discouraging early classroom experiences, rigid and long course sequencing, or departmental cultures that made persistence difficult. They also reported finding other majors more attractive, perhaps because of discouraging experiences in physics.

The timing of attrition is also significant. Some 43% of the students in the study who ultimately left the major made that decision during or immediately after their introductory physics course, and another 30% left during their second year. Although the data are not necessarily representative of all undergraduates who begin their studies with an interest in physics, they still suggest that the first two years are critical.

The longitudinal study illustrates that now, in an era of demographic contraction and increasing competition for students, departments are in critical need of retaining students who are already interested in physics. Fortunately, a substantial number of programs that have been developed by the American Physical Society (APS), the American Association of Physics Teachers (AAPT), and other organizations can help departments address that challenge. Resources such as the APS and AAPT Effective Practices for Physics Programs (EP3) guide, AAPT's ComPADRE collections, APS departmental resources, and programs supported by the Society of Physics Students provide concrete, research-informed approaches for improving pedagogy, advising, culture, and student support.

To thrive in the coming decades, physics departments will likely need to rethink introductory coursework. Rather than using introductory sequences as sorting mechanisms, departments should use them as invitations into the discipline. That effort would include prioritizing curricular innovations that support timely degree completion for undergraduates with various backgrounds, including those who arrive without preparation in calculus or advanced physics coursework. Physics education researchers have demonstrated that those kinds of changes in course sequencing and program design can be implemented and maintain rigorous standards for student learning. (For more on calculus-based physics and student readiness, see the October 2025 *PT* article by Suzanne White Brahmia and Geraldine L. Cochran.)

In the current higher-education environment, in-

vestments in evidence-based pedagogy, inclusive departmental cultures, flexible curricular pathways, and student support systems are not simply matters of educational philosophy or equity, although they are important in those areas. Those investments are increasingly central to the long-term viability of undergraduate physics programs themselves.

Departments entering a period of demographic contraction cannot afford to continue unnecessarily losing interested and capable students through discouraging introductory experiences, inflexible curricular structures, or unwelcoming departmental climates. The substantial body of work developed through physics education research and related professional initiatives increasingly offers practical institutional knowledge about how physics departments can adapt, remain sustainable, and ultimately thrive in a far more competitive higher-education environment. **PT**

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WHAT CAN PHYSICISTS DO?

An interview series that profiles scientists who opted for careers outside of academia.

Hannah Pell ensures regulatory compliance at Three Mile Island

By **Toni Feder**

Nuclear regulatory specialist, Crane Clean Energy Center

BS, physics; BA, music theory and oboe performance;
Lebanon Valley College, 2016
MA, music theory, University of Oregon, 2019

What were you looking for in a job?

I never sought out a specific role for myself. I've navigated toward questions that interest me. I was an intern with the Society of Physics Students, working in science outreach. Later, I was a research assistant at the Center for History of Physics at AIP [American Institute of Physics, publisher of *Physics Today*]. Then I was an editorial coordinator at the American Association for the Advancement of Science.

(Photo courtesy of Hannah Pell.)



How did you get into nuclear power?

My father worked at Three Mile Island in radiation protection and maintenance, and after the plant closed in 2019, I started writing about it. [See Pell's 2022 *PT* article, "Why did the Three Mile Island Unit 1 reactor close?," written with Ryan Hearty and David Allard.] That led to my being hired as a licensing engineer onto a project to complete the decommissioning of Three Mile Island Unit 2, the site of the 1979 accident. It was a unique opportunity to enter the industry. That was in 2021.

How do you spend your time?

I'm now a nuclear regulatory specialist at Crane Clean Energy Center [formerly known as Three Mile Island Unit 1; it's scheduled to restart operations next year]. My job is to understand the rules and regulations and ensure that we stay in compliance. It includes doing historical research to understand the context of the regulations. I interact with NRC [Nuclear Regulatory Commission] inspectors, with other stakeholders, and with the public when people come to tour the plant.

I've been focused on understanding Executive Order 14300, which was issued in May 2025 and directs the NRC to take steps to accelerate deployment of nuclear energy in the country.

What do you like about your job?

My favorite part is working with groups that specialize in different aspects of plant operations. I'm always learning new things.

How does your physics background come into play?

First and foremost, in understanding how the plant works. I interface with the engineering department to research requirements in support of planned modifications. My physics background helps me quickly process technical information and approach complex problem-solving with confidence.

What new skills have you needed to learn?

Soft skills, like writing and communicating. I've also had to develop strong project management skills to work in areas such as decommissioning, license renewal, and restart.

PT

Read more interviews in the series
at <https://physicstoday.org/wcpd>.

Rivers in the sky

Atmospheric rivers transport huge volumes of water great distances across the globe, and climate change could extend their reach.

By **Serena R. Scholz** and **Juan M. Lora**

Have you ever experienced several days in a row with gray skies, wind, and rain? If you live between the latitudes of 30° and 60° N or S, the chances are high that you were within an atmospheric river. At any given time, each hemisphere contains three to five atmospheric rivers, which form and dissipate on time scales of days to weeks. The long, narrow storm systems transport water vapor from the warm subtropics into the cooler midlatitudes, leading to prolonged periods of cloudy skies and precipitation and sometimes causing major flooding events.

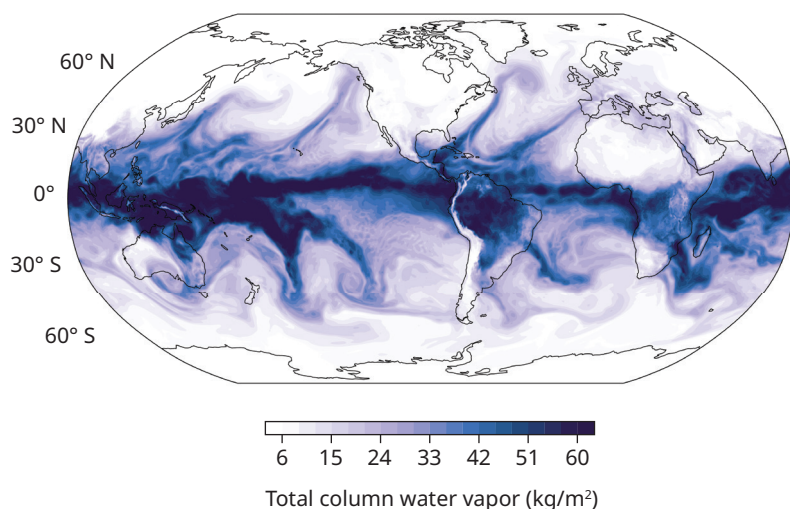
Though atmospheric rivers, shown in figure 1, are typically only a few hundred kilometers in width, they can stretch for thousands of kilometers in length, sometimes reaching across entire oceans. Since the features were first identified, they have been found to exert control over rainfall and water resources in many regions. They also play a major part in the distribution of water and energy across the globe, a role that may be changing and evolving as the climate warms.

What's in a name?

The onset of the satellite era brought a new perspective on atmospheric circulation at the global scale. In

the 1990s, researchers noticed that atmospheric moisture transport in the midlatitudes tends to be concentrated in narrow, filamentary structures. Researchers called the structures atmospheric rivers because the amount of water they transport is comparable to or greater than that in the largest rivers on Earth. Frequently, the filaments move two to three times as much water as the Amazon River, which transports over 12 million cubic meters of water per minute. Despite their limited width, atmospheric rivers account for most of the atmospheric water vapor transported toward the poles, making them crucial components of the global water cycle.

The analogy to terrestrial rivers is catchy, but it can lead to some confusion. Unlike rivers on land, atmospheric rivers do not have defined channels or locations; instead, they are constantly moving both relative to and along with the average atmospheric flow. They also primarily transport water in its vapor form, not as a liquid. And whereas terrestrial rivers can carry the same water all the way from headwaters to outlets, transport within atmospheric rivers is not always so direct: Much of the vapor is gained and lost in a cycle of continuous evaporation and precipitation along the storm's path from the subtropics to higher latitudes.



◀ **Figure 1.** A global snapshot of the total column water vapor (the total mass of water vapor above a square meter) on 12 December 2023. The Northern Hemisphere contains four distinct atmospheric rivers: two in the North Pacific and two in the North Atlantic. In the Southern Hemisphere, atmospheric rivers over Australia and the South Pacific exhibit spiral structures that highlight the cyclonic motion around low-pressure systems, which flow clockwise in the Southern Hemisphere because of deflection by the Coriolis force. (Data from H. Hersbach et al., “ERA5 hourly data on single levels from 1940 to present,” Copernicus Climate Change Service [C3S] Climate Data Store [CDS], 2023.)

A more apt analogy might be to a highway: Some cars might drive it straight from beginning to end, but most are constantly entering and exiting the flow of traffic along the way. The atmospheric river is simply the transient pathway along which water vapor travels.

Formation and propagation

The life of an atmospheric river generally begins over the warm subtropical oceans. In the Northern and Southern Hemispheres, the process is the same, but the orientations are opposite; we'll describe a Northern Hemisphere example (see figure 2). A developing low-pressure system creates a surface pressure gradient, which draws a tendril of warm, moist air northward toward the lower-pressure region. As air flows north, it is deflected to the east by the Coriolis force and begins to circulate counterclockwise around the low-pressure center to form an extratropical cyclone.

On the southeast side of the developing atmospheric river, a high-pressure center, known as an anticyclone, forms. Air flows clockwise around the anticyclone system, which increases the atmospheric river's wind speed and constrains the flow of warm, humid air into a narrow region between the two systems. That narrow region is on the order of hundreds of kilometers across, whereas the cyclone and anticyclone can be thousands of kilometers across.

Those high- and low-pressure centers are not stationary: They are embedded within the larger-scale east-

ward flow of wind in the midlatitudes. As the systems travel both eastward and poleward, the filament of air is drawn along with them, carrying warm and moist air to higher latitudes as an atmospheric river. The pressure difference between the low- and high-pressure centers determines the strength of the winds. A steeper pressure gradient leads to faster winds because of geostrophic balance, an approximate balance between the pressure gradient and the Coriolis force.

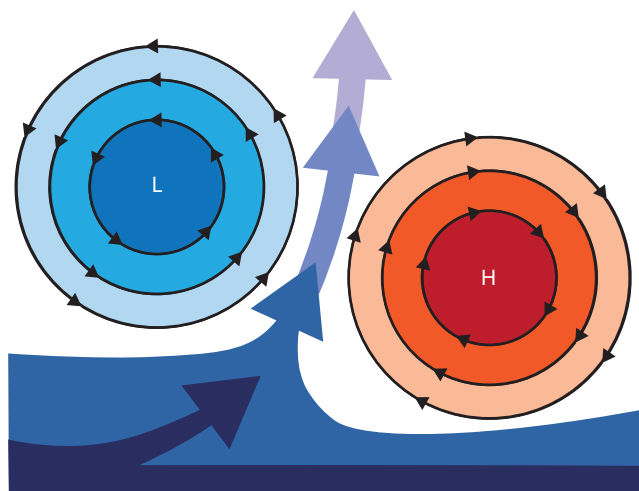
Making landfall

As the warm, moist air propagates eastward, it may run into obstacles. Atmospheric rivers form over all midlatitude ocean basins, so they can eventually affect Africa, Australasia, East Asia, Europe, and both North and South America. Those that form over the North Pacific encounter the steep, mountainous terrain of the North American West Coast. The mountains force the moisture-rich air upward, which cools it and lowers the maximum amount of water vapor that can be in the air. That causes the water to rapidly condense from vapor, which leads to extreme rainfall events and flooding.

Many extreme rainfall events and major floods in California, Oregon, Washington, and western Canada are caused by atmospheric rivers. In 2025, prolonged rainfall from an atmospheric river led to a state of emergency in Washington and part of Canada and record-breaking water heights in several rivers. Extreme events can also lead to cascading hazards that include landslides and infrastructure failures, such as dam collapses. Yet atmospheric rivers can also be beneficial to those regions: The precipitation is a crucial component of local water resources and replenishes mountain snowpack across the western ranges. Similar processes occur in other mountainous midlatitude coastal regions, such as the Chilean Andes.

In contrast, when atmospheric rivers encounter smoother topography, such as that of the eastern US or eastern China, they tend to rain out more gently and steadily. But the storms still play an important role in determining those regions' annual rainfall.

In addition to moving water vapor, atmospheric rivers carry heat from the lower latitudes. They are thus associated with warmer-than-average temperatures on the ground. In the summer, the combination of high temperatures and high water-vapor content in the atmosphere can lead to a transient enhanced greenhouse effect: Water vapor is a potent greenhouse gas that traps longwave radiation near the surface. The combination of high temperatures and humidity creates the conditions for high wet-bulb temperatures, which indicate low evaporative-cooling efficacy. Multiple days of high wet-bulb temperatures are called



▲ **Figure 2.** Atmospheric rivers that form in the Northern Hemisphere occur between a low-pressure, counterclockwise-spinning cyclone and a high-pressure, clockwise-spinning anticyclone. Moist air drawn toward the low-pressure region (L) is deflected to the east by the Coriolis force. A paired anticyclone (H) constrains the flow to a narrow region, and the horizontal pressure gradient between the two systems leads to strong winds and moisture transport—the atmospheric river.

moist heat waves, and they are particularly dangerous for human health because they make it difficult for the body to cool via evaporation.

Changes under a warming climate

As temperatures increase, the amount of water vapor that can be in the air also increases. As determined by the Clausius–Clapeyron relation, the rate of that increase is 7% per kelvin of warming at the surface. In a warmer future, atmospheric rivers could therefore transport larger amounts of water vapor, which would lead to more extreme precipitation events and more dangerous moist heat wave conditions.

Though the relationship between change in climate and the amount of water vapor in the atmosphere is straightforward, the changes to winds and larger-scale weather systems are much less certain. The tracks that extratropical cyclones and anticyclones take in the midlatitudes are expected to shift toward the poles in a warmer climate. Atmospheric river activity could therefore expand into higher latitudes. The historical record suggests that there has already been an increase in the frequency of atmospheric river conditions across many regions of the middle and high lati-

tudes, and that has led to increased rainfall and snowfall in many locations. How similar changes will manifest in the future and how atmospheric rivers will interact with other parts of the changing climate system are areas of active research. **PT**

Additional resources

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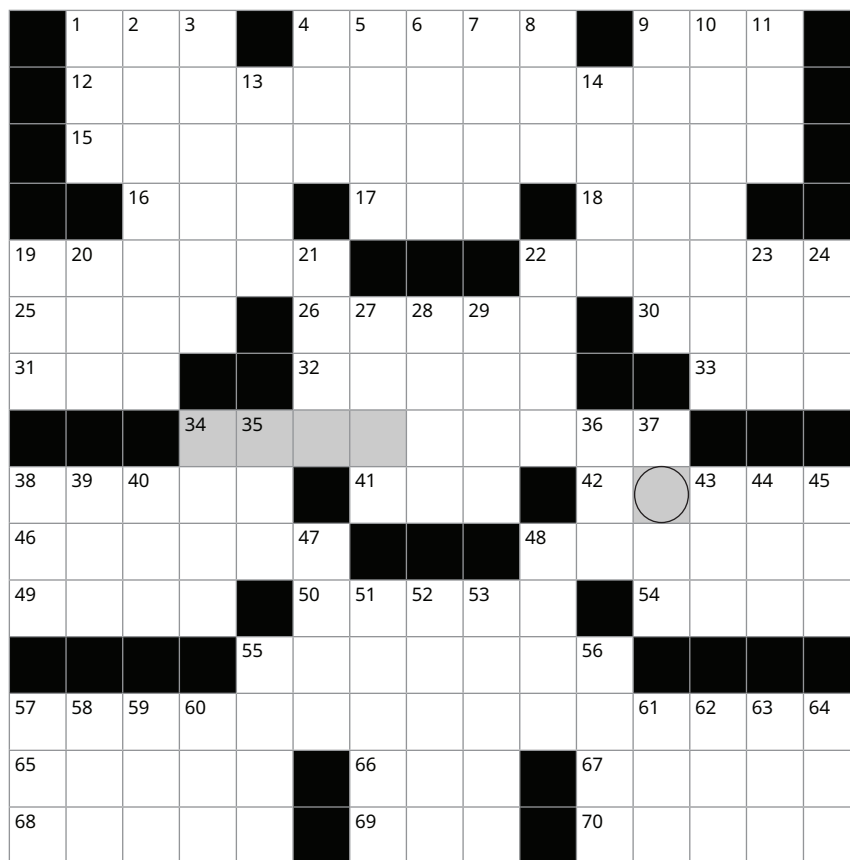
Copenhagen interpretation

By Doug Mar

The theme of this puzzle is the observational collapse of a quantum wavefunction into a single state. The shaded squares each represent two potential “states”—that is, they have two simultaneous solutions—except where the clue to 42-Across collapses the wavefunction in the circle into one of the two choices.

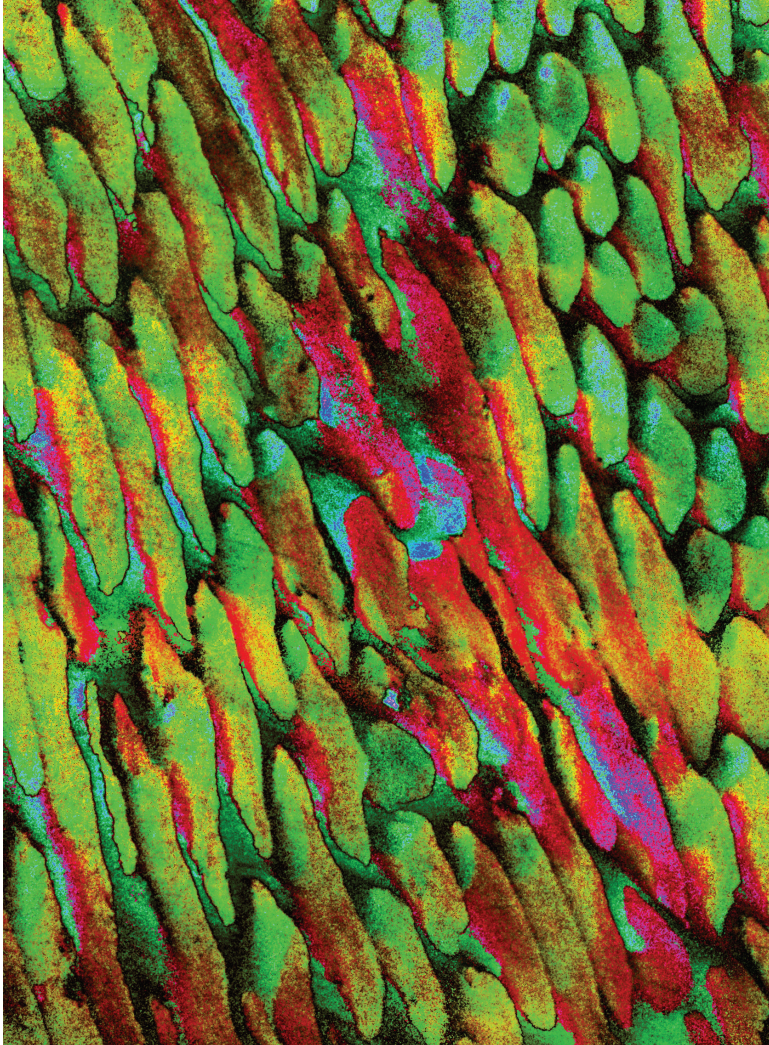
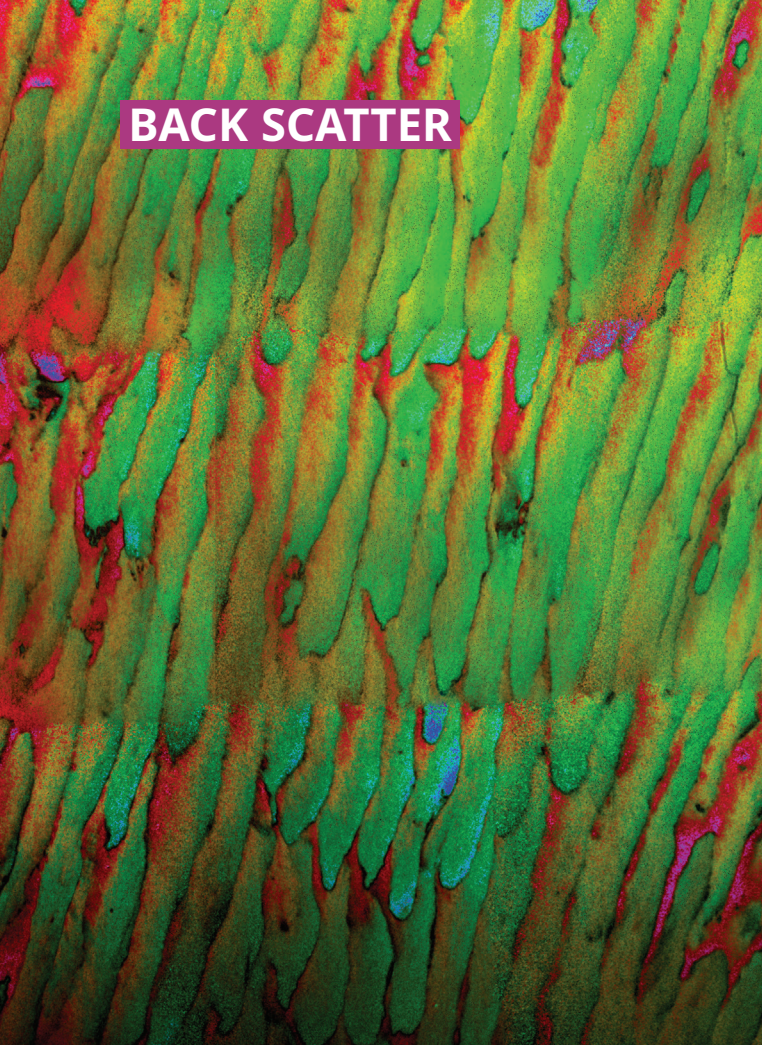
ACROSS

- 1 General on a Chinese menu
- 4 Word that, when searched, causes Google to display results off-kilter
- 9 Dined
- 12 Quantum mechanics phenomenon describing multiple simultaneous states that, upon observation, collapse to a single state
- 15 Elementary objects with quantum properties opposite to their counterparts
- 16 Accomplished
- 17 Govt. org. with a cryptologic museum
- 18 Container that is found overhead
- 19 ___ model (1913 contribution of Copenhagen’s Niels Bohr)
- 22 Planetary magnetic field generator
- 25 Reciprocal of micro
- 26 Following
- 30 Lass
- 31 Word of assent
- 32 Work of praise
- 33 Cornea cover
- 34 Charged leptons
- 38 New identity of a signal that exceeds the Nyquist limit
- 41 What A represents in hexadecimal
- 42 Zoo denizen that is observed (!) at Fermilab
- 46 Group of cells in the body
- 48 Eating this exposes you to 0.1 microsieverts of radiation
- 49 Requirement
- 50 Achieve greatness
- 54 Spider-___, character in Marvel’s Spider-Verse
- 55 NASA mission that was ended by being deliberately crashed into Jupiter
- 57 Feline that is subjected to 12-Across in a thought experiment
- 65 “Encore!”
- 66 By way of
- 67 In medical slang, this animal represents a surprising and exotic diagnosis



- 68 Gnat-like insect
 - 69 112.5° on a compass (abbr.)
 - 70 Watering holes
- ### DOWN
- 1 Org. that might foul up your travels
 - 2 Parhelia (atmospheric phenomena)
 - 3 Best conditions
 - 4 Astronomer who compiled *Atlas of Peculiar Galaxies*
 - 5 Stretch across
 - 6 Fashion designer Michael
 - 7 “¿Cómo ___ usted?”
 - 8 Nintendo game console
 - 9 Under the weather
 - 10 Pedicure focus
 - 11 What every neutron has two of?
 - 13 Muslim holiday tradition
 - 14 Frozen dessert chain
 - 19 Fictional Fowler with a Nobel Prize
 - 20 The beginning of time?
 - 21 Clothing for someone familiar with bats
 - 22 Early Bond foe
 - 23 Med. scan
 - 24 Aged
 - 27 A verifiable certainty, in an official language of Canada
 - 28 Head, in Quebec but not in Alberta
 - 29 Merit
 - 34 Oregon Trail pioneers put this behind them
 - 35 Powerhouse football sch. that played

- for the 2008 BCS championship
- 36 Org. that prohibits traveling?
- 37 Word in a nursery rhyme title that also includes “sixpence”
- 38 101 325 Pa
- 39 Skater Alysa whose spins are textbook physics examples
- 40 Research facility on which Bohr’s Nobel Prize orbited the Earth (abbr.)
- 43 Carpenter’s tool
- 44 What the letter in the circled square represents as a Roman numeral
- 45 Possible computational output when evaluating $0 \div 0$ (abbr.)
- 47 Quaint expletive
- 48 Village of the Prancing Pony inn in *The Lord of the Rings*
- 51 Branch on the Great Seal of the United States
- 52 Last word, as of a book
- 53 Aquarium buildup
- 55 Vanished
- 56 Rice-shaped pasta
- 57 Nobelist Ting, to his friends
- 58 SFX that earned Academy Awards for all three *Avatar* movies
- 59 Possessed
- 60 Semi
- 61 Aviation reference level
- 62 *60 Minutes* network
- 63 Is for two?
- 64 Some univ. instructors



A dental lens on human evolution

By **Faith Simmons**

Tooth enamel is the hardest tissue in vertebrates, and its lack of organic material prevents it from decomposing quickly. Pupa Gilbert of the University of Wisconsin–Madison and colleagues recently analyzed tooth samples, including from individuals who lived about 40 000 years ago (left) and 700 years ago (right), to see whether the nanostructure of the enamel could provide insights into evolutionary changes associated with humans' changing diet. The researchers used a polarization imaging method that they developed to measure the orientation of the enamel's thin, long hydroxyapatite nanocrystals. The elliptical shapes in the images are rods roughly 5 μm wide that contain thousands of the nanocrystals, each of which takes up about a pixel. The colors represent the measured orientation of the crystals; the contrast between adjacent crystals indicates the degree of misorientation between them.

Gilbert and colleagues found a greater degree of nanocrystal misorientation in the more recent sample.

They associate the change with humans' transition to a grain-based diet during the agricultural revolution about 12 000 years ago. Although agricultural foods became easier to chew, the byproducts of processing contribute to higher abrasion. When nanocrystals are more misoriented, enamel is better at deflecting crack propagation and is therefore more durable. Over humans' evolutionary history, enamel nanocrystals have undergone a trend toward greater misorientation, a change that researchers attribute to more mechanically challenging diets. More studies of the nanostructure of tooth enamel could indicate when humans started cooking their food. (P. U. P. A. Gilbert et al., "Enamel nanocrystal misorientation increased with meat-eating and agriculture," *Nature* **654**, 76, 2026; photos courtesy of Pupa Gilbert.)

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