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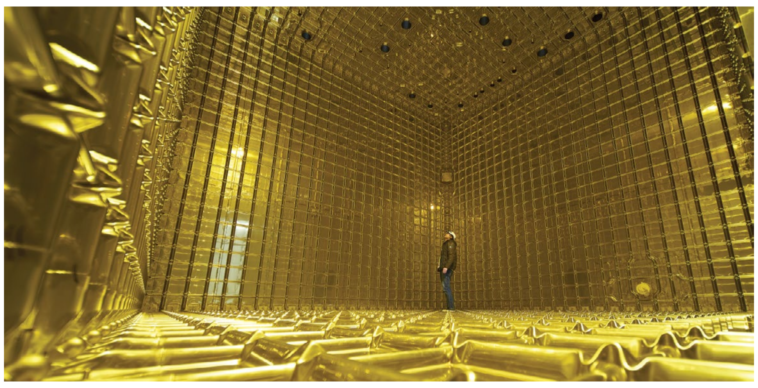
APS News

A Publication of the American Physical Society | aps.org/apsnews | December 2023/January 2024 | Volume 33 | Number 1

The P5 Report is Here: Particle Physicists Set Sights on the Multi-Billion-Dollar Road Ahead

U.S. physicists share their vision for the future of high energy physics — and ask for the funding to achieve it.

BY LIZ BOATMAN



A view of the ProtoDUNE cryostat at CERN. Credit: CERN

The discovery of the electron in 1897 marked a major shift in physics: If atoms weren't the smallest building blocks of the universe, what else could there be? A lot, it turns out. Exploration into the 20th century yielded a veritable 'particle zoo' — quarks, muons, pions, and beyond. By the 1970s, physicists had developed a unifying theory, the Standard Model, to explain the existence of so many particle types and their relationships to each other.

Many mysteries remain. How much mass do neutrinos have? What is dark matter made of? Why is most of the universe made of matter, not antimatter? But studying tiny particles requires some of the largest experiments ever built, such as multi-billion-dollar accelerators that smash particles together at 99.9999991% the speed of light, like CERN's Large Hadron Collider in Switzerland — famed home of the 2012 Higgs boson discovery, which further validated the Standard Model.

Projects of this scale require an extraordinary amount of time and money, and physicists have come up with an extraordinary way to prioritize. About once a decade, a panel of physicists drafts a budget-conscious plan, known as the Particle Physics Project Prioritization Panel (P5) report, which recommends where the field should go experimentally and how to get there technologically. The report is given to the federal High Energy Physics Advisory Panel (HEPAP), which advises the U.S. Department of Energy and National Science Foundation, which in turn decide how to dole out more than

P5 Report continued on page 4

Physicist Stuart Parkin, APS Medal Winner, on the Digital Age and "Going Beyond"

An interview with this year's recipient of APS's biggest research award.

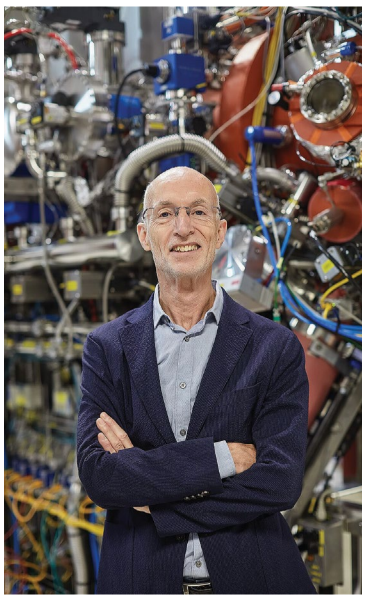
BY KENDRA REDMOND

Stuart Parkin grew up surrounded by books. "My father read thousands," he recalls from his early years in Watford, England. Now an experimental physicist and director at the Max Planck Institute of Microstructure Physics in Halle, Germany, Parkin has his own collection of books.

But unlike his father, Parkin can access his titles anytime, from anywhere in the world. "I have hundreds of books on my phone," he says. "It's amazing." That sweeping digital shift is due, in part, to Parkin's own research.

While at IBM Research in the late 1980s, Parkin invented a highly sensitive magnetic field detector. Thanks to his spin valve, the storage capacity of magnetic disk drives soared by a factor of 1,000, then 10,000. Most digital data is still

Parkin continued on page 3



Parkin at the Max Planck Institute of Microstructure Physics in October 2023. Credit: MPI für Mikrostrukturphysik / Marco Warmuth

Winner of the APS Lilienfeld Prize Urges Physicists to Combat Scientific Illiteracy

In a Q&A, cosmologist Edward Kolb discusses the Big Bang, parallel universes, and the need for public outreach.

BY LIZ BOATMAN

What's outside the universe? What came before the Big Bang? Does life exist elsewhere, and if so, would we recognize it? These are the questions that excite cosmologist Edward "Rocky" Kolb.

Kolb, the Arthur Holly Compton Distinguished Service Professor of Astronomy and Astrophysics at the University of Chicago and an APS Fellow, is the recipient of the 2024 Julius Edgar Lilienfeld Prize. The prize recognizes physicists who've made "outstanding contributions" to physics and who excel in communicating with diverse audiences.

The recognition matters, says Kolb, because he can recall a time when cosmology — the branch of physics focused on the origin and development of the universe — wasn't a "respectable" field of scientific inquiry.

When he entered the field in the late 1970s, cosmologists were mostly working with theory. "People felt it was more like a religion or metaphysics," he says. "Today, though, cosmologists perform observations and carry out experiments just like other physicists. They've even won the Nobel Prize."

Edward "Rocky" Kolb. Credit: Jason Smith

Kolb is a member of the Enrico Fermi Institute and the Kavli Institute for Cosmological Physics. He has contributed to more than 230 scholarly publications, co-authored multiple books, and taught countless courses, including some for non-physics majors and adults who enroll in the university's extension program — his favorite courses to teach.

Kolb continued on page 11

The Scientist Who Launches Rockets at the Northern Lights

At an APS meeting in Denver, astrophysicist Allison Jaynes discussed her work on auroras and the strange plasma physics that shapes them.

BY SOPHIA CHEN

Allison Jaynes's team chose the dates more than a year in advance. They knew they needed to launch in darkness, when the visible moon was at its smallest, so that moonlight wouldn't interfere with their observations. But when the time came, all they could do was hope for the right weather to launch a rocket into the flickering glow of an aurora borealis — the northern lights.

During a two-week window in March 2022, the team waited every night at Alaska's Poker Flat Research Range for a clear sky. Each night, Jaynes — a co-investigator of the mission and an astrophysicist at the University of Iowa — had to help decide whether to launch the rocket or wait for the next evening.

"These launches are nerve-racking," says Jaynes. "You don't know if you're going to get something good. In the end, you don't know if you're about to waste $4 million."

Jaynes, this year's recipient of APS's Katherine E. Weimer Award in plasma physics, discussed her research at this year's meeting of the APS Division of Plasma Physics in Denver, Colorado. She studies the physics of Earth's aurorae, known for their green and purple light shows at extremely southern or northern latitudes. The light comes from charged particles — mostly protons and electrons — that fall into the atmosphere. These particles, known as the solar wind, come from the Sun and arrive at Earth in a state of matter known as plasma. Trapped by Earth's magnetic field, the particles follow the planet's magnetic field lines toward the poles.

On March 5, 2022, the LAMP (Loss through Auroral Microburst Pulsations) rocket launched into a pulsating aurora 30 miles northeast of Fairbanks, Alaska. Credit: Justin Hartney

"The particles hit different types of molecules in different layers of our atmosphere," says Jaynes. Hitting oxygen gives off greenish yellow light; hitting nitrogen gives off reds and blues.

Scientists have been launching rockets to study auroras for decades, but data is still limited, says Jaynes. In each launch, the rocket rises and falls back to Earth in the span of ten or fifteen minutes. Even after years of rocket launches, "in total, we have hours' worth of data to analyze," says Jaynes.

Jaynes wants to understand how much energy auroras transfer to Earth, separate from other sources of solar energy, like ultraviolet radiation. "If you think of our atmosphere as a sponge, it's soaking up all the energy that comes from the Sun," she says. Engineers can use Jaynes' research to better design and protect manmade satellites, which can be damaged by solar wind.

Researchers can also use the data to explore how auroras influence Earth's atmosphere and weather. For example, a 2022 study found that auroras destroyed ozone in a 400-kilometer-wide patch, which is about a magnitude narrower than the famous ozone hole above Antarctica, about 50 kilometers above Earth's surface. The researchers expected the hole to heal naturally, but

Auroras continued on page 11

To Boost Undergrad Enrollment, Physics Departments Turn to APS Innovation Fund Program, DALI

The Departmental Action Leadership Institute has expanded the reach of EP3, a guide for physics departments looking for positive change.

BY LIZ BOATMAN

Nationwide, undergraduate physics enrollment has declined by more than 1 in 5 students since its peak in 2016, with smaller institutions bearing the brunt. Because not all programs look the same or serve the same groups of students, there's no one-size-fits-all solution.

That's where the Departmental Action Leadership Institute comes in. DALI — a one-year, cohort-based bootcamp — trains departments using the Effective Practices for Physics Programs (EP3) guide, a resource launched in 2021 to help departments respond to challenges like declining enrollment. In the search for ways to promote the guide's adoption, the EP3 team — including David Craig of Oregon State University — found the APS Innovation Fund, established in 2019 to sponsor projects that support APS's mission of advancing physics.

Craig and Joel Corbo of the University of Colorado, Boulder used an Innovation Fund grant to develop DALI, which has two main components. "One is leadership training," says Craig. "We provide the training that is otherwise missing from a typical faculty member's career ... to lead a major change effort that involves lots of people."

> Kosta Popovic ... says his department struggles to maintain consistent numbers in physics because most students arrive at Rose-Hulman intending to major in engineering.

"The other half is helping them lead a team to focus on analyzing and understanding the true nature of the challenge their institution is facing," he says. "If you don't gather the data, and analyze that data ... you can't determine the right steps."

Faculty also need help developing the right skills. "Faculty members have expertise around all sorts of things, but typically they don't have specific skills around making a change effort successful," says Corbo. "That's not a thing you learn in grad school."

The DALI curriculum requires departments to assemble a departmental action team, or DAT, composed of two faculty leaders who attend biweekly DALI sessions for a year, several more department faculty, and a few students or recent alums.

"Convincing people that student partnership is both valuable and possible can be a big hurdle," says Corbo. "But it's important to include them and to value them as part of the team."

In January 2021, Craig and Corbo organized their first DALI cohort, which included Rhode Island College, a Hispanic-serving institution.

The college's physics department had been struggling to boost enrollment and retention, with a very career-oriented student body composed largely of first-generation college-goers. Physics faculty member Andrea Del Vecchio says that, for their typical undergraduate student, "going to college is something that's going to be transformational not just for them, but for their families."

"We needed to find a way to make physics attractive and accessible to that population of students," she says.

Del Vecchio's DAT came up with several ideas for change. They adjusted their physics curriculum to accommodate the high percentage of students entering without calculus coursework, for example, and they created more flexibility with electives.

"Talking about data-driven change and how to make an action plan, how to use different tools to decide what the best course of action is — all of that was really valuable," she says.

DALI's second cohort, in October 2021, included Rose-Hulman Institute of Technology in Indiana.

Kosta Popovic, an associate professor of physics, says his department struggles to maintain consistent numbers in physics because most students arrive at Rose-Hulman intending to major in engineering. Harder still, the department manages three separate programs: engineering physics, optical engineering, and physics. Any incentive for sweeping change across the department would need to be significant.

But things at Rose-Hulman had finally reached a "critical point," with enough folks in the department interested in making changes to help stabilize the physics major, Popovic says.

"It took something like DALI and their guidance for forming a DAT to really help us dedicate that time, really meaningfully and purposefully," Popovic says. "It helped with the accountability ... and also gave us a structure."

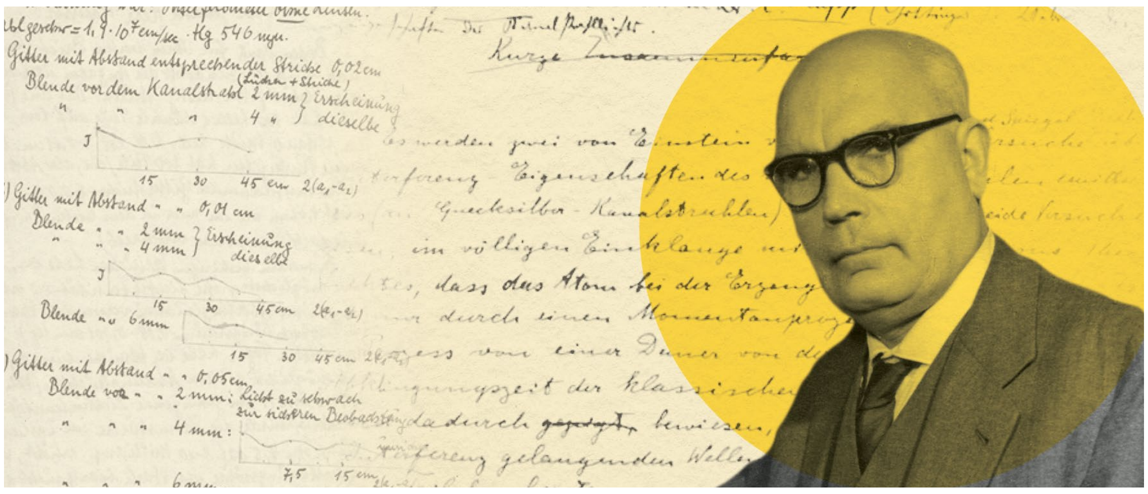
DALI continued on page 11

THIS MONTH IN PHYSICS HISTORY

December 1934: Emil Rupp's Research, Which Fooled Even Einstein, is Exposed as Fraud

After Rupp's rise to prominence for seemingly breakthrough work on canal rays, physicists noticed errors that couldn't be explained as mere mistakes.

BY TESS JOOSSE



Before Rupp's fraud was caught, he had skyrocketed to eminence. *Credit: Modified from Rupp's portrait (Familie Rupp); Rupp's letter to Einstein, 1926 (©The Hebrew University of Jerusalem, Israel); Rupp's abstract, written by Einstein (Albert Einstein Archives, the Hebrew University of Jerusalem).*

What drives a scientist to lie about their data? When these rare cases bubble up, we reach for explanations: the allure of status, perhaps, or pressure to advance professionally. But in 1935, when German experimentalist Emil Rupp published a notice in the *Journal for Physics* retracting five papers, he explained away his fraudulence with a note from his physician, Dr. E. Freiherr von Gebsattel:

"... Dr. Rupp had been ill since 1932 with an emotional weakness ... During this illness, and under its influence, he has, without being himself conscious of it, published papers on physical phenomena ... that have the character of 'fictions.' It is a matter of the intrusion of dreamlike states into the area of his scientific activity."

The retractions marked the end of a career in physics for Rupp, who had, at his peak, won over some of the era's great scientific minds — including Albert Einstein. "Many might have accepted [Rupp's] fraudulent results because of Einstein's endorsement of his experiments," writes Jeroen van Dongen, a historian of science at the University of Amsterdam. "Moreover, some aspects of Rupp's work were quite convincing, and ... he was rather agile in dealing with the criticisms."

Born in 1898, Rupp began his career in the 1920s studying canal rays, beams of positive ions and atoms formed between an anode and cathode, the latter punctured with holes (or "canals"), in a gas discharge tube. When these rays shoot through the canals and into a vacuum chamber, the ions rapidly lose and gain charge, emitting visible light that becomes less intense at the other end of the canal.

In his first experiments in the mid-1920s, Rupp measured the coherence length of light — the distance over which the light maintains a consistent phase — emitted by hydrogen and mercury atoms in the canal rays. He measured these lengths as 62 centimeters for hydrogen and 15.2 centimeters for mercury. These were blockbuster results: A moving hydrogen atom was expected to stay coherent over a much smaller distance.

What's more, Rupp's extra-long hydrogen canal ray seemed like it could be used to test one of physics' biggest questions at the time: Is light a particle or a wave? Einstein had devised experiments to test if light was emitted instantaneously or over time, but he needed a light with an extra-long coherence length — and only Rupp had achieved it.

After reading Rupp's 1926 paper, Einstein published his own "Proposal for an Experiment on the Nature of the Elementary Process of Radiation Emission" and reached out to Rupp directly to discuss a collaboration. But because Rupp's boss at Heidelberg University, the physicist Philipp Lenard, was "a fervent anti-relativist — and anti-Semite," writes van Dongen, Einstein chose to forgo a visit to the institution and sent instructions for Rupp to do the experiments on his own.

> "Many might have accepted [Rupp's] fraudulent results because of Einstein's endorsement of his experiments," writes Jeroen van Dongen.

There were red flags from the start. In one instance, Rupp appeared to have altered the mirrors in his interferometer (the instrument he used to study interference) just so, into an arrangement that would obtain desired outcomes. In another instance, when Einstein corrected the settings Rupp reported using for another instrument, Rupp chalked the mistake up to a typo. There were other "alarming discrepancies" in Rupp's calculations, van Dongen writes, and Einstein's letters show that he pushed back on several occasions. Each time, Rupp responded with new results that perfectly explained the oddities Einstein questioned.

Initially, Einstein expected to find that light was emitted instantaneously. But as the collaboration stretched on, he began to expect the experiments would confirm the alternative, the "classical" theory. "One of the reasons for his changing position likely was that that outcome had inadvertently already been corroborated by Rupp," van Dongen writes.

When Rupp furnished Einstein with a final set of results supporting the classical emission picture, Einstein facilitated their publication in the proceedings of the Prussian Academy of Sciences. They were published back-to-back with a paper by Einstein explaining the theory behind the experiments, in which Einstein cited Rupp's work. Einstein even helped Rupp draft his paper's abstract.

The association with Einstein rocketed Rupp to scientific prominence, and in 1928, he accepted a position in the research labs of German electronics company AEG, "a kind of counterpart to General Electric," writes MIT physicist Anthony French in his 1999 retrospective of Rupp's case.

However, scientists had begun voicing skepticism about Rupp's canal ray work. Among them were British spectroscopist Robert d'Escourt Atkinson, who doubted Rupp's extraordinary coherence lengths, and a researcher named Harald Straub, who tried and failed to replicate

Rupp History continued on page 3

APSNews

Series II, Vol. 33, No. 1
December 2023/January 2024
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Design and Production .... Meghan White

APS News is published 10 times per year by the American Physical Society, One Physics Ellipse, College Park, MD 20740-3844, (301) 209-3200. It contains news of the Society's units, events, initiatives, and people; opinions; and related information.

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

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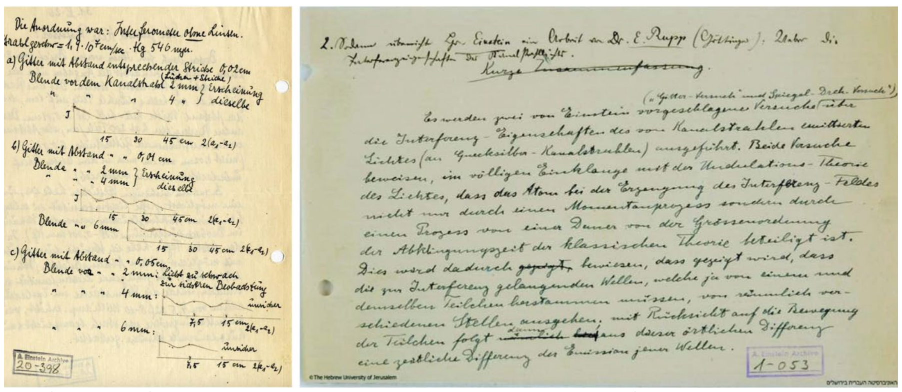
Rupp History continued from page 2

Rupp's measurements in 1930. Rupp came down hard on Straub with a rebuttal, sending photographs that supposedly showed his interference fields and forcefully defending his work in the same journal where Straub published his. Straub wrote that he had nothing else to add, and the matter appeared settled.

But Rupp's reputation was bruised in the episode, and his letters from the time indicate that his funding at AEG was drying up. He published work on electron scattering, then took up experiments with positrons, producing them by pounding lithium with protons. In a 1934 paper, Rupp claimed to have accelerated protons at potential differences of 500 kV. This was impossible for him to have done — he simply did not have the requisite accelerator in his lab.

In December 1934, two of Rupp's fellow scientists at AEG brought the glaring problem to the attention of the institute's director, who launched an investigation and subsequently fired Rupp. In January 1935, Rupp published the retraction statement appended to his doctor's note, claiming he had no knowledge of or control over the fabrications. And later that year, experimentalists Walther Gerlach and Eduard Rüchardt published "On the Coherence Length of Light emitted by Canal Rays," which essentially confirmed that Rupp's early canal ray work was also erroneous. Amid this public humiliation, Rupp experienced a nervous breakdown and spent time in a sanatorium. He never worked in physics again.

Einstein, however, escaped from the episode unscathed. Historians like van Dongen think his credulousness was an honest mistake, underpinned by his desire to see his theories confirmed by experiments. Rupp's work and life are now a footnote, but following his downfall, it appears that German scientists mentioned his name often. According to French, "for a number of years afterward, the word 'geruppt' became an epithet among German physicists to describe questionable work."



Die Anordnung war: Interferometer ohne Linsen.

a) Gitter mit Abstand entsprechender Striche 0,02 cm (Lücken + Striche)

Blende vor dem Kanalstrahl 2 mm } Erscheinung dieselbe

b) Gitter mit Abstand 0,01 cm

c) Gitter mit Abstand 0,05 cm

A. Einstein Archive 20-398

2. [illegible] Einstein [illegible] Arbeit von Dr. E. Rupp (Göttingen): Über die Interferenzeigenschaften des Kanalstrahllichts.

Kurze ~~Zusammenfassung~~.

(„Gitter-Versuche" und Spiegel-Dreh-Versuche")

Es werden zwei von Einstein vorgeschlagene Versuche über die Interferenz-Eigenschaften des von Kanalstrahlen emittierten Lichtes (an Quecksilber-Kanalstrahlen) ausgeführt. Beide Versuche beweisen, im völligen Einklange mit der Undulations-Theorie des Lichtes, dass das Atom bei der Erzeugung des Interferenz-Feldes nicht nur durch einen Momentanprozess sondern durch einen Prozess von einer Dauer von der Grössenordnung der Abklingungszeit der klassischen Theorie beteiligt ist. Dies wird dadurch ~~gezeigt~~ bewiesen, dass gezeigt wird, dass die zur Interferenz gelangenden Wellen, welche ja von einem und demselben Teilchen herstammen müssen, von räumlich verschiedenen Stellen ausgehen. Mit Rücksicht auf die Bewegung der Teilchen folgt ~~zeitlich~~ ~~hier~~aus dieser örtlichen Differenz eine zeitliche Differenz der Emission jener Wellen.

A. Einstein Archive 1-053

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האוניברסיטה העברית בירושלים

At left, a page of Rupp's letter to Einstein (1926); at right, the abstract for Rupp's paper, written by Einstein (1926). *Credit: Letter: ©The Hebrew University of Jerusalem, Israel. Abstract: Albert Einstein Archives, the Hebrew University of Jerusalem.*

Tess Joosse is a science journalist based in Michigan.

Parkin continued from page 1

stored on magnetic disk drives utilizing his technology.

IBM sold its disk drive business in 2002. "Ten thousand people were working on the business, and it just disappeared overnight," Parkin says. He took it as a challenge: "What could we do that would be better than a disk drive?" He's now 20 years into making that next technology, racetrack memory, a reality.

Parkin's innovative research has earned him dozens of high-profile awards and accolades over the years — including, now, the 2024 APS Medal for Exceptional Achievement in Research, APS's largest prize. The award recognizes Parkin "for major discoveries in spintronics leading to a revolution in data storage and memory."

Parkin spoke with *APS News* about his passion for fundamental science that makes the world better, his innovative work on memory storage, and why he tells his students to "go beyond."

This interview has been edited for length and clarity.

What sparked your interest in physics?

Both my parents went to university, and they were very interested in books and reading. That environment encouraged me to learn about other cultures and the world itself. I read a lot of books when I was a kid.

I was going to do chemistry at Cambridge, but my tutor told me, "You should really do something much more fundamental — physics or mathematics — because they can explain the world." I liked that concept. It's extraordinary that you can explain so much of the world from just a small number of equations.

What have been the central themes of your research?

My main interests have been how to build new materials one atomic layer at a time, and the interfaces between materials. An interface between material A and material B can give rise to properties that you don't find in the individual materials themselves. It is very difficult to calculate what that interface structure might be; it's more intuitive. That's the way I like to do science.

I'm very interested in exploring how we can use fundamental science discoveries to build new technologies — not tomorrow, but maybe in 10, 20, or 30 years. I'm very patient; it takes a very long time to understand even a tiny part of the natural world. I'm most excited when I can imagine ways of using some scientific concept or new material to help solve one of the challenges of today and make society better for all of us.

> "This is terrible to say, but I don't read a lot of papers. If you read too many papers in the scientific literature, you can start to think like everybody else." — Parkin

What is racetrack memory?

Racetrack has two important distinctions from conventional memory. In conventional memory, a device typically has a single bit, and the data is stored in a fixed location. In racetrack, the data is stored in magnetic spin texture walls, or boundaries between two magnetic regions. The idea is that in a very, very thin and narrow magnetic nanowire, we can store a whole sequence of these magnetic domain walls.

By passing current in this magnetic wire, you can move the data physically along the wire without moving any atoms — just by rotating magnetic spins. This means that in one device, we could perhaps store 100 bits of information. Moreover, the information can be physically moved along that wire to devices to read and write. It's conceptually very different from any memory today.

I proposed the concept in 2002, and we've effectively demonstrated that it's even better than I thought. New physics we've discovered has enabled us to manipulate these domain walls with current pulses 20 to 50 times faster than was theoretically possible 20 years ago.

Our vision is that in the next 10 years, we'll have demonstrated that we can build horizontal racetracks. If we stack several horizontal racetracks, one on top of the other, we could build very interesting devices with high performance, low energy, high volumetric capacity, and low breakdown, so they could have a million times better performance than a magnetic disk drive.

Are you working on other projects as well?

I have many! For example, if you take a conventional superconductor and inject that supercurrent into certain types of materials, including magnetic materials, you can create different forms of superconducting currents — in particular, triplet pairing. This is very interesting if the triplet Cooper pairs carry angular momentum. Our goal is to use that angular momentum at very low temperatures to manipulate magnetization and maybe build a cryogenic racetrack using totally different physics than the physics we're using today.

I'm also very interested in neuromorphic computing. The brain is very energy efficient; it uses 20 watts. To get the equivalent computing power today using CMOS, you need 10 megawatts. There are potentially huge possibilities to create ultralow energy computing systems by better understanding how the brain is able to compute.

How do you balance your research projects, director responsibilities, and other professional activities?

I'm very motivated by science. I'm super excited by what I do, and working with all the young people here is fantastic. Being a scientist is really the best job in the world. I'm always meeting new people and getting new ideas. But there are so many things to do and so many demands on my time. A lot of people are very unhappy that I don't respond to their emails quickly enough (*laughs*). It's impossible to keep track of all these emails.

Aside from patience and not worrying too much about email, what makes you good at what you do?

Parkin continued on page 11

APS's "Show Me the Money!" Webinar Helps Students Negotiate Job Offers, Kicking Off Multi-Month Careers Series

Peter Fiske advises physicists to reframe the question, "How much will I be paid?" to, "How much am I worth?"

BY LIZ BOATMAN

Students often study physics to learn about the fundamentals of our world, but they're not always sure what viable career paths they can take or, perhaps more dauntingly, what salaries they can earn after graduating.

To help students navigate these murky waters, APS is sponsoring a series of career-oriented webinars available to anyone. You don't have to be an APS member, and all webinars are recorded and accessible online.

In September, Peter Fiske, a materials scientist with career experience spanning academia to startups, spoke to students and early-career physicists from around the world about the versatility of physics degrees — and urged them to reframe the question "How much will I be paid?" to "How much am I *worth*?"

"Science-trained graduates often don't realize the breadth of what they're capable of doing," said Fiske. "With a physics degree, you possess many of the traits and skills that are actually of highest value in the world."

Physics majors learn skills that are extremely valuable to employers, Fiske noted — like the ability to defend a position with logic, speak publicly, and teach. Many physics majors don't realize this.

"We talk about the science because we think that's what matters," said Fiske. "But these [other skills] are the things that really make a difference in a successful career."

Fiske said having a clear handle on these so-called transferable skills is key to determining what you're able to contribute professionally — your 'value proposition' — which, in turn, will inform how you negotiate during a job offer.

To start, "go back to your office," he said, and "write down all the transferable skills you've learned." This exercise won't only help you develop leverage points you can use during negotiation; it will also reveal how well-rounded your physics experience has been, said Fiske, which can help you fill gaps before hitting the job market.

If you apply to a job and land an interview, go in prepared to gain more leverage. You can use subtle questions to invite a potential employer to share relevant tidbits of information.

For example, over a casual lunch, you could ask, "Have you been trying to fill this position for a while?" or "Have you had a lot of applicants like me?" In these examples, if the position has been open for several months, your perceived value in the eyes of a hirer increases; if many other applicants 'look' like you on paper, your perceived value decreases.

Fiske said it's also critical to understand the complete compensation package: salary, healthcare, remote work, and stock options, among others. If you get a job offer, ask your potential employer to spell these items out for you, and ask the hiring manager to clarify where they can be flexible.

"Now, you look at that list and you rank, from the things that are most important to you to the things that you have a lot of flexibility on," said Fiske. "It's not all just about salary."

On the employer's side, the negotiation process will boil down to economics, said Fiske, and "whatever job you take, your employer will likely [offer to] pay you less than the value you are creating."

Assuming you've done your homework, Fiske said, you should be in a good position to justify your value, while being mindful of the balance you must strike in negotiating your total compensation package.

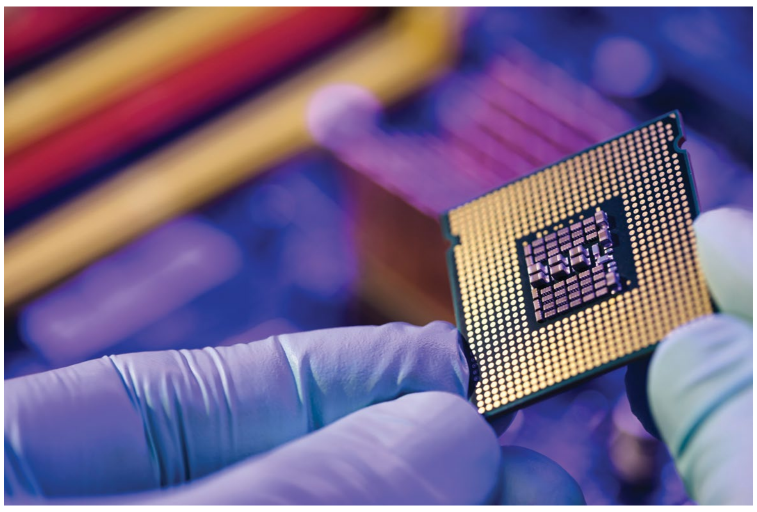
And where does Fiske think physicists should take their careers?

"Frankly, you should go where you will be the happiest and do the most good in the world."

Liz Boatman is a science writer based in Minnesota.

Science Policy Highlights

BY THE FYI TEAM



House advances update to national quantum initiative

In November, the House Science Committee unanimously advanced legislation that would update the National Quantum Initiative Act of 2018. The legislation calls for expanding the network of quantum research centers created by the NQI Act, directing NASA to establish a center focused on space-related applications of quantum science and directing the National Institute of Standards and Technology to establish up to three centers focused on quantum engineering, sensing, and measurement. It also proposes that the National Science Foundation fund a workforce and curriculum development hub, and that the Department of Energy establish "quantum foundries" to support supply chains used by quantum device manufacturers. The legislation itself doesn't provide funds for these activities; instead, it recommends amounts to be pursued through the annual appropriations process. The original NQI Act spurred federal agencies to increase funding for quantum R&D programs, but Congress ultimately did not meet the totals envisioned by the act.

AI executive order aims to expand STEM visa pathways

In October, President Biden issued an executive order on artificial intelligence that includes provisions aiming to ease visa requirements for students and workers in STEM fields. For instance, the order directs the State Department to consider permitting STEM students and scholars to renew visas in the U.S. rather than returning to their home countries. Other provisions focus on expanding visas for work or study related to what the White House deems critical and emerging technologies. Among them, the order instructs the Department of Homeland Security to consider making it easier for H-1B visa holders working in these areas to become lawful permanent residents, and to streamline visa programs that admit individuals of "extraordinary ability." However, absent new direction from Congress, agencies will be limited in what they can change.

White House explores costs of open access publishing

The White House published a report in November that explores the impact of different mechanisms for covering the cost of openly publishing federally funded research. Congress had asked the White House Office of Science and Technology Policy to estimate the degree to which federal grantees bear the costs of article processing fees (APCs) and "transformative agreements," in which research institutions and publishers strike deals to repurpose subscription fees to support open access publication. OSTP said it can't accurately estimate the costs of transformative agreements, but estimated that the APC costs borne by federal grantees and intramural researchers in 2021 was roughly $378 million — and that the average APC was $2,937 for fully open journals and $3,999 for hybrid journals.

Vision sketched for $3 billion CHIPS packaging program

The Commerce Department published a document on Nov. 20 that offers its vision for the National Advanced Packaging Manufacturing Program, which will build U.S. capabilities for placing semiconductor chips in densely interconnected groupings. The office stated the program will support "an advanced packaging piloting facility for validating and transitioning new technologies to U.S. manufacturers [and] workforce training programs to ensure that new processes and tools are capably staffed," and provide funding for related projects and materials. The program will receive roughly $3 billion over five years from the CHIPS and Science Act, as part of the $11 billion in R&D-focused semiconductor programs created by the law, with the first funding opportunity expected in early 2024.

FYI is a trusted source of science policy news, published by the American Institute of Physics since 1989.

Five APS Fellows and Past Presidents Receive National Award in Science and Tech

In a moment of pride for the American Physical Society, three APS Fellows and two APS Past Presidents have received the nation's two highest scientific honors.

In late October, APS Fellows James G. Fujimoto and Ashok J. Gadgil were awarded the National Medal of Technology and Innovation. Barry C. Barish, the 2011 APS President; Myriam Sarachik, the 2003 APS President; and APS Fellow Sheldon Weinbaum were awarded the National Medal of Science for their contributions to physics. Sarachik, who died in 2021, received the award posthumously.

APS congratulates the winners and their communities, teams, and families for this well-deserved recognition.

P5 Report continued from page 1

$1 billion in funding to high energy physics each year.

On the morning of Dec. 8, the P5 panel released its 2023 report to the public.

"We're very fortunate that the agencies that support high energy physics [in the U.S.] … ask their advisory panel, P5, to take community input and use it as the basis for constructing an effective particle physics program," says R. Sekhar Chivukula, 2023 chair of APS's Division of Particles and Fields (DPF) and a theoretical particle physicist at the University of California, San Diego.

"Community input" is an understatement: The P5 report relies on the feedback of hundreds of physicists, who joined a planning process known as 'Snowmass,' organized by DPF. First convened in Colorado in 1982, Snowmass brings together physicists from across the United States and around the world to plan the future of the field.

Last year's Snowmass process culminated in hundreds of white papers, fodder for the P5 panel as it began the arduous task of distilling everyone's hopes into a realistic vision for the next 10 years and beyond. It's scientific "democracy at work," says Hitoshi Murayama, P5 panel chair and a theoretical particle physicist at the University of California, Berkeley.

The Snowmass process is triggered when a sufficient number of advances in the field set the stage for the next generation of scientific discovery. For example, the last P5 report was published in 2014, just two years after the Higgs boson was observed. A year later, in 2015, the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected long-theorized gravitational waves. And today, the IceCube Neutrino Observatory is revealing awe-inspiring features of our galaxy through a neutrino 'camera.'

These discoveries have spurred a major shift in thinking within the field, says Karsten Heeger, P5 panel deputy chair and experimental neutrino physicist at Yale University. "We've found ourselves now in a situation where we can learn about the fundamentals of particle physics not just by looking at the smallest things, with colliders, but by also looking at the universe and the cosmos," Heeger says.

U.S. physicists call this aspirational [muon] collider their 'muon shot,' like 'moonshot. . . . "It's worth spending time and money on it, to at least see if it's going to work or not before we can talk about building it," says Murayama.

For example, many physicists searching for dark matter's clues aren't running experiments at an accelerator. Instead, they're looking at the night sky, scouring black holes for new evidence. "The way we think about what may lie beyond the Standard Model has really changed," says Murayama.

The P5 report captures these shifts, says Heeger, while balancing the need to sustain investment in major activities already underway that the P5 panel deems most important. This includes a high-luminosity upgrade to the LHC (HL-LHC), to increase its brightness by a factor of 10; the Deep Underground Neutrino Experiment (DUNE), to answer persistent questions about neutrinos; and the Vera C. Rubin Observatory, intended to help scientists understand the drivers of cosmic evolution. The report also urges funding for ongoing smaller experiments on dark matter, like DarkSide-20k, and deeper exploration of particle decay paths through Belle II, among many other projects.

Developing the report was like "putting together a big jigsaw puzzle," says Murayama: The goal is to fit priorities together in a way that maximizes opportunities for physicists, while balancing constraints. For example, "big projects are very exciting," he says, "but they take a long time." DUNE is one such project, designed to yield decades' worth of data — but because graduate students need to complete their degrees within much shorter timeframes, funding must also support small-scale efforts. The P5 team had to consider this carefully, he says.

The Rubin Observatory in Chile in 2022. The facility is under construction, with full operations slated to begin in 2025. Rubin Observatory/NSF/AURA/B. Quint

One of the panel's grandest recommendations is for the United States to develop the capacity to design and someday build a 10-TeV parton center-of-momentum (pCM) collider, perhaps using muon beams, a feat that many proponents argue would solidify the country's leadership in collider science. The project faces daunting challenges: As elementary particles, muons would be simpler and more energy-efficient to study than the protons, composed of quarks held together by gluons, that CERN's LHC smashes together — but muons also have extremely short lifespans.

U.S. physicists call this aspirational collider their 'muon shot,' like 'moonshot,' a problem that can only be solved with a radical new way of thinking. "It's worth spending time and money on it, to at least see if it's going to work or not before we can talk about building it," says Murayama. That means investing in fundamental science now, ahead of a future funding initiative.

The report also recommends supporting a broad portfolio of new projects across the field. For example, some of the new lines of support recommended by P5 would help physicists study the universe's birth through the cosmic microwave background at the South Pole (CMB-S4) and refine the properties of the Higgs boson through a new offshore 'Higgs factory,' designed to churn out the elusive particles for study.

The report recommends initiatives to nurture the nation's advanced technological workforce, too — including increases in existing federal funding, like ramping up DOE funding for research on high energy physics theory in universities by $15 million per year, and accelerator R&D programs by $10 million per year.

And the report is clear-eyed about the consequences of underfunding — what the panel dubbed a "less favorable budget scenario" that would not keep pace with inflation. In this scenario, the report warns, "the US will cede its leadership" in many areas, like off-shore dark-matter detection experiments.

This is important because many of P5's recommended projects would be collaborative and international. "The scale of particle physics experiments these days is such that it is not possible, in most cases, to have multiple experimental programs undertaking the same work," says Chivukula. "There needs to be a certain amount of sharing and prioritization, as there is in the case of the LHC and DUNE," like providing in-kind support to Europe or Japan to construct the Higgs factory.

"What we recommend here, it's not just exclusively important for particle physics," says Heeger. "It's important for U.S. R&D and the science landscape."

"We need to have structural support at all levels from funding agencies, and individuals, to make all of this happen."

Liz Boatman is a science writer based in Minnesota.

AMERICAN PHYSICAL SOCIETY

2023-24 PRIZES & AWARDS

APS congratulates all prize and award recipients. Recipients will be honored at APS meetings throughout the year, and each will be invited to give a talk at the meeting where they receive their prize or award. For the full schedule of APS meetings, visit aps.org/meetings.

APS Medal for Exceptional Achievement in Research

Stuart Parkin
Max Planck Institute of Microstructure Physics

For major discoveries in spintronics leading to a revolution in data storage and memory.

Abraham Pais Prize for History of Physics

Virginia Louise Trimble
University of California, Irvine

For extensive contributions to the history of astrophysics, particularly for reference works, articles, and biographical essays, especially works that include female astronomers, and for supporting the history of the physics community.

Andrei Sakharov Prize

Eugene M. Chudnovsky
Lehman College

For decades of leadership of prominent campaigns on behalf of oppressed scientists, including chairmanship of the APS and New York Academy of Sciences human rights committees and co-chairing of the Committee of Concerned Scientists.

Aneesur Rahman Prize for Computational Physics

Gustavo E. Scuseria
Rice University

For the groundbreaking development and application of screened hybrid density functional and ab initio methods to the accurate modeling of molecules and solids.

Arthur L. Schawlow Prize in Laser Science

Howard M. Milchberg
University of Maryland

For pioneering contributions in the fields of plasma optics, guiding ultra-intense laser beams, and developing compact, high-gradient laser-driven accelerators.

David Adler Lectureship Award in the Field of Materials Physics

Nitin Samarth
Pennsylvania State University

For seminal contributions to semiconductor spintronics through the development of atomically engineered materials.

Davisson-Germer Prize in Atomic or Surface Physics

Anne L'Huillier
Lund University

For pioneering experimental and theoretical work leading to the discovery of high harmonic generation in gases and the micro- and macroscopic physics responsible for it, and for controlling the phenomenon to create and analyze attosecond pulse trains to probe ultrafast electron dynamics in matter.

Dwight Nicholson Medal for Outreach

Tatiana Erukhimova
Texas A&M University

For leadership in bringing the excitement of physics through innovative education programs, summer boarding schools for public high school teachers, the TAMU Physics and Engineering Festival, the Real Physics Live program, and online physics videos with more than 400 million views.

Earle K. Plyler Prize for Molecular Spectroscopy & Dynamics

Anders Nilsson
Stockholm University

For seminal contributions in the application of x-ray spectroscopy methods to the molecular dynamics of water and catalytic reactions.

TEAM AWARD

Excellence in Physics Education Award

For developing outstanding educational resources that are distributed free to physics teachers in 130 countries, for fostering an international peer-to-peer teacher training network, and for delivering inclusive and inspiring educational programs to students around the world.

Lorraine Blackwell
Perimeter Institute for Theoretical Physics

Greg Dick
Open Quantum Design

Dave Fish
Perimeter Institute for Theoretical Physics

Kelly Foyle
Perimeter Institute for Theoretical Physics

Lauren E. Hayward
Perimeter Institute for Theoretical Physics

Emma Nichols
Perimeter Institute for Theoretical Physics

Damian Pope
Perimeter Institute for Theoretical Physics

Marie Strickland
Perimeter Institute for Theoretical Physics

Tonia Williams
Perimeter Institute for Theoretical Physics

Early Career Award for Soft Matter Research

Corentin Coulais
University of Amsterdam

For pioneering research into soft matter-based metamaterials with on-demand mechanical properties.

Edward A. Bouchet Award

Alvine Christelle Kamaha
University of California, Los Angeles

For leadership and key accomplishments in the experimental search for dark matter in the Universe, including advances in radioactive purity, as well as contributions to outreach, diversity, and inclusion through service and mentoring of students.

FIAP Career Lectureship Award

Azadeh Keivani
New York-Presbyterian Hospital

For the development and application of artificial intelligence techniques to problems ranging from education to clinical studies in cancer and heart disease, and for enthusiasm in the translation of esoteric academic research training into solutions for pressing real-world problems.

Fluid Dynamics Prize

Elisabeth Guazzelli
Centre national de la recherche scientifique

For ground-breaking experiments on fluid-particle systems; for advances in the unification of the rheological description of dry granular media and dense "wet" suspensions; for guidance of theory through focused and creative experiments; and for leadership in the fluid mechanics community.

Frank Isakson Prize for Optical Effects in Solids

Feng Wang
University of California, Berkeley and Lawrence Berkeley National Laboratory

For pioneering and trail-blazing works on the exploration of new physics and exotic phenomena in 1D and 2D quantum materials that have guided advances in the field.

George E. Pake Prize

Chih-Yuan Lu
Macronix International Co., Ltd

For seminal scientific innovations and outstanding contributions in device physics and semiconductor technology, and for visionary leadership of semiconductor non-volatile memory (NVM) manufacturing technology and the integrated circuit industry.

George E. Valley, Jr. Prize

Geoff Penington
University of California, Berkeley

For computation of the quantum entropy of an evaporating black hole and its radiation.

Hans A. Bethe Prize

John Richard Bond
Canadian Institute for Theoretical Astrophysics and University of Toronto

For developing conceptual and quantitative tools that have enabled cosmologists to measure the geometry, content, and age of the universe.

Henry Primakoff Award for Early-Career Particle Physics

Javier Mauricio Duarte
University of California, San Diego

For accelerating trigger technologies in experimental particle physics with novel real-time approaches by embedding artificial intelligence and machine learning in programmable gate arrays, and for critical advances in Higgs physics studies at the Large Hadron Collider in all-hadronic final states.

Herman Feshbach Prize in Theoretical Nuclear Physics

Gail C. McLaughlin
North Carolina State University

For seminal contributions to the study of neutrinos in explosive systems and for elucidating the profound impact of this microphysics on the synthesis of elements.

TEAM AWARD

Irwin Oppenheim Award

For the study of dynamical systems on large networks with predator-prey interactions that are stable and exhibit oscillations.

Chiara Cammarota
Sapienza University of Rome

Andrea Marcello Mambuca
Citi

Izaak Neri
King's College London

J. J. Sakurai Prize for Theoretical Particle Physics

Andrzej J. Buras
Technical University of Munich

For exceptional contributions to quark-flavor physics, in particular, developing and carrying out calculations of higher-order QCD effects to electroweak transitions, as well as for drawing phenomenological connections between kaons, D mesons, and B mesons.

James C. McGroddy Prize for New Materials

Harold Y. Hwang
Stanford University

For pioneering work in oxide interfaces, dilute superconductivity in heterostructures, freestanding oxide membranes, and superconducting nickelates using pulsed laser deposition, as well as for significant early contributions to the physics of bulk transition metal oxides.

James Clerk Maxwell Prize for Plasma Physics

Thomas M. Antonsen, Jr.
University of Maryland, College Park

For pioneering contributions in the theory of magnetized plasma stability, RF current drive, laser-plasma interactions, and charged particle beam dynamics.

TEAM AWARD

John Dawson Award for Excellence in Plasma Physics Research

For establishing and shaping the field of structure-preserving geometric algorithms for plasma physics.

Philip J. Morrison
University of Texas at Austin

Hong Qin
Princeton Plasma Physics Laboratory, Princeton University

Eric Sonnendrücker
Max Planck Institute for Plasma Physics

John H. Dillon Medal

Charles E. Sing
University of Illinois, Urbana-Champaign

For pioneering advances in polyelectrolyte phase behavior and polymer dynamics using theory and computational modeling.

Jonathan F. Reichert and Barbara Wolff-Reichert Award for Excellence in Advanced Laboratory Instruction

R. Seth Smith
Francis Marion University

For decades of outstanding physics instruction, introducing undergraduates to advanced physics lab topics, for inspiring first-generation students to pursue graduate study and careers in physics, and for working with colleagues in the ALPhA community to improve laboratory instruction nationwide.

Joseph A. Burton Forum Award

Galileo Violini
Centro Internacional de Física

For establishing programs in physics education and research in Latin America and the Caribbean that increased regional scientific capacity, for promoting international scientific cooperation across continents and regions of the world, and for creating the Centro Internacional de Física in Colombia.

Joseph F. Keithley Award For Advances in Measurement Science

David A. Muller
Cornell University

For pioneering a new generation of electron detectors and phase-sensitive reconstruction algorithms leading to significant advances in the resolution and capabilities of electron microscopes.

Julius Edgar Lilienfeld Prize

Edward W. Kolb
University of Chicago

For pioneering and outstanding contributions to cosmology and particle physics, and an exceptional ability to communicate the extraordinary developments at the intersection of physics and cosmology to the general public.

Lars Onsager Prize

Jacques Prost
Curie Institute

For influential contributions to the statistical physics of nonequilibrium phenomena and applications to soft matter and biological systems.

Leo P. Kadanoff Prize

Mark Newman
University of Michigan

For fundamental contributions to the statistical physics of complex networks.

Leo Szilard Lectureship Award

Robert J. Budnitz
Lawrence Berkeley National Laboratory (retired)

For outstanding leadership in formulating and guiding the US Nuclear Regulatory Research program in areas of reactor safety, waste management, and fuel-cycle safety, and for significantly advancing seismic probabilistic risk assessments as applied to nuclear power worldwide.

LeRoy Apker Award

Denisse Córdova Carrizales
Harvard University

For the development of a new method to intercalate Li into thin films of indium tin oxide.

LeRoy Apker Award

Cailin Plunkett
Amherst College

For the development of a novel method to compute survey sensitivity to accreting protoplanets.

Maria Goeppert Mayer Award

Alison Patteson
Syracuse University

For important contributions in characterizing the physics of living systems, including demonstrating how mechanics influences the collective behavior of bacteria and how intermediate filaments in a cell's cytoskeleton impact its mechanics, migration, and signaling.

Max Delbrück Prize in Biological Physics

Eric D. Siggia
Rockefeller University

For powerful theoretical approaches to the physics of life and incisive connections between theory and experiment, from the mechanics of DNA to the dynamics of genetic networks, and from noise in gene expression to pattern formation in embryos and populations of stem cells.

Mildred Dresselhaus Prize in Nanoscience and Nanomaterials

Naomi Halas
Rice University

For creating nanoparticles and complexes with tunable optical resonances resulting from hybridized surface plasmons, and demonstrating applications of these nanomaterials that range from photothermal cancer therapy to hot electron photodetection and modular plasmonic photocatalysis.

Neil Ashcroft Early Career Award for Studies of Matter at Extreme High Pressure Conditions

Mitchell A. Wood
Sandia National Laboratories

For the development and application of ground-breaking computational approaches to the study of complex physical processes in materials undergoing dynamic compression, including initiation in energetic materials, strength in metals, and phase change kinetics in compressed diamond.

TEAM AWARD

Norman F. Ramsey Prize in Atomic, Molecular and Optical Physics, and in Precision Tests of Fundamental Laws and Symmetries

For pioneering work in molecular physics, cooling, and spectroscopy that has profoundly advanced the search for the electric dipole moment of the electron, and for placing stringent constraints on modifications to the Standard Model in a tabletop experiment.

David DeMille
University of Chicago

John M. Doyle
Harvard University

Gerald Gabrielse
Northwestern University

TEAM AWARD

Oliver E. Buckley Condensed Matter Physics Prize

For groundbreaking theoretical and experimental studies on the collective electronic properties of materials that reflect topological aspects of their band structure.

Ashvin Vishwanath
Harvard University

Qikun Xue
Tsinghua University

Polymer Physics Prize

Zhen-Gang Wang
California Institute of Technology

For contributions to the theories of polymer physics in regard to nucleation, block polymer self-assembly, and polyelectrolytes, in particular, for the application of these theories to experimentally-motivated phenomena.

Prize for a Faculty Member for Research in an Undergraduate Institution

Lars Q. English
Dickinson College

For innovative experiments involving undergraduate students on nonlinear patterns in electrical lattices and networks that have elucidated the interplay of nonlinearity and geometry in the emergence of coherent spatial and temporal structures.

Richard A. Isaacson Award in Gravitational-Wave Science

Manuela Campanelli
Rochester Institute of Technology

For extraordinary contributions to and leadership in the understanding and simulation of merging binaries of compact objects in strong-field gravity.

Robert R. Wilson Prize for Achievement in the Physics of Particle Accelerators

Kaoru Yokoya
High Energy Accelerator Research Organization (KEK)

For seminal contributions to the theory and control of beam polarization in electron storage rings, beam-beam interactions in linear colliders, crab-crossing and coherent beam-beam interactions in circular colliders, and bunched beam instabilities.

Rolf Landauer and Charles H. Bennett Award in Quantum Computing

Shruti Puri
Yale University

For advancing the theoretical understanding of quantum fault-tolerance in the presence of biased noise.

Stanley Corrsin Award

George Haller
ETH Zurich

For long-lasting contributions to the predictive understanding and mathematical underpinnings of the nonlinear dynamics of fluid flows and Lagrangian coherent structures, and for novel data-driven approaches to reduced order modeling.

Stuart Jay Freedman Award in Experimental Nuclear Physics

Elise Novitski
University of Washington

For the development and analysis of the Cyclotron Radiation Emission Spectroscopy method and its application to the measurement of neutrino mass.

Thomas H. Stix Award for Outstanding Early Career Contributions to Plasma Physics Research

David Turnbull
University of Rochester Laboratory for Laser Energetics

For pioneering experimental work on plasma photonics in the pursuit of laser-plasma applications, including Raman amplification, plasma optics, and inertial confinement fusion.

Tom W. Bonner Prize in Nuclear Physics

Wit Busza
Massachusetts Institute of Technology

For pioneering work on multi-particle production in proton-nucleus and nucleus-nucleus collisions, including the discovery of participant scaling, and for the conception and leadership of the PHOBOS experiment.

TEAM AWARD

W.K.H. Panofsky Prize in Experimental Particle Physics

For leading the synthesis of precision microwave cavity techniques, superconducting quantum sensing, and cryogenic technology into the modern axion haloscope, and for the subsequent demonstration of experimental sensitivity to high-priority models of axions as dark matter.

Leslie J. Rosenberg
University of Washington

David B. Tanner
University of Florida

Will Allis Prize for the Study of Ionized Gases

Vincent M. Donnelly
University of Houston

For sustained, pioneering research elucidating fundamental physical and chemical mechanisms of plasma etching of microelectronic materials, enabled by the invention of novel plasma and plasma-surface diagnostics, including advanced optical spectroscopy and the 'spinning wall' method.

Dissertation Awards

Andreas Acrivos Dissertation Award in Fluid Dynamics

Karol Bacik
University of Cambridge

For an elegant study of dune-dune repulsion and dune-obstacle interaction using laboratory experiments, data analysis, and mathematical modeling, elucidating the intricate feedback between sediment dynamics and fluid mechanics.

Award for Outstanding Doctoral Thesis Research in Biological Physics

Diederik Laman Trip
Delft University of Technology

For discovering how temperature constrains and drives cell replication and revealing that cells can cooperatively survive in extreme heat and cold, revising accepted views of temperature-dependent cell growth by integrating single-cell and genome-scale experiments with dynamical systems theory.

Dissertation Award in Nuclear Physics

Matthew Ramin Hamedani Heffernan
McGill University

For the application of state-of-the-art Bayesian analysis techniques in the determination of transport coefficients of strongly interacting matter, and for first-time investigations of multistage simulation approaches in heavy-ion collisions with statistical learning methods.

Dissertation Award in Nuclear Physics

Evan Rule
University of California, Berkeley

For the timely development of a flexible and fully general effective theory of muon-to-electron conversion. The formulation establishes an interface between the nuclear and particle physics components of this process that will encourage coordination between the two communities.

Dissertation Award in Statistical and Nonlinear Physics

Colin Scheibner
Princeton University

For groundbreaking contributions at the interface between soft matter and dynamical systems including the theoretical formulation of odd elasticity as well as studies of interfacial excitability and spontaneous wrinkling of atomically thin films, all in striking agreement with experiments.

Marshall N. Rosenbluth Outstanding Doctoral Thesis Award

Ian Emanuel Ochs
Princeton University

For developing rigorous constraints on charge extraction across magnetic fields and powerful theorems relating lower hybrid current drive to alpha channeling, and for studying unusual transport effects with diverse applications in multi-species magnetized plasmas.

Fellowships

DAMOP

Paola Cappellaro
Massachusetts Institute of Technology

Kaden Hazzard
Rice University

Irina Novikova
College of William & Mary

Cheng-Zhi Peng
University of Science and Technology of China

Nina Rohringer
Deutsches Elektronen-Synchrotron (DESY)

Artem Rudenko
Kansas State University

Jonathan Simon
Stanford University

C. Wesley Walter
Denison University

DAP

Arif Babul
University of Victoria

James S. Bullock
University of California, Irvine

Adrienne L. Erickcek
University of North Carolina, Chapel Hill

Katrin Heitmann
Argonne National Laboratory

William Raphael Hix
Oak Ridge National Laboratory

Philip von Doetinchem
University of Hawaii, Manoa

DBIO

Laura Finzi
Emory University

Vernita D. Gordon
University of Texas, Austin

Kerwyn Casey Huang
Stanford University

Pankaj Mehta
Boston University

Sarah Veatch
University of Michigan, Ann Arbor

DCMP

Brian M. Andersen
Niels Bohr Institute, University of Copenhagen

Anton Andreev
University of Washington

Erez Berg
Weizmann Institute of Science

Anton Burkov
University of Waterloo

Fiona J. Burnell
University of Minnesota, Minneapolis

Nicholas P. Butch
National Institute of Standards and Technology

Amalia I. Coldea
University of Oxford

Cory R. Dean
Columbia University

Wei Guo
Florida State University

Chaoxing Liu
Pennsylvania State University

Andriy Nevidomskyy
Rice University

Marco Polini
University of Pisa

Kai Sun
University of Michigan, Ann Arbor

Gertrud Zwicknagl
Technische Universitaet Braunschweig

DCOMP

Davide Donadio
University of California, Davis

Andrzej Michal Oles
Jagiellonian University

Adrienn Ruzsinszky
Tulane University

Aidan Thompson
Sandia National Laboratories

Xifan Wu
Temple University

Jin Zhao
University of Science and Technology of China

DCP

Javier Aizpurua
Donostia International Physics Center

Michael Heaven
Emory University

Ahren Jasper
Argonne National Laboratory

DFD

Linda Cummings
New Jersey Institute of Technology

Bérengère Dubrulle
CNRS/CEA/University Paris-Saclay

Bharathram Ganapathisubramani
University of Southampton

Dennice F. Gayme
Johns Hopkins University

David L. Hu
Georgia Institute of Technology

H. Pirouz Kavehpour
University of California, Los Angeles

Aditya Khair
Carnegie Mellon University

Steve Tobias
University of Leeds

DGRAV

Harald Pfeiffer
Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Joseph D. Romano
University of Texas, Rio Grande Valley

Bram J. J. Slagmolen
The Australian National University

DLS

Alexandra Boltasseva
Purdue University

Manfred Helm
Helmholtz-Zentrum Dresden-Rossendorf

Vinod Menon
City College of New York, CUNY

DMP

Dillon D. Fong
Argonne National Laboratory

László Forró
University of Notre Dame

Nikhil Ashok Koratkar
Rensselaer Polytechnic Institute

Steven J. May
Drexel University

Cheng-Wei Qiu
National University of Singapore

James M. Rondinelli
Northwestern University

Adri C.T. van Duin
Pennsylvania State University

DNP

Christine A. Aidala
University of Michigan

Christian Iliadis
The University of North Carolina, Chapel Hill

John Lajoie
Oak Ridge National Laboratory

Anna Stasto
Pennsylvania State University

Derek Teaney
Stony Brook University

Itzhak Tserruya
Weizmann Institute of Science

André Walker-Loud
Lawrence Berkeley National Laboratory

Liang Yang
University of California, San Diego

DPB

Chandrashekhara M. Bhat
Fermi National Accelerator Laboratory

Agostino Marinelli
SLAC National Accelerator Laboratory

Robert Miles Zwaska
Fermi National Accelerator Laboratory

DPF

Claudio Campagnari
University of California, Santa Barbara

Sarah Demers
Yale University

Eilam Gross
Weizmann Institute of Science

Mark Lancaster
University of Manchester

John A. McGreevy
University of California, San Diego

Adam Ritz
University of Victoria

Anders Ryd
Cornell University

Marcelle Soares-Santos
University of Michigan

Henry Tsz-King Wong
Academia Sinica

DPOLY

Dean M. DeLongchamp
National Institute of Standards and Technology

Bradley D. Olsen
Massachusetts Institute of Technology

Rodney Dewayne Priestley
Princeton University

DPP

Frederico Fiuza
Instituto Superior Técnico, University of Lisbon

Frank R. Graziani
Lawrence Livermore National Laboratory

Per Helander
Max Planck Institute for Plasma Physics

Maria Gatu Johnson
Massachusetts Institute of Technology

Mounir Laroussi
Old Dominion University

Lorin Swint Matthews
Baylor University

Felix I. Parra
Princeton Plasma Physics Laboratory

Caterina Riconda
Sorbonne University

DQI

Adolfo del Campo
University of Luxembourg

Sophia Economou
Virginia Tech

Jonathan Home
ETH Zurich

Jens Koch
Northwestern University

Xiongfeng Ma
Tsinghua University

Graeme Smith
University of Waterloo

Krysta M. Svore
Microsoft

DSOFT

Sibani Lisa Biswal
Rice University

Laura I. Clarke
North Carolina State University

Moumita Das
Rochester Institute of Technology

Alberto Fernandez-Nieves
University of Barcelona

Charles M. Schroeder
University of Illinois, Urbana-Champaign

FDI

Jennifer Blue
Miami University

Mario Francisco Borunda
Oklahoma State University

Jami Valentine Miller
United States Patent and Trademark Office

FEd

David A. Craig
Oregon State University

Marie Lopez del Puerto
University of St. Thomas

Michael Jackson
New Mexico Institute of Mining and Technology

Don S. Lemons
Bethel College of Kansas

Timothy A. McKay
University of Michigan

FHPP

Donald Salisbury
Austin College

FIAP

Laura Na Liu
University of Stuttgart

Samuel E. Lofland, Jr.
Rowan University

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Parkin continued from page 3

This is terrible to say, but I don't read a lot of papers. If you read too many papers in the scientific literature, you can start to think like everybody else. I don't want to discourage people from reading the literature, but sometimes you can have more new ideas if you don't.

I'm also very persistent. If I have an idea and want to prove it, I'll continue working on it even if the experiments show something else. Eventually, I'll have the right intuition. Of course, I'll change my mind if I discover my idea is wrong, but many people give up when they just have to persevere.

What advice do you share with your students?

I tell my students to "go beyond," which means that we should go beyond what others are doing — that we should come up with our own ideas. I also like to say, "You should do the impossible." Come up with something that nobody has done, and then imagine ways of achieving that goal if it's exciting from a fundamental science point of view or if you can imagine it being technologically useful. And then never give up. It's very exciting to try to achieve something that nobody has done before.

Kendra Redmond is a writer based in Minnesota.

Auroras continued from page 1

Allison Jaynes at the University of Iowa's Van Allen Observatory. *Credit: Jill Tobin, University of Iowa CLAS Photographer*

it's a case study in auroras' impacts. "Local sudden changes in ozone ties into the entire climate system of our planet," says Jaynes.

To describe auroras, Jaynes represents the solar system as an "ocean" of plasma, with the planets sitting like rocks in this ocean. The plasma arrives at Earth in waves of varying frequencies and structures. "Think of throwing some gravel into a lake," says Jaynes. "You see all kinds of ripples. Some move slowly, and some move quickly. Some make these big splashes, some small, and they overlap each other to create interference."

Different plasma waves cause different types of auroras. For example, Jaynes studies pulsating auroras, which appear as "big patches of light that turn on and off all at once" and stem from plasma waves known as dawn chorus waves. The name originates from World War I, where military officers' communications antennae picked up the dawn chorus waves' telltale chirp while listening for enemy transmissions in the early morning.

Planets beyond Earth interact with surrounding plasma in their own way. Jaynes is particularly interested in Jupiter, which has the largest magnetic fields in our solar system aside from the Sun. "Jupiter has [auroras] all the time," she says. "It's just constant, particles dumping into the atmosphere."

But astrophysicists aren't the only ones studying auroras, Jaynes says. Scientists have drawn on the expertise of passionate members of the public — namely, aurora chasers and photographers. For example, in 2016, these citizen scientists discovered a new type of aurora, a purplish ribbon fringed with green, which they named Steve. Rather than forming directly from charged solar wind particles hitting atmospheric particles, Steve's light comes from the charged particles heating the sky. (Researchers retroactively made Steve an acronym, "Strong Thermal Emission Velocity Enhancement.")

For Jaynes, this is great news, because *who* is doing the science is as important as the science itself. During her talk, she mentioned the "disturbingly low" number of gender and racial minorities in plasma physics: Over the last decade, women have made up about 10% of the membership of APS's Division of Plasma Physics, compared to about 18% of APS at large. In Iowa, Jaynes runs a summer undergraduate research program and high school summer camp that recruit students whose backgrounds are underrepresented in physics.

As for last year's rocket launch, Jaynes's team successfully captured the data they sought. They were studying light pulses known as microbursts, lasting less than a second, that occur during pulsating aurora. "They're these little confetti flashes of light," she explains. They measured the energy of these microbursts to understand their contribution to auroras.

Some of their results have been accepted for publication, but the work itself is rewarding. "That's what captured my imagination," Jaynes says. "Going to a place, observing the natural world, and trying to uncover the fundamental laws that govern that beautiful thing you're seeing."

Sophia Chen is a writer based in Columbus, Ohio.

DALI continued from page 2

Popovic says the DAT framework helped reduce the power differences between students, staff, and faculty, creating "a comfortable group of people that work together as partners."

He also highlights the DALI mantra: *Go slow to go fast*. "Some people were pleasantly surprised by how DALI changed their perspective on taking the time to make a data-driven change and waiting to see real, good results," he says.

In 2022, with the DALI curriculum refined, Craig and Corbo were ready to expand the program. They invited two prior DALI participants, including Del Vecchio, to join them as facilitators, and recruited for two simultaneous cohorts. Wake Forest University in North Carolina started the program in September 2022.

To Wake Forest faculty member Jed Macosko, DALI seemed like a great opportunity to support the physics department's goals of increasing enrollment and undergraduate diversity.

Since completing the DALI curriculum last school year, those "two overall goals have stayed the same, but the number of intermediate goals to those two goals has grown," says Macosko.

As undergrad enrollment falls at some schools, departments are turning to DALI.

He says the department also realized what they had been missing before. "There needs to be that constant transformational change," says Macosko. "We have committees — for the undergraduate curriculum, for the building — and those are great, but you need something that represents the heart and soul of what the department's trying to do."

The DAT framework gave Wake Forest's physics department that "heart and soul," says Macosko. And with a whole team in place, he says their work is more sustainable.

With their Innovation Fund grant expiring soon, Craig and Corbo hope to have the DALI curriculum packaged for dissemination by the end of the year, which will allow others to work through the program on their own.

Macosko's team, meanwhile, will stay focused on the big picture. "We want our department to reflect the diversity that is out in the world," he says, "and to give everybody a chance to be a physicist."

To future-proof your physics department through positive change, get free resources at ep3guide.org.

Liz Boatman is a science writer based in Minnesota.

Kolb continued from page 1

Kolb is particularly passionate about public outreach. "It validates for postdocs and grad students that it's a good thing for them to do," he says. His passion is inspired in part by the late Leon Lederman, a Nobel Prize-winning particle physicist who Kolb says led by example, encouraging Kolb's own outreach work in his early career.

Kolb spoke with *APS News* about his views on the universe and the importance of public engagement.

This interview has been edited for length and clarity.

What about the early universe captivates you?

It's the origin of everything, and it entailed conditions of temperature and pressure and density that we cannot reproduce here on Earth. So if we ask questions about the nature of matter at extreme temperatures or extreme energies beyond those which we can reproduce in laboratories, then we can look to the early universe as our 'particle accelerator' — a type of experimental facility that physicists might use to answer those types of questions. It's comparatively cheap because the experiment has been done — the Big Bang already happened. We just have to understand the results of the experiment by looking back in time to develop our understanding of the early universe.

How did you enter the field of cosmology, and how has it changed?

I stumbled into cosmology, as a particle theorist. How we view the field of cosmology has been a really big change over the course of my career — that a field that was once looked down upon is now at the forefront of so much activity. Today, cosmology is bridging the gap between the 'inner space' of quantum physics and the fundamental laws of physics with 'outer space' — the cosmos. Those connections didn't exist when I first entered the field, but now we recognize that we can learn something about fundamental physics from studying the universe, and we can learn something about the universe from studying fundamental physics.

A good example of this is 'dark matter.' We still don't know what most of the matter of the universe is made of. We believe it's a particle beyond the standard model of particle physics, which we call 'dark matter.' Even though we still don't know the true nature of dark matter, it represents a connection between the inner space and outer space that is yet to be discovered.

On your website, you list the "top 10 questions about the universe" that still need to be answered. Let's get your thoughts on a few of them. What came before the Big Bang?

There was nothing before the Big Bang. Not only was there no matter or galaxies or radiation, there was no space and no time. So, if there was no time, perhaps the question doesn't make sense. How can 'before' make sense if time did not exist? The Big Bang was time equal to zero and the origin of everything in the universe, including space and time.

What's outside the universe?

When I give a public lecture, I can predict that invariably either this question will come up or a question about the Big Bang. It's really difficult to get these concepts across, even in a graduate course on cosmology — but there is no 'outside' the universe.

Is there a parallel universe?

The idea of a parallel universe is mixed up with the idea of a multiverse, which is an idea that's come up in the past 20 years or so, driven by the theory of cosmic inflation — that what we call the universe, the vastness of space that we see as just one universe, actually exists in a population of multiverses.

This is a great idea. It's compelling. But it hasn't been proven true, in part because we don't know how to prove it. It has some interesting implications, though, that there are other universes that we just don't see, and will never be able to see, because space is so warped that we wouldn't be able to see outside of the universe we're in now.

Do any of these topics make you uncomfortable?

No. Perhaps they are just indicators that our knowledge is incomplete.

You've won several awards for teaching. Do you have a secret recipe for that?

It's important to respect the students. I enjoy teaching at all levels, but particularly students who are not science majors, because I think it's important to reach them as well. Some of those students may not be as mathematically sophisticated as a typical physics major, but they have other talents. I try to respect that and to reach them at their level.

What do you hope to achieve with your outreach work, and who do you hope to impact?

If scientists want to reach wider audiences — and we should — we need to engage with the public using formats beyond what an academic might prefer. You can reach people through TV or social media who may not otherwise be motivated to attend a public lecture or read a book. In my efforts, I hope I'm helping people develop an appreciation of science and to learn more about the scientific process.

Plus, because our scientific knowledge and understanding is growing every day, there's a widening gulf between what scientists know and the knowledge base of the general public. It's a very unsustainable situation — and potentially even a dangerous one, thinking of climate change or vaccines — to have a scientifically illiterate population. It's incumbent on all scientists to engage with members of the public, to help continue to fight scientific illiteracy.

Liz Boatman is a science writer based in Minnesota.

The Extraordinary Life and Science of Hilde Levi

Levi, a Jewish German-Danish physicist, escaped the Nazis in the 1930s. In the decades after, she built a diverse career that spanned from biophysics to radiation safety.

REBECKA MÄHRING

Hilde Levi (center) and Lise Meitner at the University of Copenhagen Institute for Theoretical Physics in 1963. *Credit: Hilde Levi Collection, Niels Bohr Archive*

The physicist Hilde Levi doubted that her life story would "ever be used for any purpose except to supplement," modestly, the stories of other famous physicists.

She was wrong: Her story is remarkable. During her 50-year career, Levi — who was born in 1909 and died in 2003 — conducted research on the frontiers of biophysics, taught scientists and doctors in training, introduced radiocarbon dating to Denmark, drafted legislation on radioactive safety, and, after her "retirement," became a science historian.

Levi's story contributes to growing scholarship on how World War II impacted the careers of female Jewish physicists, and how women in science continuously renegotiate their identities in a predominantly male profession. And Levi's career, which spanned diverse fields, challenges the idealized notion that all good scientists are intensely specialized.

Hilde Levi's life and work

On Jan. 30, 1933, Levi, then a 23-year-old doctoral student in physics in Berlin, heard an announcement on the radio: Adolf Hitler had been named the Chancellor of Germany.

Levi wept at the news. "I realized that this was the end of my possibilities for a future in Germany," she later recalled.

Despite her fear, Levi stayed in Berlin until she had finished her thesis and passed her final examinations in 1934. She then reached out to the Danish branch of the International Federation of University Women, which arranged with Niels Bohr for her to come to the Niels Bohr Institute. At the age of 25, Levi left her home and family and moved alone to Copenhagen.

Levi worked there as a research assistant for six years. In 1934, she and James Franck studied the physics of photosynthesis, co-authoring two papers on the fluorescence of chlorophyll. The next year, Levi began working and co-authoring papers with George de Hevesy, studying induced radioactivity in rare-earth elements and radioactive isotopes as tracers in biological processes, like animal metabolism. Because Hevesy traveled widely, Levi often experimented alone. She also assisted Otto Frisch extensively in 1935 and Lise Meitner briefly in 1939.

As Levi's background was not in biophysics, she had to learn new concepts and techniques — and since radioisotopes were quite new, scientists at the Institute built much of the equipment themselves. With Franck, Levi assembled the optical bench and spectrographs; with Frisch, she built Geiger counters, amplifiers, and even advanced resistors that were not commercially available.

Levi was also adept at fostering connections, befriending both male scientific staff and female secretaries and physicists' wives. She went on evening bike rides and visited Copenhagen's amusement park with colleagues, and even spent Christmas with the Bohr family.

Roles in science then were sharply divided by gender, and Levi also carried out menial tasks for her male colleagues. She acted as a "secretary and helper" for Franck, who asked her to "type letters for him or to make telephone calls for him and things of that kind," she recalled, noting that she "didn't mind at all." In her later oral history, she mentions George Placzek, for whom she "had the great privilege, almost every day at lunchtime, to make scrambled eggs." She regularly served coffee with the secretaries at conferences.

By April 1940, the German occupation of Copenhagen had largely forced Levi into hiding. She transitioned her work to the Carlsberg Laboratory, which was closer to her apartment. When the war stymied their supply of radioisotopes, Hevesy and Levi worked instead on using heavy water in biological research.

In September 1943, as the Nazis' persecution of Jews intensified, Levi and other colleagues of Jewish descent, including Hevesy, fled to Stockholm. There, she resumed research on radioisotopes at the Wennergren Institute for Experimental Biology, until her return to Denmark in 1945.

After the war, Hevesy stayed in Stockholm, and Bohr discontinued biological research at the Institute, so Levi was recruited in 1946 to the Zoophysiological Laboratory in Copenhagen. There, she worked as a research assistant to biologist Hans Henrik Ussing — a major adjustment. "The way of thinking, the way of doing experiments, the way of organizing a laboratory" was "entirely different again" from her experiences in physics, she later said.

In the late 1940s, "the thought occurred to me and also to the others that maybe it was time for me to get out and look at the world outside Copenhagen," she recalled. So during the 1947-48 academic year, Levi went to the U.S. for the first, but not the last, time. Although Levi initially planned to study tracer techniques with Franck, who was then at the University of Chicago, she was snagged by Willard Libby, also at UChicago.

That visit, and later ones, proved to be a turning point. Levi learned methods of experimental biophysics that were not well-known in Europe at the time, like how to handle radiocarbon, perform autoradiography, and date biological samples using the carbon-14 isotope. She also gained valuable contacts and secured independent funding sources.

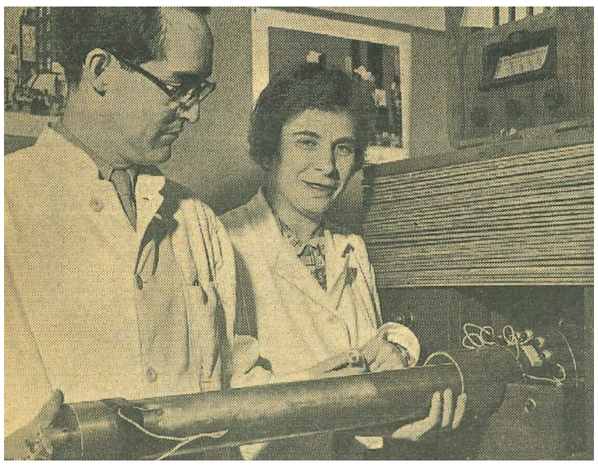
In the three decades that followed, Levi's work blossomed. In 1949, Levi began teaching a course at the Zoophysiological Laboratory on uses of radioisotopes in medicine (e.g., for imaging, and radiation therapy) and how to handle radioactive materials and operate relevant machinery. Since most of the students were medical professionals and scientists, lectures took place during evenings and at night. The courses were "so much in demand," she recalled, that she taught several parallel courses each year until 1970.

Levi's work also attracted the attention of archaeologists. In 1950, soon after her return to Copenhagen, Levi was contacted by archaeologists at the National Museum, who consulted her on the feasibility of dating samples using carbon-14. Levi's expertise and American contacts enabled Denmark to build Europe's first functioning dating machine by 1951. For the next 20 years, she was one of three scientists on a committee that decided which samples to date. Levi said later that the experience was "exceedingly interesting."

Also starting in the 1950s, Levi began working on the regulation of radioactive materials. From 1952 to 1970, she consulted for the Danish National Board of Health and helped draft Denmark's first laws around radiation protection, which regulated the purchase and storage of radioisotopes. This legislation was new in Europe in the 1950s — only the U.S. had expertise at the time — so Levi leveraged her American contacts to learn about U.S. regulations and adapt them to Denmark. In 1954, Levi also started assisting Danish health authorities in investigating radioactive fallout from bomb testing. She became "exceedingly busy" with preparing and analyzing groundwater and soil samples and answering questions from the press.

Meanwhile, the financial support Levi secured in the U.S. allowed her to pursue independent research in autoradiography. She hired a lab assistant, Elise Fredriksen, who for 30 years aided her in the lab and carried out experiments while Levi was away, and Arne Nielsen, who helped with advanced statistical analyses. In the 1970s, Levi — then working to develop a method of quantitative autoradiography — discovered a mechanism for a molting process in frogs that contradicted the prevailing consensus among biologists. The published results were received positively by the community.

After her "retirement" in 1979, Levi became a science historian, helping to assemble materials at the Niels Bohr Archive and publishing a biography of Hevesy. When she died in Copenhagen in 2003, she was 94 years old.



A newspaper clipping shows Levi in the radiocarbon dating lab, originally housed in the cellar of the Zoophysiological Laboratory, in 1952. *Credit: Hilde Levi Collection, Niels Bohr Archive*

Levi's identity and her work in science

Clearly, Levi's story isn't merely a supplement to the stories of others. Her life was rich and productive, despite the real challenges she faced — challenges intertwined with her identity as a woman, and as a Jewish refugee.

Consider two aspects of her life: the non-scientific, menial tasks she performed for male colleagues at the Niels Bohr Institute, like serving coffee and cooking, and her focus on interdisciplinary work over specialized science.

At the Institute, it's unlikely that a male research assistant with a PhD would have performed secretarial duties, since these were only considered "appropriate" for women. In taking up this role, Levi ostensibly lost productive time as a scientist and perhaps reinforced, in the minds of male colleagues, the notion that she was a low-status worker. But Levi performed these tasks with enthusiasm, recalling that she felt like "one of their comrades or colleagues" and that "the Institute never presented any problem for me as a woman."

Through 21st-century eyes, these comments can seem puzzling. But science in the 1930s was dominated by men and often hostile to women; for Levi, secretarial work likely had concrete, strategic value for her career. By doing gender-conforming tasks alongside her scientific work, she may have garnered goodwill among her male colleagues, helping her gain access to spaces where she might otherwise have been unwelcome — like conversations over coffee at conferences — and cement relationships that would later help her win positions and grants.

Levi's identities as a woman and Jewish refugee are also woven into her interdisciplinary work. In the 1930s and 1940s, Nazi persecution upended her life and career, forcing her to flee and start work anew multiple times. Even well-established Jewish female physicists, like Lise Meitner and Marietta Blau, struggled to continue their research after they fled the Nazis; as a newly minted PhD, Levi would have faced even more difficulty. Research assistantships may have been the only available option. As a result, Levi worked primarily as a research assistant until the 1950s, which left her mostly unable to pursue her own interests and hone her expertise in one discipline. She often changed scientific fields and had to learn new concepts and techniques.

Levi seems to have eventually embraced an interdisciplinary approach to physics. Even when she secured funding for her own research in the 1950s, she continued to engage in "excursions or side trips to various fields rather than sticking to my own research [...] as many scientists do." She spoke enthusiastically about learning new concepts and skills, arguing that her willingness to jump into new fields was not "a weakness," but instead made her "life rich and eventful."

Levi's life was indeed rich and eventful, but so far, science historians and the public have paid her too little attention. To pass over her is a mistake: Her career highlights the vital importance of teaching, cross-pollination between research disciplines, and using science for the good of society. These successes don't necessarily align with the ideal of the specialized scientist, as enshrined in the Nobel Prize, which was difficult for women in the 20th century to attain. But in this way, Levi's life challenges this narrow ideal, expanding our view of what a successful scientist looks like.

Rebecka Mähring graduated in 2023 with a bachelor's degree in physics from Princeton University, where she also developed an interest in the history of science. Mähring won the APS Forum of the History and Philosophy of Physics' 2023 essay contest; this article is adapted from her winning essay.

To learn more about Mähring or read her original essay and sources, visit the FHPP site at go.aps.org/3QWFIZt.