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ILLINOIS PHYSICS

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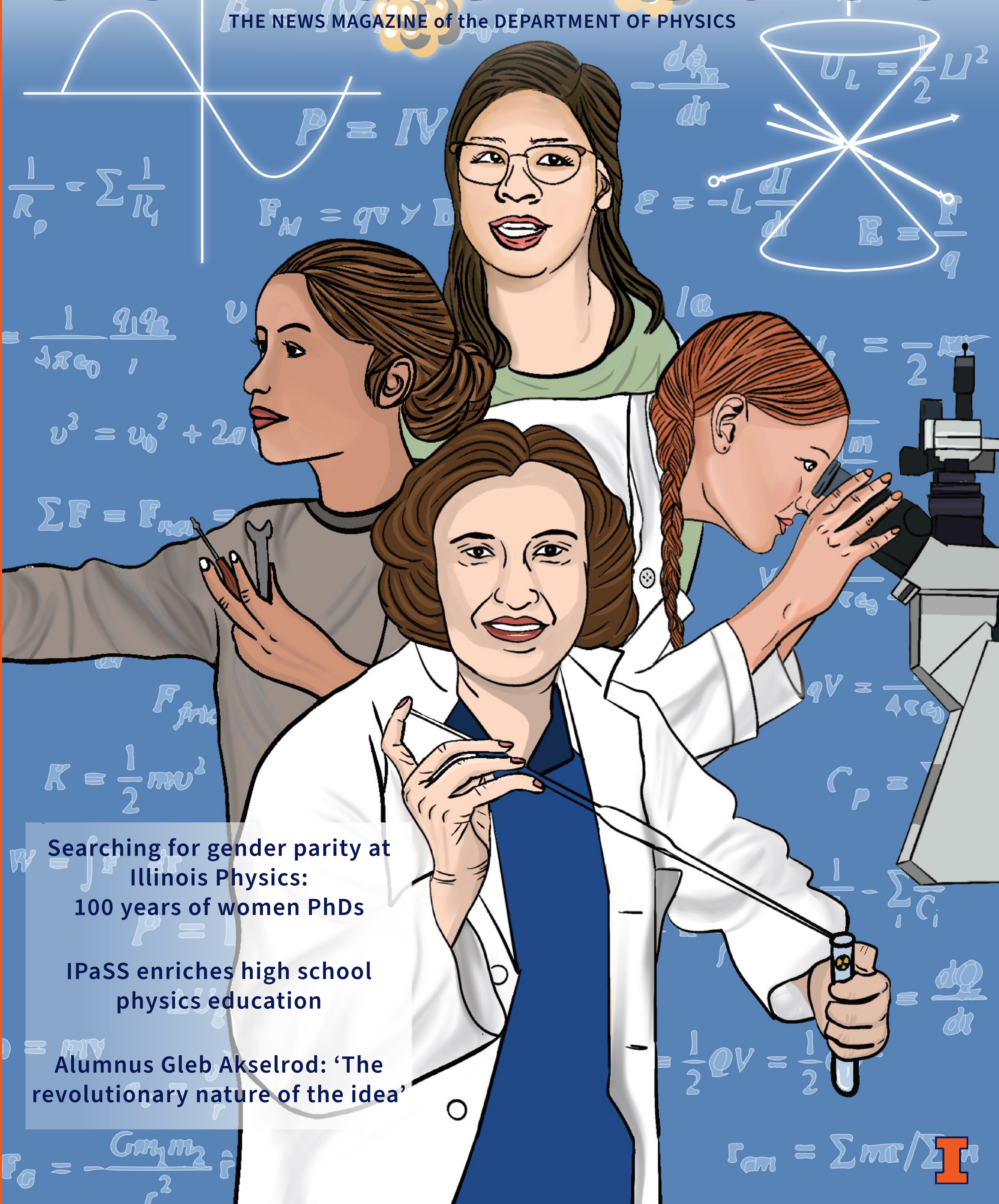
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN



Searching for gender parity at Illinois Physics: 100 years of women PhDs

IPaSS enriches high school physics education

Alumnus Gleb Akselrod: ‘The revolutionary nature of the idea’

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is a semiannual publication of the Department of Physics at the University of Illinois Urbana-Champaign. The final editing and printing of this issue, Fall 2022, was delayed by staffing issues. We didn't want to deprive our readers of the great content developed last Fall—hope you'll enjoy!

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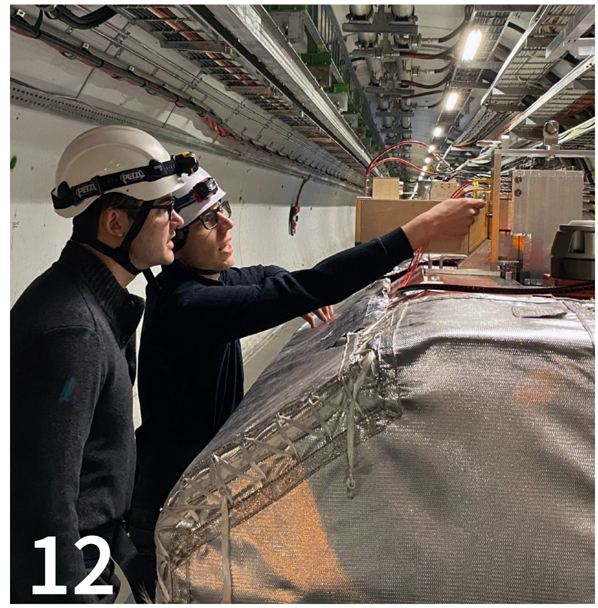

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ILLINOIS

Physics

GRAINGER COLLEGE OF ENGINEERING

The success of our department is measured by the accomplishments of our alumni.

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Please send us your comments or ideas for future stories:

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Cover image: 'Luminous: Women PhDs of Illinois Physics'
Original artwork by Yasmine Steele for Illinois Physics

Printed on recycled paper with soybean ink.

WELCOME

FROM OUR *Department Head*

MATTHIAS GROSSE PERDEKAMP

Dear Physics Family,

We are fully back to in-person teaching and have enrolled a record number of students. The 141 first-year students who joined us this year are the inaugural class in our new unified bachelor's degree program in The Grainger College of Engineering. This degree program—titled simply Physics—consolidates multiple similar degree programs we had offered across Liberal Arts & Sciences and Engineering. Many thanks to Yann Chemla and Jonathan Makela for managing this transition successfully and to Brian DeMarco for his earlier work to establish a cohesive program that better serves all our students.

100 years of women PhDs at Illinois

This year we celebrate the centennial of our first woman PhD, Eleonore Frances Seiler. For her 1922 thesis, "The Color-Sensitivity of Photo-Electric Cells," she measured the wavelength-dependent photoelectric sensitivities for alkali elements. Twenty-three years later, in 1945, Rosalyn Yalow became the second woman to earn a PhD in our department. She would later become the first American-born woman to win a Nobel Prize in Physiology or Medicine.

Today, 100 years later, our graduate program has 91 women physicists—29 percent of our total doctoral students, well above the U.S. average of 21 percent recorded by the American Institute of Physics (AIP). When Lance Cooper took over as associate head for graduate studies in 2011, the representation of women graduate students was at 13 percent. I am grateful to Lance for his leadership in diversity, equity, and inclusion.

Our department is enriched by the brilliant women who do leading-edge research, initiate and organize social and outreach opportunities, and exemplify the high-level training we offer tomorrow's scientific leaders. To celebrate our women PhDs, we are kicking off a special series in this issue, giving voice to their experiences.


Faculty success in research

Our faculty, students, and postdocs demonstrated tremendous resiliency and determination throughout the global challenges of the past few years, and this is reflected in the continued successes of our research programs. For example, Fahad Mahmood won a $1.6 million Emergent Phenomena in Quantum Systems (EPiQS) investigator award from the Gordon and Betty Moore Foundation. And as I write this letter, Jeff Filippini's balloon-borne cosmic microwave background experiment SPIDER has launched from McMurdo Station, Antarctica; Anne Sickles' $3.5 million UIUC-built electromagnetic calorimeter has been installed in the sPHENIX collider experiment at Brookhaven National Laboratory; and Nadya Mason has been appointed to President Biden's National Quantum Initiative Advisory Committee.

Several of our faculty have been recognized this term for outstanding achievements. Among them, Nancy Makri received the 2023 Award for Theoretical Chemistry of the American Chemical Society (ACS); Jen-Chieh Peng, the 2023 Bonner Prize for Nuclear Physics of the American Physical Society (APS); and Nico Yunes, Emily Edwards, and Prashant Jain were elected APS Fellows. Additionally, two faculty members were appointed to leadership roles: Nadya Mason is director of the Beckman Institute for Advanced Science and Technology, and Brian DeMarco, director of IQUIST (Illinois Quantum Information Science and Technology Center).

Rethinking laboratory instruction

The use of the highly innovative iOLab in our introductory laboratory courses has advanced our ability to teach students creative and independent problem-solving in experimental physics. Now we are also modernizing our upper-division instructional laboratories. In Spring 2022 we completed the renovation of two new advanced laboratory classrooms on the fourth floor of the Engineering Sciences Building. This instructional space supports three additional quantum optics experiments in *PHYS 403* and enables a new biological physics laboratory course, *PHYS 498 EBP* (the latter has already been taught twice). Next, we'll be implementing an $800 thousand plan to enhance instruction across the upper-division laboratory courses. This plan was developed by the upper-division laboratory instructors under the leadership of Eugene Colla. While training our students in the use of state-of-the-art instrumentation, we aim to emulate real-world research conditions, fostering independence, scientific rigor, and creative problem-solving in our students.

New degree programs

We continue to develop several new degree programs. Future undergraduate degrees in *Computer Science + Physics* and *Physics + Data Science* are aimed at students seeking careers as industrial physicists. A future program offering a master's in physics education will provide high-school science teachers a valuable continuing-education opportunity. And two separate concentrations in Grainger Engineering's Professional Master's in Engineering (M.Eng.) program will train industrial physicists in *Instrumentation and Applied Physics* and in *Quantum Information Science*.

I am very thankful to the faculty colleagues who are developing these programs. Among the many strong contributors, I would especially like to thank George Gollin, who is directing the first of these programs to launch: The *M.Eng. in Instrumentation and Applied Physics* program is accepting students for Fall 2023. Special thanks also to Tim Stelzer for leading the overall development of our new degree programs. We are hoping for input and support from our numerous alumni working as industrial physicists. Please contact George, Tim, or me with your suggestions.

Please let us know if your travels bring you to Central Illinois. You will always be welcomed home at the Department of Physics at the University of Illinois!

Warmly,

ILLINOIS PHYSICS Spectrum

The Department of Physics at the University of Illinois Urbana-Champaign is known for its long history of collaborative research—the "Urbana style of physics"—that frequently reaches across research areas and involves close coordination between theoretical and experimental physicists. Here is an inside glimpse of what some of our physicists are working on.

ANTONIOS TSOKAROS

ASTROPHYSICS, RELATIVITY, AND COSMOLOGY

When two neutron stars orbit each other, they gradually spiral inward because of gravitational radiation and finally merge in a spectacular collision. For the first time in history, on August 17, 2017, such a binary neutron star merger was observed at both gravitational and electromagnetic observatories, marking the advent of so-called "multi-messenger" astronomy.

My research focuses on understanding such cosmic phenomena and more generally on the physics and mathematics of strongly gravitating systems. This area of research involves general relativity, relativistic hydrodynamics, and magnetohydrodynamics, as well as nonlinear partial differential equations. Some of the topics my group is working on include the inspiral and coalescence of compact binaries (binary black holes, binary neutron stars, or black hole-neutron stars); the generation of gravitational waves from merging binaries and other promising astrophysical sources and their counterpart electromagnetic and neutrino signals; the effect of the neutron star equation of state on the merger remnant; and the stability of rotating, magnetized neutron stars. Einstein's theory of gravity underlies all these problems—it's the stage where the various actors play and the drama unfolds.

Research Professor Antonios Tsokaros (left) meets with an undergraduate student at Loomis Laboratory of Physics. Photo by Siv Schwink for Illinois Physics

In my research, numerical modeling is key to making quantitative predictions. From the calculation of a binary neutron star in a circular orbit to its merger and the subsequent launching of a relativistic jet, large-scale computer simulations are required. My group has developed state-of-the art codes for modeling compact objects—some for the first time. These models have been used by many groups around the world to make concrete predictions on a large number of scenarios, including the neutron star maximum mass, the premerger neutron star's spin, and the fate of the merger remnant for the event observed in 2017.

Antonios Tsokaros is an NCSA Faculty Fellow and a member of the Relativity Group at Illinois Physics.

KATIE ANSELL

PHYSICS EDUCATION RESEARCH

We often talk about classrooms as places where classes are held, but the concept of classroom is incomplete without the participation of teachers and students. My work in physics education and physics education research focuses on bringing students in as central contributors to the learning space of the classroom. The field and subtopics of physics education research are broad, and the work I do is best classified as "action research"—which means, I draw on a rich body of cognitive science and education literature to inform changes in the courses I teach and then I assess student outcomes.

Illinois Physics Teaching Professor Katie Ansell works with a student in an introductory physics laboratory course. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

In 2016 my mentor and I began changing the introductory physics laboratories at Illinois to a new curriculum that invites creativity and that trusts students to learn from their experiences to develop a rich, adaptive form of expertise. Individual and group tasks in this format not only develop students' technical skills, they also require innovation and decision-making. Our students begin the semester with simple tasks and within several weeks have the skills and confidence to design and do high-quality experiments completely on their own. As of Spring 2022, all students in our four largest introductory courses—the algebra- and calculus-based mechanics courses and the electricity & magnetism courses—now get to experience these student-supportive labs.

My research seeks to understand what happens in these classrooms where students hold expertise and agency over their own experiments. How well are students mastering technical skills? How do individual students or their groups respond to experimental and/or social difficulties? How do instructor styles support or inhibit student independence? To answer these questions, I collect and analyze quantitative and qualitative data that includes written work from class, survey responses, and video recordings of student groups working on lab activities. So far, I have learned that the curriculum is effective at developing laboratory skills while increasing students' resilience in response to challenges. My work both examines and impacts student-student and student-instructor interactions in a reiterative process designed to engage students and instructors in building a better, more supportive learning environment.

Katie Ansell's research has been funded by the National Science Foundation under Grant No. DUE 17-12467, by a Strategic Instructional Innovations Program (SIIP) Grant of The Grainger College of Engineering's Academy for Excellence in Engineering Education (AE3) at UIUC, and by a Faculty Retreat Grant of the Center for Innovation in Teaching & Learning at UIUC. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

DEKRA ALMAALOL

THEORETICAL NUCLEAR PHYSICS

My research in the Noronha-Hostler group aims to build theoretical simulations of ultra-relativistic heavy-ion collision (URHIC) experiments. My focus is on developing the theory of dissipative hydrodynamics and incorporating all the physical aspects of the collision system in a fully integrated theoretical framework. The goal of my work is understanding the nature of strongly interacting matter, and in particular the formation and properties of the quark gluon plasma (QGP).

In quantum chromodynamics (QCD), the fundamental particles are the quarks and gluons which are confined in bound states forming the strongly interacting hadrons. At high energies, the quarks and gluons become deconfined, and at extremely high energies and/or densities, they even become weakly coupled. The QGP is the deconfined phase of QCD and is transiently formed in URHIC experiments. In the regions where the deconfinement phase transition occurs, the physics of the QCD matter is highly nonlinear and not well understood.

Illinois Physics Postoctoral Research Associate Dekra Almaalol (left) collaborates with colleagues at Loomis Laboratory of Physics. To Almaalol's right are Illinois Physics Postdoctoral Researchers Enrico Speranza,and Willian Serenone and Illinois Physics Professor Jorge Noronha. Photo by Joaquin Vieira for Illinois Physics

Observations of the momentum distributions of the final-state hadrons (protons, neutrons, and heavier, more exotic, and short-lived assemblages of quarks) produced in URHIC experiments suggest a strong signal of collectivity, and fluid dynamics has been widely and successfully used to describe the dynamics. A challenge that we face in theoretical modeling the experiments is that the QCD matter is produced with large out-of-equilibrium corrections. For this reason, addressing out-of-equilibrium phenomena in hydrodynamics models is essential to building theoretical simulations for these experiments. Part of my research focuses on quantifying the applicability of fluid dynamics in the presence of these out-of-equilibrium corrections, in addition to building in the correct physics describing the QGP dynamics.

An important aspect we focus on in the Noronha-Hostler group is the incorporation of local baryon, strange, and electric charge fluctuations in fluid dynamics. While previously the community was interested in the high temperature and zero chemical potential limit of the QCD phase diagram, understanding charge dynamics is directly relevant to the search for the QCD critical point and the beam energy scan program. Incorporating charge dynamics in the collision system could also introduce qualitative and quantitative impacts on the QGP properties extracted previously, which is something we aim to scrutinize.

Research in the Noronha-Hostler lab is supported by the U.S. Department of Energy under Grant No. DESC002063, by the National Science Foundation's support of the MUSES collaboration under Grant No. OAC-2103680, and by an Alfred P. Sloan Foundation Research Fellowship. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the funding agencies.

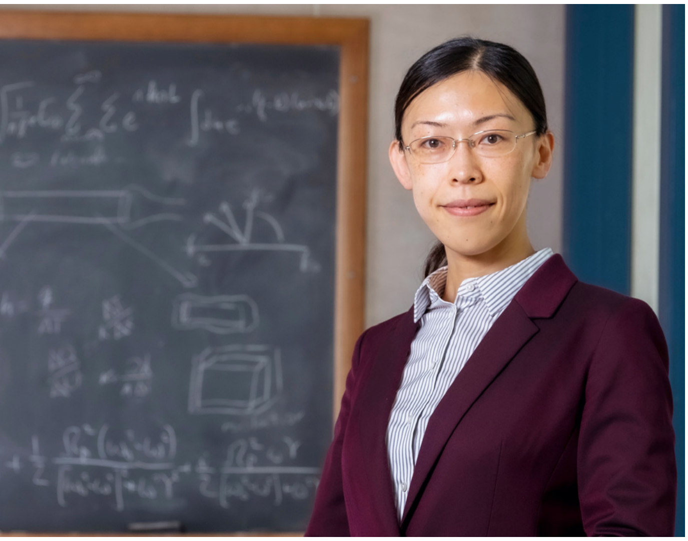
LAIMEI NIE

THEORETICAL CONDENSED MATTER PHYSICS

Condensed matter theory has long been at the center of interdisciplinary endeavors, with its thriving interactions with quantum information and high energy physics, as well as inseparable connection to experiments. During the past few years my work has focused on the characterization of quantum dynamics in many-body systems. In particular, I'm interested in deterministic quantum evolutions that exhibit chaotic behaviors.

Chaos in the classical world is more or less well understood, but its quantum counterpart remains elusive—even its definition is not completely clear, despite decades of efforts. The glory and mystery of many-body quantum chaos is tightly connected with quantum thermalization, a puzzling phenomenon where certain isolated quantum systems (such as ultracold atomic gases) behave "thermal" under unitary time evolution, without being in contact with a thermal bath.

Furthermore, the footprints of quantum chaos have recently been witnessed in two seemingly disparate research thrusts—resolving the black-hole information paradox and building quantum computers. My research aims to address fundamental questions regarding the precise definition of many-body quantum chaos and its relation to key concepts in condensed matter physics, AMO physics, quantum information, and high-energy physics. By applying insights from quantum entanglement and the anti-de Sitter/conformal field theory correspondence (AdS/CFT), which is sometimes called gauge/gravity duality, my collaborators and I revealed an important, universal aspect of quantum chaotic dynamics: the ability to efficiently and thoroughly delocalize quantum information. We further showed that certain condensed matter toy models and artificial black holes both possess this ability to its maximum extent, making them the perfect candidates for quantum chaotic dynamics.



Illinois Physics Postoctoral Research Associate Laimei Nie. Photo by Bill Wiegand for Illinois Physics

The other thrust of my research is to understand exotic properties of real-world materials through collaborations with experimental colleagues. For example, in the past I have worked on how disorder affects various charge orders seen in X-ray measurements in high-temperature superconductors. My newly found interest is the search for and characterization of Majorana zero modes in the planar topological Josephson junction, a promising experimental platform for the formulation of topological qubits. With a combination of analytical and numerical treatments of the junction models, we aim to predict the locations of the Majorana modes and perform braiding operations by tuning parameters such as the external magnetic field. Our next step in this work will be to transfer our knowledge of the theoretical models to more realistic setups, to provide guidance and feedback to experimentalists working on these problems.

Laimei Nie's research has been funded by the National Science Foundation under Grant Nos. DMR-2004825, OMA-2016136, and DMR-1725401. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

Alumnus Gleb Akselrod:

‘The revolutionary nature of the idea’

Gleb Akselrod has always been interested in optics—from his dad’s lab to his startup Lumotive’s flagship product, solid-state optical semiconductors for next-generation LIDAR.

BILL BELL
for Illinois Physics Condensate

You have 20 minutes to pitch your startup idea to Bill Gates—yes, that Bill Gates. You want a prototype, right? A proof of concept? Customers lined up? Other backers who already came in during a seed round?

Gleb Akselrod didn’t have any of those things when he joined Intellectual Ventures (IV) in 2016 as part of an incubator cohort. Run by former Microsoft CTO Nathan Myhrvold, IV is a private equity company that creates high-impact inventions and spins them out into companies.

“Every person in a startup has a direct impact, and you can see that impact immediately. It’s not for everybody. There’s no place to hide when you can have that kind of influence.”

“It was just me in an office with a pad of paper,” Akselrod recalls.

From that office, he developed a small team and a very sharp idea.

The team wanted to engineer changes in existing materials to create optical semiconductors that can steer light. They would then use those “metamaterials” to build LIDAR, the laser range-finding equipment that is used in everything from satellites, to precision agricultural mapping technologies, to robots that can “see.” By the time he pitched to Gates in 2017, there was “still very little to show. A PowerPoint and nothing working,” according to Akselrod. “But that’s what venture capital is.”

“[Gates] saw the revolutionary nature of the idea. We have a shared vision for what it can do and a shared passion to change the world and make some money doing it,” Akselrod says.

That idea is now Lumotive, where Akselrod is CTO. The Seattle-based company is doing just what it set out to do, building light-control metasurface beam-steering chips for what they call "LIDAR 2.0"—smaller, cheaper, and more reliable than traditional LIDAR. In 2022, EE Times named Lumotive one of its "Emerging Startups to Watch." Its technology won a pair of Innovation Awards at CES, the annual consumer electronics show, where the team demonstrated a car headlight having integrated LIDAR.

Samsung's venture capital arm provided an additional funding round to the company in July 2022.

LIDAR is particularly important in our current technological moment—on the cusp of autonomous technologies like self-driving cars or delivery drones.

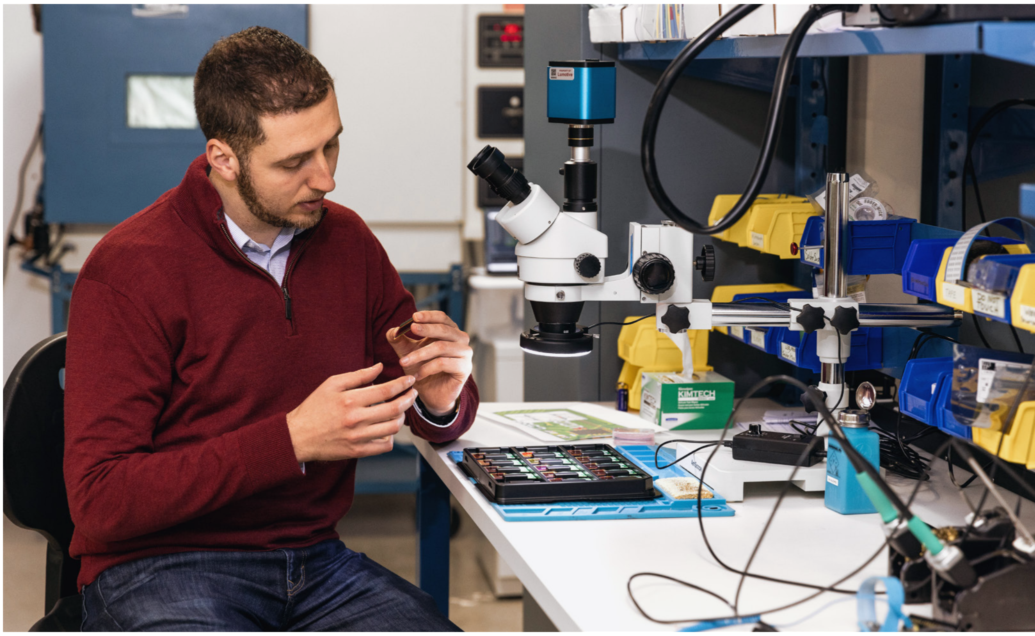
"The world is going to be full of autonomous things very soon," Akselrod affirms. "These all need a way to interact with the world. That means sensors, and that means LIDAR. But LIDAR is heavy, expensive, and handmade right now," Akselrod notes.

research, more than the classes. I was always self-directed, trying to create something new," says Akselrod, who went on to earn a PhD at the Massachusetts Institute of Technology, then did postdoctoral work at Duke University, before making the choice to pursue innovative research in industry.

Akselrod's experience in the field goes back even further than his undergrad years. At 15, Akselrod took a summer job with his father. The family business? The design and manufacture of radiation sensors that are used by X-ray technicians or people who work in nuclear power plants, to ensure that they are not being unduly exposed. A visiting professor at Oklahoma State University, Akselrod's dad developed a new technology in which crystals absorb radiation and a laser is shined on them to detect whether the crystals have changed in response to that radiation. The company was purchased about 20 years ago by Landauer, a leader in radiation safety and nuclear medicine.

Akselrod compares Lumotive's new LIDAR technology to the development of the camera. Thirty years ago, a camera was full of mechanical gears, lenses, mirrors. It was so big you had to carry it on a strap around your neck, and a good one cost hundreds of dollars. Today, your cellphone might have four cameras, they all fit in a tiny bit of real estate, and they're only one part of a device that costs hundreds of dollars. And your phone takes much better pictures.

The same goes for LIDAR. What used to be bulky, expensive, and mechanical has shrunk and can be produced fast and cheap—steering light using Lumotive's metamaterials. The same technology may someday be used in optical computing and 6G communications.



Lumotive CTO and founder Gleb Akselrod at work in his Seattle office. Photo by Rafael Soldi

Akselrod worked in optics even while an undergrad at UIUC, with Illinois Physics Professor Paul Kwiat and with Illinois Electrical & Computer Engineering Professor Greg Timp, who is now at Notre Dame University. With Timp, he explored using lasers to manipulate cells and developed new laser techniques to study how cells work. Before graduation, his work on the laser-guided assembly of living bacterial arrays made the cover of *Biophysical Journal*.

"I was always interested in fundamentals, but not in fundamentals for fundamentals' sake. Fundamentals for the sake of applying them to something. So the most impactful thing was all that

Akselrod says he has been focused on optics and the thrill of generating ideas ever since.

"I had no idea what research meant at the time, but I fell in love with it—this unstructured space where I get to go and do my own thing and run with it."

That perspective has served him well in the startup world.

"It makes you comfortable with making sense of chaos," he notes. "Every person in a startup has a direct impact, and you can see that impact immediately. It's not for everybody. There's no place to hide when you can have that kind of influence." ■

ATLAS Experiment heavy-ion reaction plane detectors, built at Loomis Lab

UIUC Nuclear Physics Laboratory researchers and students develop novel reaction plane detectors and new machine learning algorithms for the Large Hadron Collider

JAMIE HENDRICKSON AND SIV SCHWINK
for Illinois Physics Condensate

The world's largest particle accelerator, the Large Hadron Collider (LHC) at CERN in Switzerland, smashes tiny particles together at high energy to study the fundamental constituents of matter and the forces that bind them together. Most of the time, the particles that the LHC collides are protons, but each winter for about a month, the beams are switched to heavy-ion particles—usually the nuclei of lead atoms—to enable the heavy-ion experiments that since 2010 have been garnering increased interest from theorists and experimentalists looking for new physics.

Since 2010, CERN scientists have been planning for the next-generation High-Luminosity Large Hadron Collider (HL-LHC), now slated to come online in 2029. The HL-LHC will usher in a new era in particle physics, enabling precision studies of the LHC's findings to date, yielding potential new discoveries, and expanding our understanding of the fundamental interactions of matter. But first, major technological upgrades to multiple systems must be designed, built, tested, and installed in one of the most extreme laboratory environments on Earth.

Work on those upgrades is well underway. As part of this international effort, the UIUC ZDC-RPD Group in Urbana has designed and constructed novel reaction plane detectors (RPDs)—the first-ever RPDs to be installed in the ATLAS zero-degree calorimeter (ZDC)—for use in heavy-ion collision experiments. The project is led by principal investigator Illinois Physics Professor Matthias Grosse Perdekamp and managed by co-principal investigator, Illinois Physics Research Scientist Riccardo Longo.

Perdekamp explains, "In such experiments, ZDCs and RPDs together let us characterize the geometry of lead-lead collisions. The ZDC measures the degree of overlap between two colliding lead ions. The RPD measures the orientation of the two colliding nuclei in relation to the laboratory reference frame."

Characterizing the collision geometry will enable ATLAS scientists to study the physics of the quark gluon plasma (QGP), the ultra-hot matter present during the first microseconds of the universe following the Big Bang.

Opposite page, Illinois Physics graduate student Matthew Hoppesch (left) and Illinois Physics Postdoctoral Researcher Riccardo Longo install the Urbana-built Reaction Plane Detector system for a test run at CERN. Photo courtesy of Riccardo Longo, Illinois Physics

Enhancing detector capabilities

The ATLAS RPDs employ a novel design and material, developed by the Perdekamp team, to withstand the extreme radiation inside the collider. The new detectors will employ machine-learning algorithms to achieve a two-dimensional mapping of the collisions' neutron showers, in a transverse profile. The algorithms were written by Illinois Nuclear, Plasma & Radiological Engineering alumnus Sheng Yang while he was a student researcher in the UIUC ZDC-RPD Group. If the software meets performance expectations, ATLAS researchers around the world will be able to use nuclear collision geometry information in their studies of the QGP formed in nuclear collisions at the LHC.

Perdekamp comments, "Using machine-learning algorithms to measure the nuclear collision plane has not been done before, and we're looking forward to testing our instrument and new analysis techniques."

The performance of the RPDs and algorithms in Run 3 will serve as a pilot program for what the Perdekamp team plans to build for Run 4 and the high-luminosity era.

High luminosity refers to higher particle collision rates and the associated increase in the volume of experimental data collected. It should be noted that for heavy-ion collision the main increase in luminosity will occur in Run 3, with small additional increases for Run 4.

"Increases to proton beam intensity and to lead-ion beam intensity are separate undertakings," notes Perdekamp. "Comparing LHC's Run 2, completed in 2018, with Run 3, the current experimental campaign, the integrated luminosity is increased by a factor of 2 for proton-proton collisions and by a factor of 5 for heavy ion collisions. In Run 4, starting in 2029, the HL-LHC will again double the proton-proton collision rate, but will increase the heavy-ion collision rate only slightly."

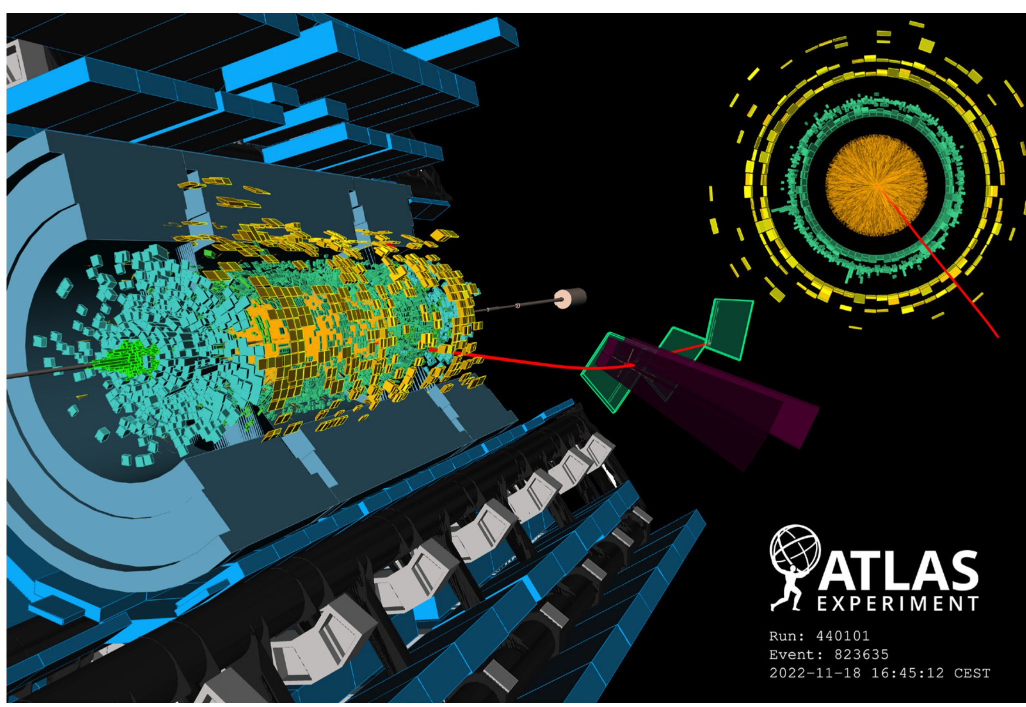
Where particle physics and heavy-ion nuclear physics overlap

Some of the most promising experimental approaches to studying new fundamental phenomena in collider experiments are being proposed at the intersection of particle and nuclear physics. The annual switch over to heavy-ion collisions at CERN is rooted in two closely related lines of scientific inquiry.

First, heavy-ion collisions are the only way to produce the quark-gluon plasma (QGP) in a laboratory setting, recreating the conditions of the early universe. The QGP is theorized to have existed in the first 10–20 microseconds after the Big Bang. As the universe expanded and cooled, quarks and gluons condensed into protons, neutrons, and other hadrons, the building blocks of nuclear matter as we know it.

The QGP cannot be directly observed. Its properties are studied through the experimental signatures it leaves behind in the aftermath of heavy-ion collisions. When heavy nuclei collide, the hundreds of protons and neutrons that make up the nuclei release a large portion of their energy into a tiny volume, momentarily liberating quarks and gluons from their bound states in protons and neutrons to form a hot, dense plasma of free quarks and gluons. Just as quickly as the plasma forms, it expands, cools, and condenses into composite particles and anti-particles, bound quark states including protons, pions and kaons, which zoom out in all directions from the collision point.

Second, heavy-ion runs allow scientists to test at the highest temperatures and densities ever achieved in a laboratory setting the predictions of quantum chromodynamics (QCD)—the theory of



Lead-lead event display in 3D blowout, from the 2022 LHC Heavy Ion pilot run on November 18, 2022. Orange, green, and cyan boxes indicate energy deposits in the calorimeter systems. Orange lines indicate the trajectories of charged particles recorded by the inner detector tracking systems. Image courtesy of CERN/ATLAS the strong force that binds quarks and gluons together into protons and neutrons inside the nuclei of atoms. Outside of the accelerator laboratory environment, quarks and gluons cannot be pried apart—the further apart the particles, the more tightly the strong force binds, like a Chinese finger trap.

Longo notes, “Our group is most interested in the QCD-related questions enabled by data collected within the heavy-ion program. But our new RPDs will enable new measurements of particle flow, providing insights into how the QGP expands after its formation in heavy-ion collisions, and graduate students in our group do plan to carry out QGP analyses as well, once the RPDs are operative.”

Design challenges

The ATLAS RPD has been developed in the context of a cooperative effort between the ATLAS and CMS ZDC groups, in the first-ever joint instrumentation project between the otherwise fiercely competing collaborations. To minimize systematic uncertainties resulting from collision-geometry characterization in lead-lead collisions, the two experiments will use identical ZDCs in Run 4. From the ATLAS side. the institutions involved in the Joint Zero-Degree Calorimeter Project (JZCaP) are UIUC, Ben–Gurion University of the Negev, Columbia University, and Brookhaven National Laboratory. CMS is participating with groups from Kansas University and University of Maryland. JZCaP scientists meet weekly to coordinate instrumentation design, Monte Carlo simulations, test-beam measurements, software development, and detector construction.

It has not yet been determined whether CMS will use the same RPD design or the openly shared machine-learning software developed in Urbana. The decision will likely wait until the new innovations are deployed in Run 3 and proven successful.

According to Longo, the most significant RPD design and construction challenges

Left, a test assembly of the pan-flute-shaped reaction-plane-detector (RPD) active area, carried out by Illinois Physics undergraduate student Farah Mohammed Rafee at Loomis Lab. A total of 256 fibers of four different lengths are arranged in eight distinct layers characterized by a staggered pattern that ensures a homogeneous sampling of the particle showers illuminating the RPD. The fiber pattern is visible in this test: the aluminum front panel was replaced with transparent plexiglass to assess the fit of the fibers within the pan-flute channels, as well as their stability during movement of the detector. Photo courtesy of Daniel MacLean

Opposite page, above, pictured left to right, University of Kansas Physics & Astronomy Professor Michael Murray, Illinois Physics Research Scientist Riccardo Longo, and Illinois Physics Professor Matthias Grosse Perdekamp pose for a photo at the Large Hadron Collider at CERN. Photo courtesy of Matthias Grosse Perdekamp, Illinois Physics.

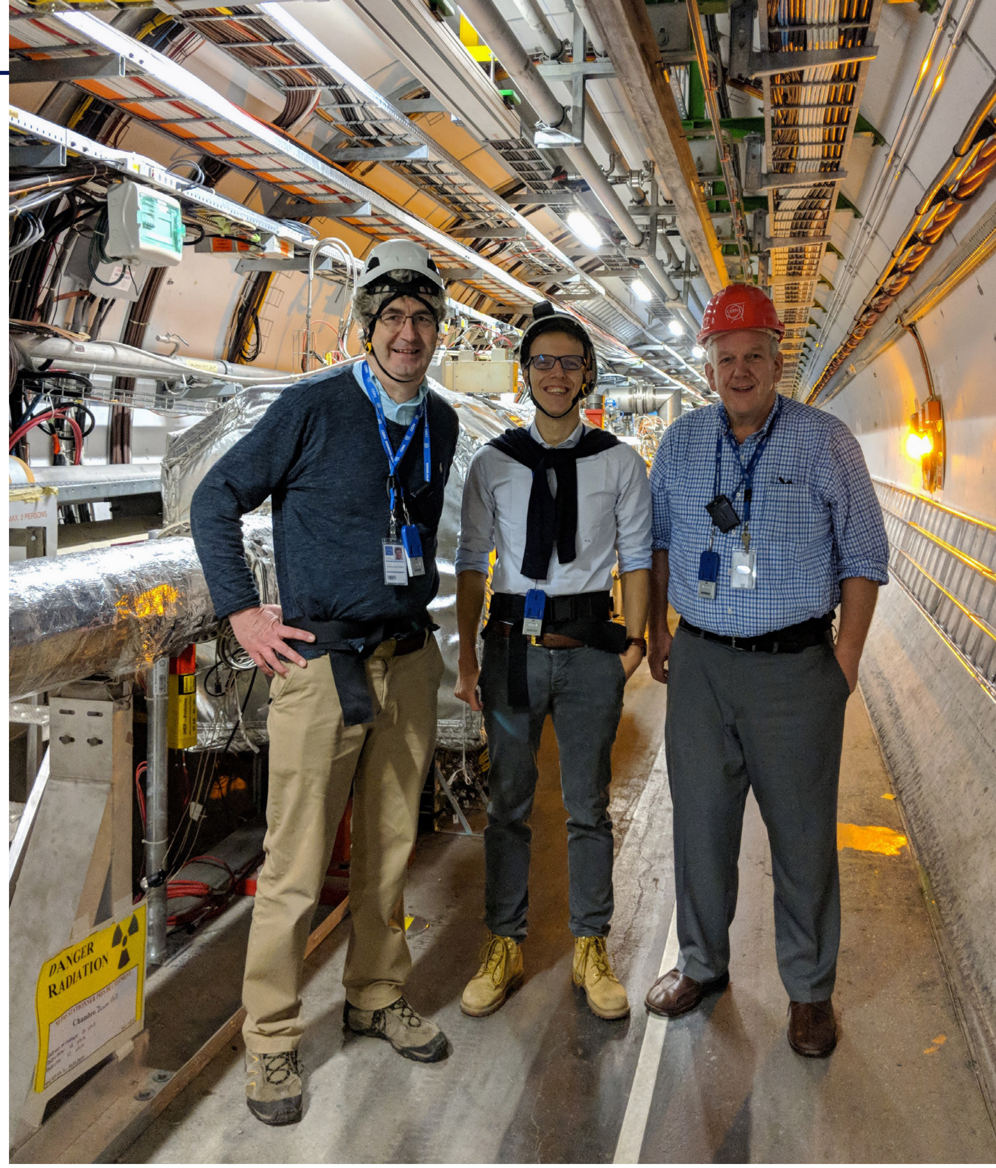
Opposite page, below, the Urbana-built reaction plane detector system is installed for a test run at the Large Hadron Collider (LHC) at CERN in January 2023. Photo courtesy of Riccardo Longo, Illinois Physics

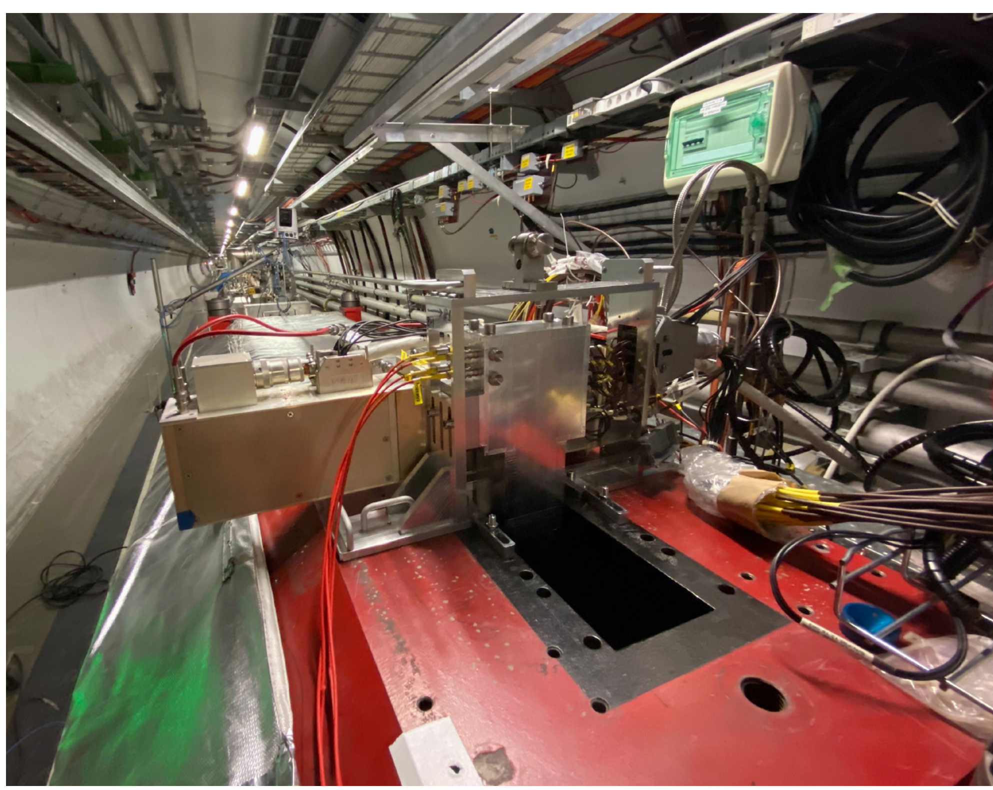
CERN and the European Energy Crisis

Located astride the Franco-Swiss border near Geneva, CERN has actively been making sustainability efforts to decrease its energy consumption over the past decade and has already succeeded in reducing the laboratory's overall energy consumption by 10 percent.

In light of the current global energy supply and cost crisis that has been escalated by Russia's war on Ukraine, CERN announced on September 30, 2022 that it would take steps to significantly reduce its energy consumption into 2023. This included moving the 2022 year-end-technical stop (YETS) up by two weeks to November 28, and reducing the operation of the accelerator complex by 20 percent in 2023. Additional measures are being taken to optimize the buildings' energy usage in accordance with the EU's recent emergency regulation for its member states to reduce electricity usage by 5 percent during the peak hours of the upcoming winter.

"This choice was made by CERN as a part of its social responsibility," Illinois Physics Research Scientist Riccardo Longo explains, "so as not to induce additional energy cost increases for people residing in France. It was agreed that this reduction in beam time should be borne equivalently by proton-proton and heavy-ion programs, so, after several discussions among the CERN experiments, it was decided to cancel the 2022 heavy-ion run and to slightly extend the heavy-ion runs in 2023, 2024, and 2025. On the current schedule, our new detector, built for this fall's heavy-ion run, will first be used in fall 2023."





faced by the Urbana team included finding a radiation-hard material that could withstand the harsh radiation environment, to maintain stable performance over the running period; constructing a detector that could easily be installed and connected using available remote-handling technologies at CERN, to reduce radiation exposure to personnel; designing a detector capable of providing insight on the distribution of non-interacting particles, because the reaction plane of heavy-ion collision is deduced from "spectator" neutrons; and accomplishing all of this within strict size limitations, because two out of three dimensions are on the order of a few centimeters.

The ATLAS Run-3 RPDs each comprise 256 fused silica-core optical fibers of four different lengths, grouped into 16 channels in a novel pan-flute-shaped design.

First deployment of the new ATLAS RPDs, originally slated for November 2022, is now scheduled for the end of 2023. CERN cut short its 2022 season in response to the European energy crisis. The Urbana team took advantage of the early shutdown to ensure a smooth installation in 2023.

Longo notes, "We have studied in great detail the integration of our RPD with the machine and with ATLAS Data Acquisition System. However, when operating a new system for the first time, there are usually unexpected issues that must be quickly resolved during operations. We decided to take advantage of the additional time provided by the first heavy-ion run getting postponed until next year to install the RPDs and fire up the ATLAS trigger and data-aquisition system, in order to check for any integration or commissioning issues. Graduate student Matthew Hoppesch travelled with me to CERN to complete this full system test. Graduate students Mason Housenga and Chad Lantz and undergraduate students Yi Liu and Maya Vira supported the dry-run data-taking remotely, from Urbana."

It will not be possible to overhaul the Run-3 RPDs and ZDC for Run 4, because the beam and magnet configuration in the tunnel will change significantly, reducing the horizontal space available for the detectors by a factor of 2. For this reason, new ZDCs and RPDs will be constructed for both ATLAS and CMS. Illinois Physics is leading this $2.5 million Department of Energy–funded upgrade.

Training next-generation scientists

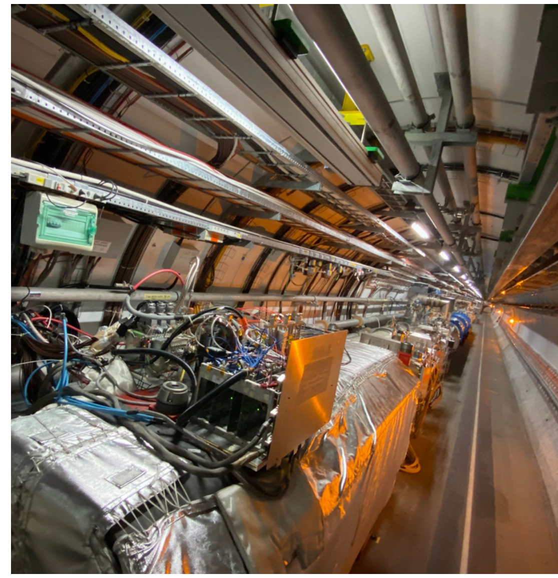
Over the past two years. Longo has overseen and mentored 7 graduate students and 25 undergraduate students in the UIUC ZDC-RPD Group in Urbana, during the R&D, building, and testing of the new RPDs. "I believe that a crucial part of our role as researchers is to help train the next generation of scientists," he shares.

Physics graduate students Matthew Hoppesch, Mason Housenga, Chad Lantz, Aric Tate, and class of 2023 undergraduate Farah Mohammed Rafee all had the chance to visit CERN over the past two summers and to take part in testing the RPD prototypes. Daniel MacLean, an Illinois Physics alumnus, now an engineering physicist in the accelerator division at Fermi National Laboratory, served as an academic hourly in the group for over two years.

Left, the Illinois ZDC-RPD team poses for a photo. Pictured left to right are (front row) graduate student Sheng Yang (now graduated); undergraduate students Samantha Lund, Xuesi Ma, Farah Mohammed Rafee, and Benjamin Liu; (middle row) undergraduate student Paul Malachuk; Illinois Physics graduate student Aric Tate; junior technician Daniel MacLean (now an engineer at FermiLab); undergraduates Kristopher Young (now a junior technician in the group) and Yi Liu; and technician Lucas Reeves; (back row) graduate student Matthew Hoppesch; Research Scientist Riccardo Longo; Professor Matthias Grosse Perdekamp; Senior Research Engineer Eric Thorsland. Illinois Physics team members not pictured include undergraduate students Anna Przybyl, Aryan Vaidya, Chinmay Ambasht, Elise Hutchins, and Maya Vira; graduate students Chad Lantz, Jacob Fritchie, and Mason Housenga; and technicians Adam Wehe and John Blackburn. Photo courtesy of Riccardo Longo, Illinois Physics

“Gradually involving young scientists in a project like this and in operations at CERN is of incredible value,” Longo asserts. “It allows them to get in touch with a vibrant international scientific environment, fueling their interests. And it gives them hands-on experience of the applications of the research that they carried out in our lab at UIUC.”

Perdekamp adds, “I couldn’t be prouder of the hard and ingenious work of our students, technicians, and postdocs who successfully carried out this challenging project during the pandemic and deployed the two detectors successfully at CERN.” ■



Right, view inside the LHC tunnel near the ATLAS Experiment: In the foreground is the target neutral beam absorber (TAXN), where the new ZDC and RPD will be installed for future heavy ion running at CERN. Photo courtesy of Riccardo Longo, Illinois Physics

This research is funded by the National Science Foundation under Grant Nos. NSF PHY 18-12377 and NSF PHY 21-11046. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the scientists and do not necessarily reflect the views of the National Science Foundation.

Illinois Physics alumnus Daniel MacLean (BS, 2019) worked as an hourly technician and research assistant in the ATLAS ZDC-RPD group after graduation, under Longo’s supervision. He is now an engineering physicist at Fermi National Laboratory.

MacLean recalls, “I began working for the ATLAS ZDC group in September 2019. My primary task was the mechanical and electrical design of the ATLAS Reaction Plane Detectors. I also oversaw the manufacturing of the detector components, did most of the detector assembly, and, in parallel, managed our group’s laboratory facility in Loomis.

“The first stage was a single prototype detector as a proof-of-concept, which we completed in 2021 and tested in the Super Proton Synchrotron at CERN that September. Using that experience, we improved many aspects of the detector during my next task, which was to redesign and build the two identical (mirror-image) ATLAS RPDs for Run 3 in the LHC. These were completed and commissioned at CERN by Dr. Longo and I in the Spring of 2022.

“I have since moved on from the group and now work in the Accelerator Division at Fermi National Accelerator Laboratory as an engineering physicist, specifically at the FAST/IOTA Facility. I can say with no doubt that the three years I worked with Dr. Longo in the ATLAS ZDC-RPD Group were the most important of my life in terms of learning and honing the technical skills I now use every day at my new job. It solidified my desire to work in the field of particle accelerators, which I would not have been able to do without the experience I gained as part of the ATLAS ZDC-RPD Group. It is difficult to overstate how lucky I was to have the opportunity to do that job; it has completely altered the trajectory of my life in the most positive way possible.”

THE LOOMIS CONFESSIONS

F. Wheeler Loomis. Image digitized at the Emilio Segrè Visual Archives

These interview questions are inspired by a Victorian parlor game known as the confession album, famously known as the Proust questionnaire after French writer Marcel Proust's thoughtful and witty answers were discovered and published in 1924 in the French literary journal *Les Cahiers du Mois*. We have named our "album" for Wheeler Loomis, Illinois Physics department head from 1929 to 1957. Loomis is revered for having hired the highest caliber early-career scientists and for diligently nurturing them, expanding the department's research program and elevating it to world-class status, while putting special emphasis on good teaching. The collaborative, open-door "Urbana style of physics" emerged under Wheeler's supportive and strategic leadership.

Professor Elizabeth Goldschmidt

If you couldn't be a physicist, what career would you choose?

I would likely work in government or public policy in some form or another. I worked at a think tank before grad school and spent most of my career before coming to Illinois at various government labs. I have seen how important it is to have capable and knowledgeable people in science-policy roles, and also how interesting and complex the issues are that they tackle.

What is your favorite place?

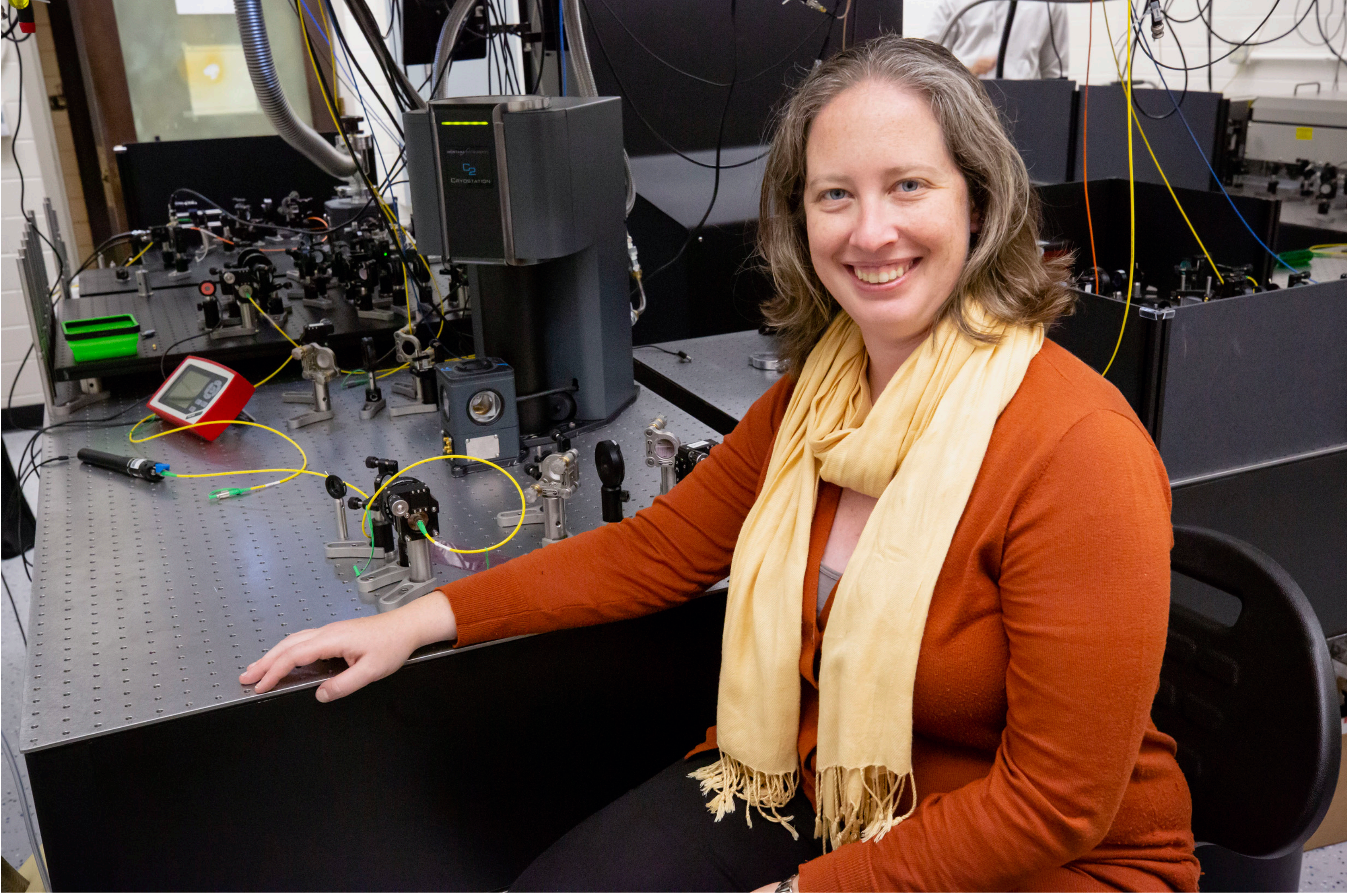
I'm definitely a homebody, so it's probably sitting on the couch with my partner, reading or watching tv.

What is the greatest scientific blunder in history?

I would say the failure to avoid or mitigate the unfolding effects of climate change. And importantly this was a failure of both science and the communication of science, which is often just as important.

Who is/are your favorite artist(s) in any medium—painters, composers, authors, filmmakers?

I am an avid reader. Recently I have been reading a lot of science fiction, a mix of older and newer stuff. So right now I would say Octavia E. Butler, N. K. Jemisin, Tade Thompson, Emily St. John Mandel, and probably more that I'm forgetting.



Illinois Physics Professor Elizabeth Goldschmidt is an experimentalist in quantum optics and quantum information. In her laboratory in the Materials Research Laboratory, her group investigates the generation, storage, characterization, and manipulation of photons for quantum information applications. Currently, her group is using rare-earth atom ensembles in innovative experiments having implications for the development of solid-state quantum memory. Photo by Michelle Hassel, University of Illinois Urbana-Champaign

Who is/are your favorite hero(es) in life or in fiction?

Good scientific management is often overlooked but is absolutely vital to successful research. I was lucky to work under one of the great scientific managers at NIST in the late Katharine Gebbie. She knew how to bring the best out of the hundreds of technical staff in the physics laboratory, as exemplified by the four Nobel prizes awarded to NIST physicists during her tenure.

Who is/are the villain(s) you love to hate?

Elon Musk and the rest of the techbro CEOs.

What is your idea of happiness?

Figuring something out in the lab. It never gets old to solve a mystery that I'm presented with, whether it is unexpected data or noise from some unknown source. And I think that the stubbornness that drives me to figure these things out is part of what makes me a good scientist, even if the same stubbornness can be annoying for the people in my life outside the lab!

What is your idea of misery?

Group theory.

What quality do you most admire in others?

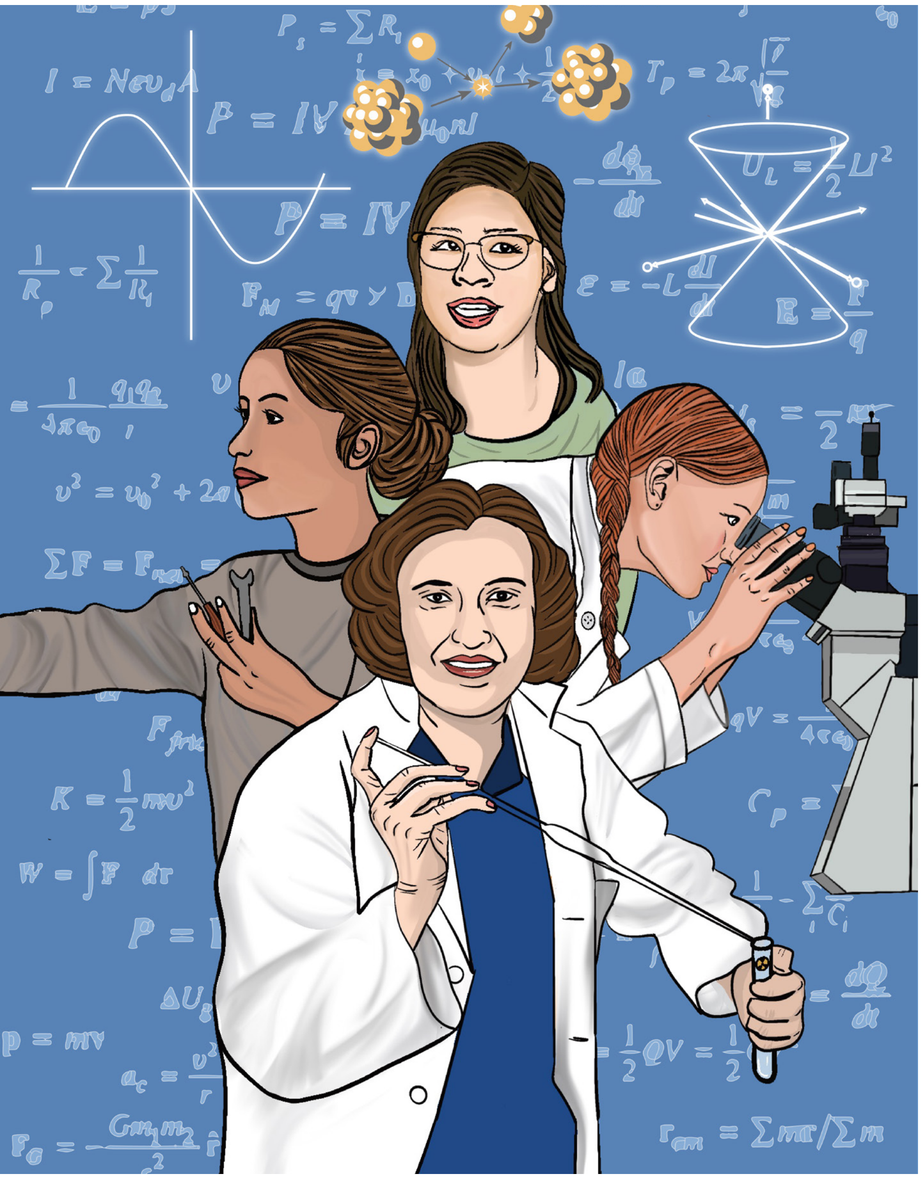
Honesty. I always appreciate it when people are straightforward with me, and little makes me angrier than someone trying to intentionally mislead me.

What scientific question do you hope will be answered in your lifetime?

What will the killer apps be for quantum computing and other quantum information technologies? I think it is broadly accepted in the quantum information community that quantum computers will have a major impact on the world, but we can't quite predict the form that impact will take.

Searching for gender parity at Illinois Physics:

100 years of women PhDs



‘Luminous: Women PhDs of Illinois Physics’ by Yasmine Steele for Illinois Physics

*In 1956, Chien-Shiung Wu demonstrated one of the most critical experiments in the history of physics: testing parity violation under weak interactions. Wolfgang Pauli famously quipped, “*Ich glaube aber nicht, daß der Herrgott ein schwacher Linkshänder ist.*” (I do not believe that the Lord is a weak left-hander.) Wu’s experiment did indeed prove that the universe, by a margin of roughly 1 in 10,000, really is left-handed. Despite her landmark discovery and 26 nominations, Wu was left out of the Nobel Prize winners’ list.*

This report by Illinois Physics doctoral candidate Shraddha Agrawal introduces a two-part series of articles, written in the first person by our women PhD alumnae and students. We hope you’ll enjoy this ode to women physicists like Wu and the women PhDs of our own department, past and present.

SHRADDHA AGRAWAL

for Illinois Physics Condensate

Illinois Physics’ history is full of stories that exemplify excellence. The department has produced and hosted several Nobel laureates and remarkable discoveries in physics. But until the 1960s, the PhD program had very few or no women. One early example of the caliber of research women can bring is Rosalyn Sussman Yalow, a student of Maurice Goldhaber who earned a PhD in 1945—the second woman in the department’s history to accomplish this. Yalow would later win the 1977 Nobel Prize in Physiology or Medicine “for the development of radioimmunoassays of peptide hormones,” a technique she invented with her colleague Solomon Berson.

When Yalow started her graduate studies in 1941, she was the only woman in the classrooms where she learned or

Members of the Department of Physics at Illinois circa 1915/16. Physics alumna Eleanor Frances Seiler, the department's first woman PhD graduate (1922), stands in the front row in a white dress. Just behind her to the viewer's left is Head of Department Albert P. Carman and next to him, department secretary Della M. Rogers (then the only other woman in the department). Photo credit Illinois Physics, courtesy of AIP Emilio Segrè Visual Archives

taught—in fact, the only woman among the 400 teaching fellows and faculty members of the College of Engineering at the University of Illinois Urbana-Champaign.

Before Yalow, Eleanor Frances Seiler was the first woman to earn a PhD from Illinois Physics, in 1922. Unlike Yalow, Seiler did not find her way into a scientific career in academia or industry.

Today, the department—one of the largest physics doctoral programs in the country—is a second home to 91 women PhD students. That's as many as graduated from the department in the 100 years from 1910 to 2010.

Head of Department and Professor Matthias Grosse Perdekamp credits the department's current success in enrolling women PhD students to the leadership and diligence of Associate Head for Graduate Programs and Professor Lance Cooper.

Perdekamp notes, "In his 11 years at the helm of our graduate program, Lance Cooper has transformed admission practices and the climate of equity and inclusion. During his tenure, the proportion of students from historically underrepresented groups rose from 3 percent to 8.5 percent and the number of women from 13 percent to 29 percent—both now well above national averages. Lance's perseverance in implementing bold ideas and his data-driven approach to optimizing outcomes have proven a tremendously successful mix to effect positive and lasting change."

The student experience

While a student, Illinois Physics PhD alumna Karmela Padavic-Callaghan contributed to the formation of diversity support groups and community-building efforts at Illinois Physics.

She recalls, "I left Urbana with this sense of optimism, because I saw that change could happen. I was there six years. Over those six years, we built up a lot more support and had a lot more conversations, a lot more awareness. I do think that I saw the culture of the department change over the years, and it was very encouraging to see that if you organize and if there's institutional support for organizing, then institutions can change.

"I'm going to emphasize that we would

have done absolutely nothing had it not been for Lance, who was willing to give us space and money and advocate for us."

Illinois Physics doctoral candidate Preetha Sarkar shares, "I can only speak from my own experiences, but this department holds up pretty well to what I thought a department should be. No segregated groups, all graduate students so friendly and welcoming. The department, Lance especially, put in a lot of effort towards making our workspace a safe, inclusive space. It is very encouraging to see so many diversity and equity efforts going on and being appreciated."

Illinois Physics doctoral candidate Anabel Romero comments, "I've heard a lot of minority students say they don't consider themselves minorities because they are 'just as capable as everyone else.' The idea of disparate capabilities based on gender, race, or ethnic group is a misconception. Of course, we are all equally capable! The difference is that minority students face more issues and have less access to resources. What stops minority students from further succeeding in life is not a lack of talent or intrinsic abilities, it's harsher circumstances. Therefore, I thought it was superb that the department has started presenting the *Excellence in Outreach, Service, and Diversity Award*—definitely a step in the right direction."

Cooper says the increase in diversity, including the greater enrollment of women, has only benefitted the graduate student community and the department's research programs.

"Broadening participation in our graduate program has allowed us to draw from the largest possible pool of scientifically talented physics students," notes Cooper. "Increasing diversity in our program has also significantly benefited the academic experience, research activities, and social climate for graduate students in our department, particularly for students from groups that have been traditionally underrepresented in physics."

Historical correlations with enrollments

Looking at historical enrollment data from the Illinois Physics doctoral program, there are interesting correlations between the number of PhD graduates and historical events. For example, there was a significant increase in the number of PhD graduates in 1950, five years after the end of World War II, and then again in the mid-1960s, reflecting the post-Sputnik era in the United States (Figure 1). Not surprisingly, the total number of women PhD graduates from Illinois Physics does not follow the same historical trajectory. Women have only sporadic representation until about 1970, after which enrollment of women graduates became more regular.

Since 1970, the Illinois Physics enrollment data show three distinct periods in women PhD graduations. In the 30-year

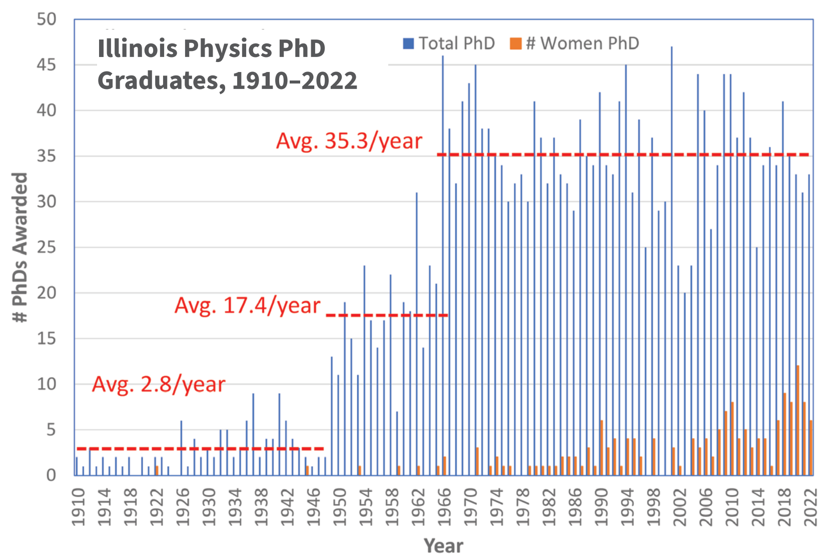


Figure 1: From 1910 to 2022, the average number of women PhD graduates is significantly below the number of men graduates, but progress toward greater equity has been made over the last decades. Graph courtesy of Lance Cooper, Illinois Physics

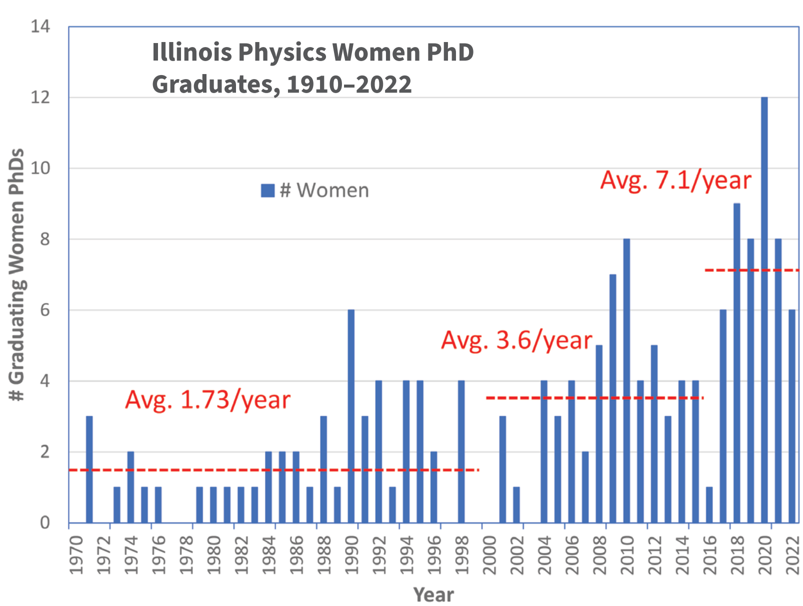


Figure 2: From 1910 to 2022, the number of women PhD graduates trends slowly upward. Graph courtesy of Lance Cooper, Illinois Physics

span 1970–1999, women graduated fairly consistently each year, but at a very low average rate of 1.7 women per year. In the following 16 years, 2000–2015, the average PhD graduation rate for women roughly doubled to 3.6 women per year. In the past 7 years, 2016–2022, the average PhD graduation rate roughly doubled again to 7.1 women per year, as shown in Figure 2.

While these jumps in women PhD graduations have little to no correlation with historical events prior to 1970, both our department's data and the national data compiled by the American Institute of Physics indicate a consistent increase in the number of women seeking undergraduate or graduate degrees in physics after 1975 (Figure 3). Interestingly, this increase correlates with the passing in 1972 of Title IX of the Education Amendments, which prohibits sex discrimination in educational programs or activities that receive federal funding. Title IX is one example of how systemic changes can propel an underrepresented group forward.

Breaking through enrollment barriers

At Illinois Physics, several admissions requirement changes put in place by the associate head for graduate programs have contributed to a marked increase in the number of women PhD graduates. Cooper, who has administered the graduate program since 2011, meets annually with each graduate student to discuss progress toward degree and career aspirations. He has a reputation among the students for providing individualized mentorship and support. He applied the same attentiveness to his review of admissions policies, having greater equity as a goal.

Cooper recalls, "During the decade 2000 to 2009, we had plateaued at 13 percent women in our PhD program enrollment—13 percent seemed to be the fundamental constant of our graduate admissions."

Surpassing this mark required a change in PhD program admissions and recruiting procedures. Among these changes, significantly less emphasis is placed on the standardized Physics Graduate Record Examination (PGRE). Since 2017, submitting the PGRE as part of the application has been optional.

Without the PGRE, a more holistic evaluative approach considers applicants' letters of recommendation, personal statements, and undergraduate grade point averages (GPAs) on equal footing. According to Cooper, this review process has resulted in significantly more offers made to qualified women, which in turn has contributed to a more inclusive environment for all genders.

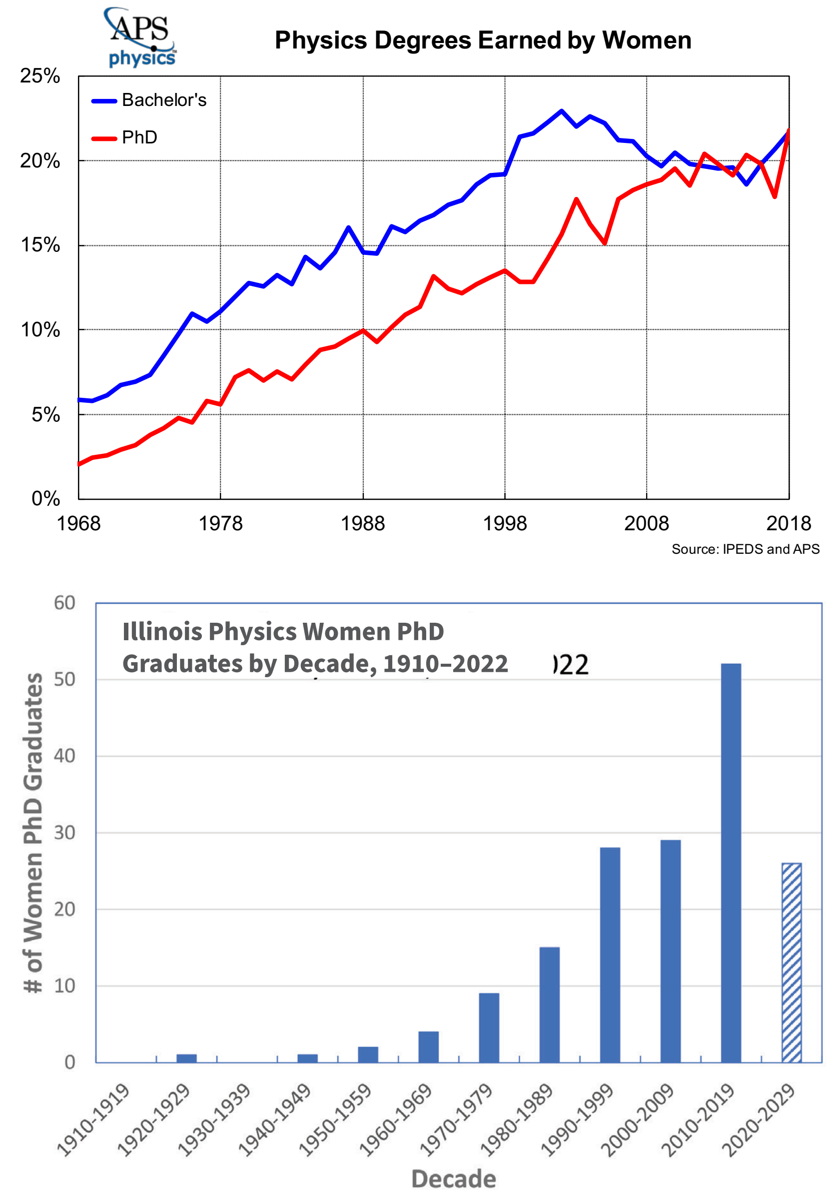


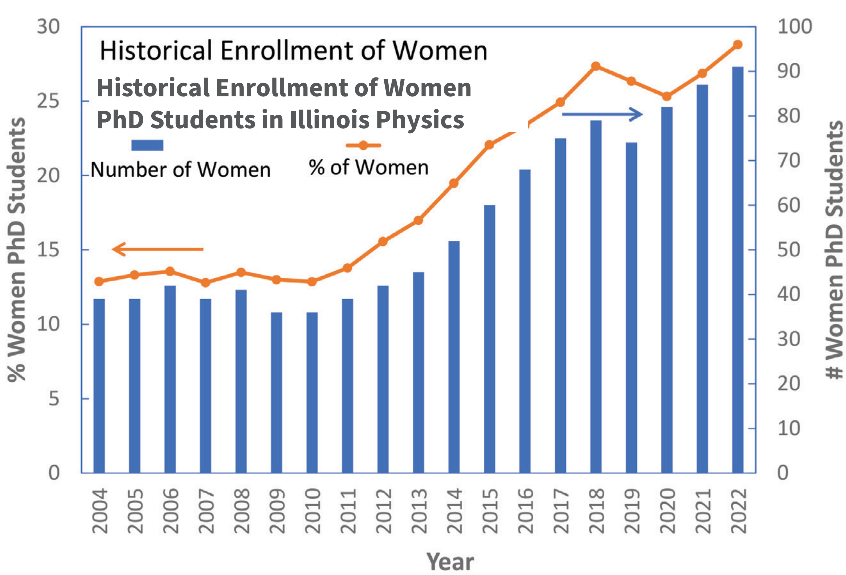
Figure 3: Top, national data on the percentage of undergraduate and PhD physics degrees earned by women, collected by the American Physical Society (APS), shows increased representation in the field by women since 1968; consistent growth in the percentage of women PhD graduates starting around the mid-70s is consistent with Illinois Physics' numbers. Bottom, the number of Illinois Physics women PhD graduates by decade reflect the national trend of increased accessibility to women, but shows contiued growth from 2010 forward, in part due to our holistic admissions criteria. Upper graph courtesy of the APS, lower graph courtesy of Lance Cooper, Illinois Physics

This was a bold move—physics programs were the slowest to drop GRE requirements in the US.[1] However, some studies have shown that GRE scores are uncorrelated to student productivity in graduate school[2] and are particularly disadvantageous to groups historically underrepresented in physics, like women. Not content to rely on data from other fields, Cooper collected Illinois Physics graduate program data over a span of many years and studied the correlation of admitted students' PGRE scores with their success in the program.

Figure 5 shows the GPAs of first-year Illinois Physics graduate students relative to their PGRE scores from 2010 to 2020. The data reveal only a weak correlation between test scores and grades.

Since implementing these changes, the enrollment of PhD women in the first-year class doubled during the decade 2010 to 2019, climbing to 12 women per year from an average of 6 women per year during the previous decade (Figure 4).

While offering more admissions to women was certainly an important factor in increasing the enrollment of women in the Illinois Physics PhD program, creating an inclusive environment for the women applicants was equally essential. Offering departmental fellowships to women and gender-minority applicants has been crucial to creating a sense of belonging and safe spaces. For example, women faculty and graduate students in the department started hosting a fun and inclusive Women in Physics coffee hour for prospective women PhD students during the Prospective Student Open House. Imagine walking into a room full of women physicists, sipping coffee, talking about their lives and research experiences, and sharing a few laughs during the prospective graduate student open house. That is some "Urbana-style physics" for you!



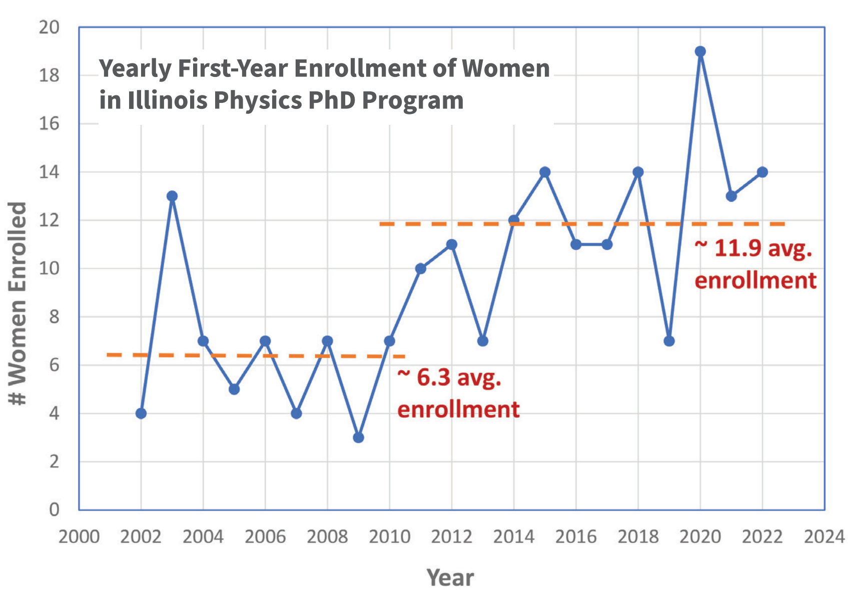


Figure 4: Top, From 2004 to 2022, the number of Illinois Physics women PhD graduates trends slowly upward. Bottom, Bottom, breaking through a plateau in the number of first-year women PhD enrollments in the 2000s required thoughtful changes in admissions requirements and practices. Graphs courtesy of Lance Cooper, Illinois Physics

Additionally, Professors Nadya Mason, Smitha Vishveshwara, Sangjin Kim, and other women faculty organize regular Women in Physics coffees for women PhD students. Mason secured funding from the Heising-Simons Foundation to support an annual Women and Gender Minorities (WGMP) retreat, Women in Physics luncheons, and other social activities for women PhD students and faculty in the department. Most recently, women graduate students at Illinois Physics secured a Women in Physics Group Grant from the American Physical Society to support social and professional development activities for women and other gender minorities at Illinois Physics.

Impacts of increased participation of women in physics

Cooper points out that enrolling more women graduate students at Illinois Physics has not only promoted greater participation of women in physics, but it has dramatically changed the culture and improved the climate in the department. Women PhD students at Illinois Physics are disproportionately the founders and leaders of the many social and professional-development groups in the department or on campus, they have disproportionately received national fellowships, and their graduation and job placement rates are at least as high as those of the male PhD students.

Indeed, the placement of women graduate students after graduate school is a particularly important metric for measuring the success of the program and the cause of equality. Cooper has tracked down the post-graduation jobs of about 80 percent of the 167 women PhD graduates from the department. He learned that, of the 129 women PhD graduates he could track, 43 percent stayed in academia, 39 percent went to industry, and 12 percent went to national labs. It is also noteworthy that 33 percent of women graduates became faculty in some form.

The success of women PhD students from Illinois Physics and from institutions across the U.S. securing jobs in academia, national labs, and industry is encouraging given the challenges that women have historically faced in the pursuit of scientific careers. In the not-too-distant past, all too often women physicists had to give up on their careers to become caregivers of their families or faced obstacles in getting hired at the same institutions as their husbands. In this way, women bore the brunt of the infamous “two-body problem,” which made it hard for couples to pursue their chosen professions in the same geographical location.

The increasing number of women graduates from Illinois Physics can be particularly important for bridging the glaring gender gap in the field of physics. Now with so many women PhD graduates from Illinois Physics finding placements in academia, at national labs, and in the private sector, the physics community can

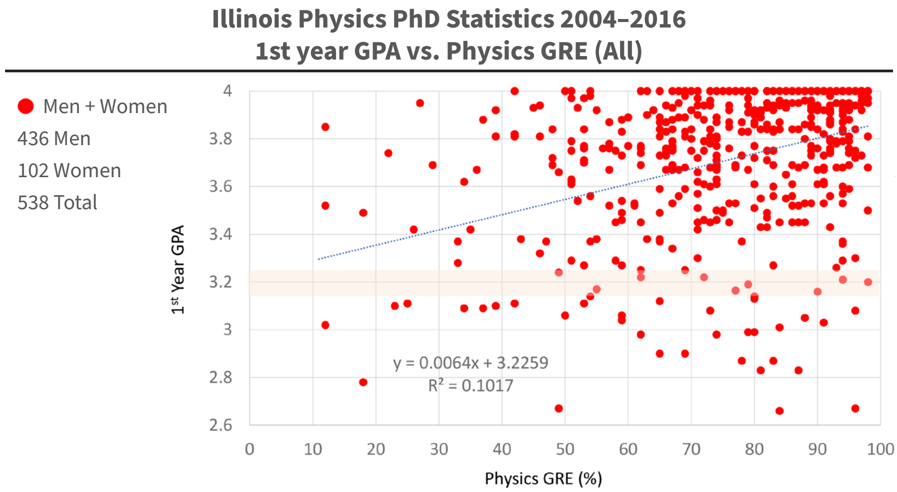


Figure 5: Illinois Physics PhD program statistics from 2004 to 2016 demonstrate that students’ Physics GRE scores are not a reliable predictor of academic performance in the first year of study, as measured by students’ grade point average (GPA). Plot courtesy of Lance Cooper, Illinois Physics

continue its promising work to reverse some of these trends.

The higher number of women graduates from Illinois Physics can also help address a related problem in STEM: the lack of women mentors and role models in high-level academic and industrial positions. With the increasing number of women PhD graduates from this department, the scientists of future generations will benefit from the strong professional mentoring, physics training, and social networking offered by the many excellent women scientists from Illinois Physics.

Ultimately, the hope of gender-inclusion efforts is that one day—unlike the parity violation that Chien-Shiung Wu not only discovered, but in another manner experienced—gender parity in physics can be an attainable goal, enabling many more significant discoveries by a growing network of outstanding women scientists, from Illinois Physics and elsewhere. ■

Shraddha Agrawal is a fifth-year PhD student at Illinois Physics. Her research focuses on exploring novel topological phenomena using ultra-cold atoms. Her future interests involve exploring gravity in quantum mechanical regimes. She was recently awarded fourth place in an essay contest organized by the Gravity Research Foundation for her essay about the key role of large momentum transfer optics in atom-based interferometers. She is passionate about increasing participation of underrepresented groups in STEM fields, especially physics. Her essay about an incredible, little-known Indian woman physicist, Anna Mani, and her contributions to Indian metrological science was selected by the American Physical Society as a runner-up in its 2022 History of Physics Essay Contest.

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Elanna Yalow, on behalf of her mother, Rosalyn Sussman Yalow

Elanna Yalow, Chief Academic Officer, KinderCare Education. Photo courtesy of Elanna Yalow

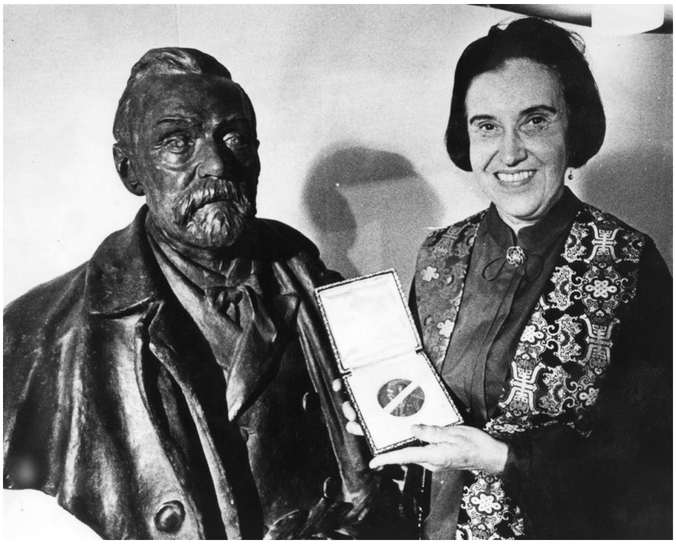
Rosalyn Sussman Yalow (1921–2011) was the second woman ever to earn a PhD from Illinois Physics and the first American woman ever to win a Nobel Prize in Physiology or Medicine (1977), "for the development of radioimmunoassays of peptide hormones," a technique she developed with colleague Solomon Berson.

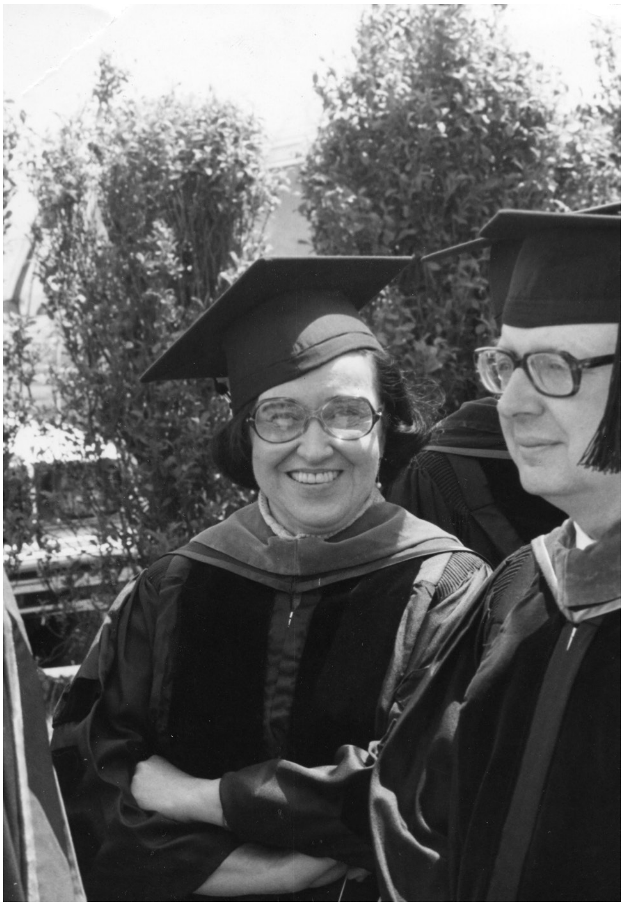
As the daughter of Dr. Rosalyn Yalow, I am honored to share a few memories of my mother that have stayed with me throughout my lifetime. There truly were two sides to my mom. Her life in science where she was bold and determined—brilliant and nurturing to the next generation of scientists who came to her lab to study, learn, and contribute. And then there was her personal life, where her commitment to her family was strong and unwavering. In retrospect, I realize the challenges she must have faced to give herself fully to both her science and her family, but as a child I never perceived that one needed to be compromised to support the other.

And so I grew up to pursue my own career and raise my own family, knowing my mother as a scientist, but also of her love for our family. She brought to us the same degree of focus that she brought to her work, instilling a sense of responsibility by her words and actions. She would constantly remind me of my obligation, her obligation, to use whatever skills and gifts she was blessed with on behalf of others. She held herself to the standard that she leave the world a better place than the one she inherited, and she expected that her children would do the same.

What defined my mom was a fierce sense of responsibility, self sacrifice, and integrity. She believed that no one was owed anything because of who they were, where they came from, or even what obstacles they had to overcome. One had to work hard to earn life's privileges as she had to overcome all the obstacles that society placed in her way as a Jewish woman with a love of science, a curiosity about the world, and a relentless commitment to use her talents and skills on behalf of others.

As I tried to pull my thoughts together for this piece it is clear that I do not know how to do justice to the remarkable person that she was. What I do know are the invaluable lessons she taught me. I learned to believe in myself, to work hard on behalf of others, to





Historical images from Illinois Physics, courtesy of AIP Emilio Segrè Visual Archives

put my family and friends above all, and to strive to use the many advantages I have been afforded to try to make a difference. I learned that it matters little how big your house, the clothes you wear, the possessions you amass. Her honesty, determination, compassion, brilliance, and accomplishments are her legacy. I doubt that I have been able to live up to the standards she set, but I know that she did. And while she changed the world, she never lost her focus on her family.

"... she had to overcome all the obstacles that society placed in her way as a Jewish woman with a love of science, a curiosity about the world, and a relentless commitment to use her talents and skills on behalf of others."

More than anything, my mom lived her life on behalf of future generations. She willed her science to the world, her efforts to humankind, and her values and beliefs to her children and grandchildren. And so her torch has been passed on to the next generation, particularly to women scientists, to honor her memory, if they so choose, by finding their own path to making a positive difference in the world in which we live. The most powerful but simple message that has endured through the years is that the true rewards in life come from devoting your efforts on behalf of others. My mom's gifts to the world were great. But her inspiration to those who found their own professional calling in service of others, particularly women in science, can have an ever greater impact. For it will take their collective wisdom and dedication to help overcome the challenges that beset our world today into the future. ■

Alumna Karmela Padavic-Callaghan

Karmela Padavic-Callaghan is a physics reporter at New Scientist. *Her writing has been featured in* Wired, Slate, *and* Scientific American, *among other publications.*

Growing up in a small Croatian town, my main exposure to science was watching my father, an electrical engineer, fix broken appliances. From him, I knew what engineering was—building and fixing things. In school, I learned that math is about solving countless problems about dividing up candy or counting combinations of pants and shirts. It was all fun, but I didn't overthink it.

I took my first physics class in the seventh grade, and it knocked me off my feet.

Physics was different. Here were some numbers, of the familiar kind, and some operations, also familiar, but now they meant something. Something as tangible as a ball rolling down a hill or a penny falling from the top of a skyscraper. Math could, apparently, help us understand the physical reality around us. Immediately, I decided to become a physicist.

Ten years later, when I was starting graduate school at Illinois, I still had that sense of awe. I had left Croatia, first for a boarding school in New York (where I polished my English and took standardized tests so a college with a strong physics program would accept me), then for the University of Chicago (where I learned abstract math and sat in research meetings so a school with a strong graduate physics program would accept me), and had finally landed in Urbana-Champaign. A mentor from college told me it was a place where I could really immerse myself in physics. My new adviser presented me with a cornucopia of ideas when I first met her.

We were going to send extremely cold atoms into space and shape them into bubbles, we were going to find fractals by shooting potassium gas in a small glass box with lasers, we were going to find special quantum effects in a chain of fidget spinners… This was better than anything I could have imagined in the seventh grade.

I never fell out of love with physics, nor did physics fail me. But turning it into a profession and a livelihood was difficult, not because I lost my enthusiasm and curiosity, but because everyone who told me enthusiasm and curiosity would be enough might have been even more idealistic than I was. Now, as a science journalist and a former physics teacher, I am grateful for the way studying at Illinois rewired my brain to think like a scientist and for all the incredible lessons in what the physical world is, which I absorbed. I can also now see how my often having been among the minority with respect to my nationality, gender, and sexuality created moments that dampened my excitement and made me feel like I needed to be more small and hard.

When I came to Illinois, having left my college study groups behind me, I thought I'd also left behind the experience of having my ideas affirmed only after a man repeated them. But I still got talked over often enough to remember it.

No one ever told me I could not be a physicist, but colleagues noted that I didn't look like one. No one ever told me I was not respectable, but my teaching reviews called me condescending and referenced my clothes, all in one breath. No one ever told me my research was not good, but friendly faculty occasionally remarked that they would not let their own students work on what I was working on. No one ever told me I could not have a life outside of physics, but after I got married, questions about my postgraduate career stopped flowing as freely.

Illinois Physics alumna Karmela Padavic and Illinois Physics alumnus Luis M. de Jesús Astacio cook together at a GPS (Guidance for Physics Students) retreat while still graduate students. Photo courtesy of Karmela Padavic

Graduate students are trained to be problem solvers, and I wanted to solve these troublesome moments that became an inextricable part of what being a physicist and doing physics was like for me. This resulted in some of the most nourishing experiences I had in graduate school, because many of my peers also wanted a little more kindness, support, and inclusion, and we only had to find each other.

I was an early member and was later part of the leadership team of the Guidance for Physics Students (GPS) mentoring program. I co-organized the first two Women and Gender Minorities in Physics retreats and put together workshops about everything from CV writing to what intersectionality means. Other student leaders became dear friends. I traveled across the country for the Access Network Assembly and eventually also co-organized it at Illinois.

At Illinois, I learned as much about community as I did about mean field theory or the Gross-Pitaevskii equation, and the former made the latter possible. From my involvement in graduate student–labor organizing on campus, I learned about a broader need for solidarity, beyond my immediate community.

All of these lessons are still with me.

At my PhD defense, I devoted a few slides to acknowledging how much all this work improved my graduate school experience and me as a person. And, after graduate school, when I had to summarize it in a way that a potential employer could understand, words like "organizer" and "community facilitator" sounded too cold for what it had been—had meant.

The groups I worked with did not solve all equity and inclusion problems in the Physics Department—we probably just scratched their surface. Still, I left feeling hopeful because I could see that we'd nudged some changes into being. Some were visible and structural—groups like GPS became a fixture in our community, and the department leadership took action toward making admissions more equitable and buildings more comfortable for more bodies. Some changes were less tangible, like the feeling that we now had more ongoing conversations—and more honest conversations—about how who you are and how you identify affects your individual experience of becoming a physicist. And that we were now a department that intentionally tried to make room for all its students to show up as full people.

These days, I am always on the phone with physicists, interviewing them about research in my role as a physics reporter at New Scientist. Inevitably I mention that I also used to be a physicist, and we end up talking about Illinois. Almost everyone has either been to Illinois or has a dear colleague or acquaintance there. I often say that it was a very singular place to be trained at. I never mean to imply that it was an easy one, but rather that it was often a home for people that wanted to, and could, find excitement and deliberation for both incredible science and for each other.

I still frequently get awestruck by a physics paper or an experiment.

ALUMNUS JOHN KOSTER:
FROM BIG SCIENCE TO BIG INDUSTRY

KAREN GREENE
for Illinois Physics Condensate

John Koster knows all about big. From his doctoral training at Illinois Physics to his current role as principal engineer at Amazon, collaborating on large-scale projects has been a constant.

In his graduate student days, Koster did research at the intersection of nuclear physics and high-energy physics. He was part of a 500-person international collaboration called the Pioneering High Energy Nuclear Interaction eXperiment, or PHENIX, the largest of four experiments using data from the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory.

RHIC is the only operating particle collider in the U.S., and physicists regularly send beams of heavy ions or polarized protons on a collision course along its 2.4-mile accelerator ring to study the state of matter that existed just after the Big Bang and to understand the spin substructure of protons.

The graduate student experience at Illinois Physics was a big opportunity for Koster, who had come from a small liberal arts school in Maine. Koster remembers the one-on-one mentoring he received and the collegial atmosphere of the department and says these were just as important to his education as the big opportunities or big research projects.

“The department has a really good system for training physics students,” he remarks. “It’s also a very open place where it’s very easy to talk to professors.”

As a student in the Nuclear Physics Group, Koster enjoyed meeting informally with researchers—professors, postdocs, and

Opposite page, Illinois Physics alumnus John Koster poses for a photo on the Amazon headquarters campus in Seattle, where he works as as a principal engineer. Koster, a native of Connecticut, earned his bachelor's degree in 2004 from Bowdoin College in Brunswick, ME. He came to UIUC as a physics doctoral student in August 2004 and by the following spring was the first graduate student in the research group of Illinois Physics Professor Matthias Grosse Perdekamp. Photo by Rafael Soldi

Below right, the PHENIX experiment detector, called the Muon Piston Calorimeter, is installed at Brookhaven National Lab in 2006. Illinois Physics alumnus John Koster built the detector at Loomis Lab while a student, then drove it to Brookhaven National Lab to install it. Photo courtesy of John Koster

other students—to ask questions, learn about other research, and give presentations.

"It was good for the physics but also for the comradery," he recalls. "We were not disappearing into a library. The Nuclear Physics Group emphasized group learning, so there was a practical aspect but also a social aspect."

As one of Perdekamp's students, Koster had the chance to build several different particle detectors designed to measure ionizing radiation and high-energy photons. Those projects required teamwork and cooperation, and Koster participated in everything from assembling the hardware and calibrating the instruments to performing measurements and collecting data.

At Loomis Lab in Urbana, Koster was on the team that built a detector called the Muon Piston Calorimeter, and Koster drove it to Brookhaven in Upton, NY, where it was integrated into the PHENIX project. Koster stayed on to operate the instrument. Then in May 2006, he moved from Illinois to Long Island to work full-time on the electromagnetic calorimeter, measuring the energy and spin of high-energy photons produced by collisions of polarized protons at the RHIC.

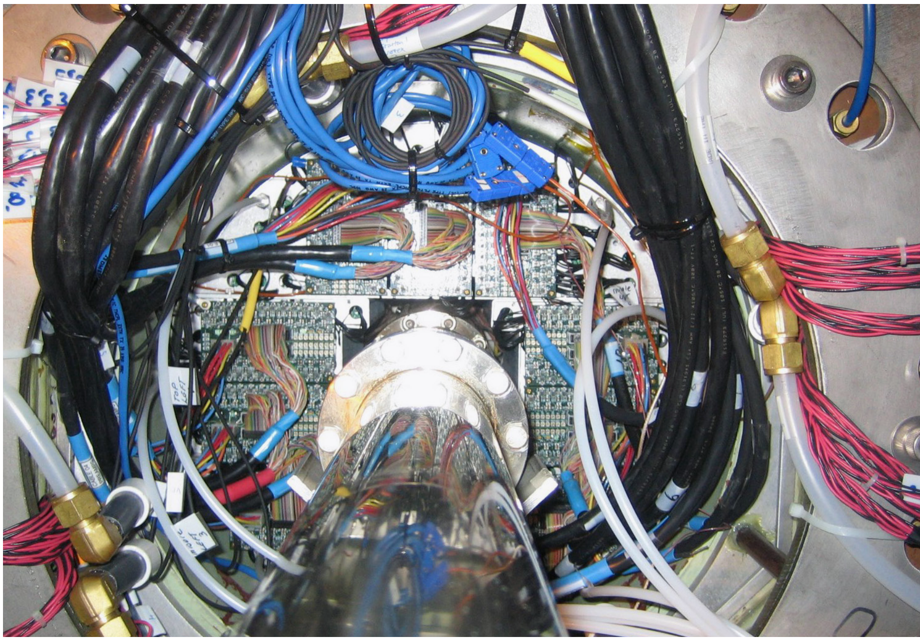
Koster's work at Brookhaven focused on understanding the spin of protons. The direction and strength of a proton's spin determines its magnetic and electrical properties. By smashing protons together at speeds near the speed of light, researchers seek to understand the properties of spin, including direction, momentum, and energy, and to determine how specific particles within protons, such as gluons and quarks, contribute to spin.

Koster and the Perdekamp research team explored the spin substructure of protons by alternating the colliding protons' spins and measuring asymmetries in the results of the collisions. The work required collecting hundreds of terabytes of data, using efficient algorithms to parse and interpret datasets, and performing statistical analyses on the results.

Although it might seem esoteric to those without a physics background, understanding spin does have practical implications. For example, magnetic resonance imaging (MRI) depends on aligning the spin of protons in hydrogen atoms in the body with the strong magnetic field of the MRI.

Koster completed his PhD in 2010. His thesis on the properties of spin using the Muon Piston Calorimeter earned an award for outstanding thesis research. He then took a postdoctoral position at RIKEN, a Japanese scientific research institute just outside of Tokyo, but remained stationed at Brookhaven to continue his work on the PHENIX experiment.

In 2013 Koster decided to leave the research sector for business. Once again, he went big, joining Amazon, initially as a software development engineer.



"I was excited about all the other opportunities out there, and the things I was going to be doing at Amazon seemed interesting and fit well with my experience," he says.

Through the PHENIX project Koster had learned to work with big data, and Amazon offers plenty of data. Now as a principal engineer, Koster works with marketing teams to analyze the performance of advertising products and to present aggregated results to Amazon's advertisers. It's a job that requires skills in big data and machine learning, as well as the ability to ensure data quality, speed, and reliability.

John Koster poses for a photo outside one of the spheres on the Amazon headquarters campus in Seattle. Photo by Rafael Soldi

“I am genuinely happy at Amazon,” says Koster, who lives in the Seattle area with his wife, Qin Liu (the couple met while working at Brookhaven), and their two young sons. “It’s a growing group, and there are a lot of challenges that I find exciting to work on, especially in the machine learning space.”

He credits his education from Illinois Physics—and particularly the advice and guidance he received from Perdekamp—with helping him develop the scientific and social skills to succeed in both research and business settings.

Being part of the international PHENIX collaboration taught Koster how to “influence without authority.” The communication skills needed to succeed in an international collaboration—working with experts in different fields and from different countries, using the terms and language they understand—helped Koster to succeed at Amazon and to navigate the challenges of the COVID-19 pandemic.

“There are not many traditional bosses in a 500-person collaboration,” he explains. “To influence the collaboration’s direction, you need to be able to communicate effectively, use data convincingly, and present clearly.”

The RHC complex has a lot of moving pieces, Koster adds, and whether or not their hardware is ready, scientists must follow the collider’s fixed schedule, which typically seals up in January and opens again in June.

“Working backwards from a date is extremely important. If you push to add more features to the project, you might miss out and need to wait a year until the collider operates again,” he adds.

His doctoral training and the PHENIX experiment also helped Koster to understand the importance of the science of data, including how to handle it, clean it, ensure its provenance, and protect it from biases. But beyond Illinois Physic’s depth and breadth of expertise and the chance to work with renowned scientists, Koster says the most important skill he learned as a physics graduate student was problem-solving.

As an engineer who now works to build tools that are scalable and can be used for years to help advertisers with their bottom lines, a strategy for problem solving is essential.

“You can have all the knowledge in the world, but translating that into action is what’s important for success. That’s one thing my time at the University of Illinois taught me. Learn from what others have done before you, create a strategy, break the problem into pieces, and collaborate with your team members to drive forward.” ■

ILLINOIS PHYSICS
Time Dilation

In case this news hasn't reached you yet, here are some of the top headlines from our newsfeed. Check out these stories and more at physics.illinois.edu.

NASA renames GLIDE Mission after trailblazing UIUC alumnus

Grainger Engineering

Dec 2—NASA renamed its Global Lyman-alpha Imager of the Dynamic Exosphere (GLIDE) mission the Carruthers Geocorona Observatory, at a ceremony hosted by The Grainger College of Engineering. The renaming honors Dr. George R. Carruthers, a prominent three-time alumnus (BS physics, 1961; MS nuclear engineering, 1962; and PhD aeronautical and astronautical engineering, 1964).

Kahn, Shelton, and Hooberman to characterize AI deep neural networks for scientific research

SIV SCHWINK *for Illinois Physics*

November 29—The U.S. Department of Energy (DOE) announced $4.3 million in funding for 16 projects that will use artificial intelligence (AI) to spur advances in high-energy physics and will use tools from high-energy physics to better understand how AI works. Among these, a team of physicists at UIUC will apply tools from theoretical high-energy physics to develop a first-principles understanding of the uncertainty inherent in analyses using deep neural networks.

Peng wins 2023 APS Bonner Prize

SIV SCHWINK *for Illinois Physics*

Oct 11—Illinois Physics Professor Jen-Chieh Peng has been selected for the 2023 Tom W. Bonner Prize in Nuclear Physics of the American Physical Society (APS). This prize is the highest honor conferred by the society for work in experimental nuclear physics. The citations reads, "For pioneering work on studying antiquark distributions in the nucleons and nuclei using the Drell–Yan process as an experimental tool, and for seminal work on elucidating the origins of the flavor asymmetries of the light-quark sea in the nucleons."

Physicists create ultracold atomic bubbles in space

DANIEL INAFUKU *for Illinois Physics*

Sep 12—In a paper published in *Nature*, a multi-institutional team of scientists reported the first experimental observations of ultracold atomic bubbles in a microgravity environment. The experiment, conducted in the NASA Jet Propulsion Laboratory's Cold Atom Laboratory (CAL) on the International Space Station (ISS), continues theoretical work initiated two decades ago by Illinois Physics Professor Smitha Vishveshwara and colleagues. In the current work, Vishveshwara joined forces with a team from Bates College, NASA's Jet Propulsion Lab at the California Institute of Technology, Smith College, and the University of Massachusetts Amherst.

Illinois Physics graduate student Anuva Aishwarya wins Nottingham Prize

SIV SCHWINK *for Illinois Physics*

Sep 12—Illinois Physics graduate student Anuva Aishwarya was selected for the 2022 Wayne B. Nottingham Prize, awarded annually at the Physical Electronics Conference for the best paper presenting new research results in the field of surface science. Aishwarya, a member of Illinois Physics Professor Vidya Madhavan's research group, presented a novel scanning tunneling microscopy (STM) method. She and her colleagues developed a new class of STM probe tips using nanowires of crystals. The innovative microscopy tool is ideally suited to explorations of excitations in materials and has implications for new developments in quantum computing.

Breakthrough work has found a new way to read antiferromagnets electrically

JENNY APPLEQUIST *for MRL*

Aug 8—A multi-institutional team devised a new way to "read" the magnetic state of an antiferromagnet electrically. Magnets play a foundational role in much of today's technology, but ordinary magnets exhibit uncontrollable pole reversals, whether spontaneously or in response to heat or light. As devices become smaller, such reversals are expected to cause increasing instability. However, antiferromagnets—magnetic materials in which neighboring microscopic magnetic regions are alternately oriented north-south, south-north, north-south, and so on—are largely free from this problem, because their configuration tends to lock everything into a stable orientation. This work, a collaboration of Illinois Physics Professor Nadya Mason's group with Materials Science Professor Axel Hoffmann's group, as well as researchers at Argonne National Lab, Wayne State University, and Case Western Reserve, has implications for spintronics.

IPaSS builds community, provides resources to enrich high school physics education

KAREN GREEN
for Illinois Physics Condensate

It's well documented that early physics exposure plays a crucial role in routing students onto the pathway to science, technology, engineering, and mathematics (STEM) careers. But physics is often viewed as intimidating and elitist by high school students.

Maggie Mahmood believes the key to undoing those stereotypes—and ultimately to encouraging students' pursuit of further STEM education—is improving high school students' access to high-quality physics curricula, delivered by inspiring, innovative teachers.

Creating these opportunities means equipping teachers with the tools to make physics tangible, culturally relevant, and accessible to the communities they serve, she asserts.

Now the coordinator of secondary education partnerships for Illinois Physics, Mahmood spent years as a high school physics teacher in Boston and Baltimore. She understands that the quality of physics education varies widely in real-world high schools. A shortage of teachers having physics backgrounds combined with a lack of resources for teachers means access to high-quality physics education is not equal.

Often, schools in low-income areas have the fewest resources for teaching the foundations of physics. In Illinois, the most pronounced inequities in access exist at two extremes: small rural-community schools and densely populated urban districts. This trend disproportionately affects Black and Latine students.

"Some schools have such a shortage of physics teachers, they offer physics on a rotating schedule or not at all," notes Mahmood.

Opposite page, IPaSS coordinators and teaching fellows pose for a photo during the August 2022 workshop at Loomis Lab in Urbana. Pictured left to right are (back row) Eric Kuo, Nathan Gayheart, Rodger Baldwin, Matt Bonges, Nathan Rassi, Brendan Aydt, Eric Potter, Tim Stelzer, and Bill Coyle; (middle row) Maggie Mahmood, Jill McLean, Anna Wetherholt, Joanna Matlock, Jamie Piper, Julie Zaborac, J. Derrick Conner, and Devyn Shafer; (front row) Laura Regnery, Cassy Baker, Marianna Ruggerio, Hamideh Talafian, and Kunal Pujara.

Below right, Principal IPaSS coordinators Morten Lundsgaard and Maggie Mahmood introduce a group activity during the August 2022 IPaSS workshop.

Photos by Michelle Hassel, University of Illinois Urbana-Champaign

“If students don’t graduate high school with a quality physics education, it can hamper their ability to get any kind of engineering degree.”

Disparity in physics education is a complex problem that impacts students, teachers, and the universities that educate physicists and engineers. Many high school students lack opportunities to build a strong physics foundation, teachers face isolation and burnout, and universities—including UIUC—are hindered in their efforts to grow a diverse community of physics and engineering professionals. Mahmood and her Illinois Physics colleagues are taking action to address this multifaceted problem through a program called the Illinois Physics and Secondary Schools Partnership (IPaSS).

IPaSS brings together Illinois high school physics teachers—the IPaSS teaching fellows—for professional development, giving them access to research-based, university-level instructional materials and helping them adapt these materials for use in high school physics courses. A team of Illinois Physics faculty and staff members, led by Mahmood, recruits and works with IPaSS teaching fellows to adapt university resources for high school use, to introduce new resources into the classroom, and to build a community of teachers who collaborate and support each other.

As the IPaSS teaching-fellow community of practice grows, it’s building pathways for high school students to high-quality college-level physics and engineering programs, including those offered by The Grainger College of Engineering and Illinois Physics.

“Everyone in physics is aware of the problem and the need to address it, but it’s a time-intensive and people-intensive issue,” says Illinois Physics Professor Tim Stelzer, who initially came up with the idea for the IPaSS program. “The big question is: can we address this as a university-level department of physics?”

Building a community of practice, from the ground up

Stelzer and Mahmood, along with Morten Lundsgaard, the coordinator of physics teacher development at Illinois Physics, put their heads together to develop a program that would provide teachers with new resources for physics education as well as professional development. They realized their goal and launched IPaSS in summer 2020, at a time when schools, teachers, and students were struggling to deal with the unprecedented problem of a worldwide pandemic. In many ways, it was the perfect time to begin sowing the seeds for a statewide community of physics teachers, as feelings of isolation and teacher burnout had reached new heights.

“We told Maggie about our ideas for a partnership program when she came here in 2019,” recalls Stelzer. “She was game. We wrote a grant and got it funded. All the pieces came together.”

The program started with a cohort of four teaching fellows, all veteran high school physics and science teachers. Since then, IPaSS has expanded to include 24 teaching fellows from across the State of Illinois—some of them veterans and some new to teaching. They come from urban, suburban, and rural school districts. The nearly 1,000 students they collectively teach each year represent the diverse socioeconomic, ethnic, and racial backgrounds of communities across the state. The IPaSS organizers plan to bring more teaching fellows into the program, representing more school districts, to futher build a statewide community of practice that will serve as a support system for high school physics teachers.

IPaSS teaching fellows (L-R) Nathan Rassi, Eric Potter, Matt Bonges, and Jamie Piper design an iOLab physics experiment. Photo by Michelle Hassel, University of Illinois Urbana-Champaign

"Our teaching fellows are a community of practice from different areas who have different lived experiences in the classroom," says Lundsgaard. "They get together in the summer, and their sharing with each other is as important as what they learn from us. When it comes to teaching their students, we know they are the experts, and they take the lead."

IPaSS teaching fellows spend one week in June and one week in August on the Illinois campus in Urbana-Champaign. During those visits, they familiarize themselves with the innovative undergraduate physics curriculum developed at Illinois Physics, explore how to adapt it for their high school students, and experiment with resources for physics education, such as the iOLab wireless lab system. The handheld iOLab device, developed by Stelzer and Illinois Physics Professor Emeritus Mats Selen, includes built-in sensors for measuring a wide range of physical phenomena, including force, acceleration, velocity, displacement, magnetic field, rotation, light, sound, temperature, and pressure.

"Schools have limited budgets to buy equipment and that makes it hard to do interesting things," notes Lundsgaard. "The iOLab has tons of sensors to collect data, so students can experience the joy of science, not just the frustration of decomposing vectors."

IPaSS teaching fellow Jill McLean, a longtime physics and Advanced Placement (AP) Physics teacher at Champaign Centennial High School, says many of her students have ambitions to attend UIUC, and the IPaSS program gives them access to the same curriculum used in the introductory undergraduate courses.

"During the pandemic, I was thrilled to have something my students could do," she shares. "They could pick up an iOLab and continue lab work without my being there. I'm not sure my AP kids would have done as well during the pandemic without this."

Although IPaSS teaching fellows have much to gain from the expertise and resources offered through the program, they benefit most from interactions with their teacher peers. The IPaSS partnership model positions the university as another partner in this community of practice, not an outsized authority on physics education, explains Mahmood.

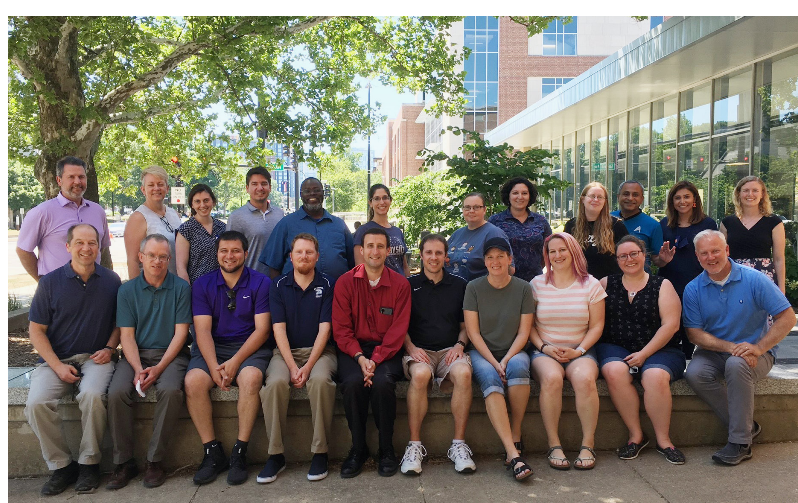
When IPaSS teaching fellows come together in the summer, they set goals for the school year and share experiences from the previous year. They continue to meet virtually either weekly or biweekly to discuss ideas and learn from each other. Teaching fellows participate in IPaSS for four years, and the more senior participants provide guidance and support to the newer ones. Teaching fellows in their second summer with the program are encouraged to present short workshops for their peers, to support the sharing of ideas, curricula and pedagogies. Teaching fellows use online folders to share successful curricula and tips on creating new activities and curricula.

"I absolutely love the iOLabs," says IPaSS teaching fellow and Illinois Physics alumnus Jacob Rangel. He joined IPaSS in 2021 as a new teacher at Curie High School, a diverse urban school in Chicago. "Kids who can't do math in their heads can work with iOLab. The math doesn't intimidate them, and the iOLab encourages them to participate and work together."

But more important than new tools and access to high-quality curriculum is the opportunity to build a statewide supportive community of physics teachers, says Mahmood.

"This project is about helping students, but a byproduct is what happens when you get teachers together in the same room," she notes. "We see teachers connecting on a level we didn't expect. They share on a personal level and talk about how they support

Images from top down: 1. IPaSS coordinator Maggie Mahmood (middle) and IPaSS teaching fellows Brendan Aydt (left) and Cassy Baker interpret data represented on an iOLab graph. Photo by Michelle Hassel, University of Illinois Urana-Champaign 2. IPaSS PI and Illinois Physics Professor Tim Stelzer (middle) works with IPaSS teaching fellows J. Derrick Conner (left) and Bill Coyle on a rotation iOLab activity. Photo by Michelle Hassel, University of Illinois Urana-Champaign 3. IPaSS teaching fellows Jacob Rangel (left) and Kunal Pujara collaborate to develop an iOLab activity for the electricity & magnetism curriculum. Rangel is an alumnus of Illinois Physics. Photo courtesy of Maggie Mahmood, Illinois Physics 4. Between the time the article was written and its publication, the community of IPaSS teaching fellows more than doubled in size. Pictured here, IPaSS teaching fellows from four cohorts pose with IPaSS organizers during the June 2023 IPaSS workshop. Pictured left to right (back row) David Smulson, Chris Swan, Brendan Aydt, Jen Grady, Eric Potter, Bart Frey, Jeremy Paschke, Jacob Rangel, and Eric Kuo; (third row, standing) Cassy Baker, Joanna Matlock, Julie Zaborac, Bill Coyle, Marvin Allen, J. Derrick Conner, Nathan Rassi, Mike Baker, Sandra Azubuike, Mike Berry, and Kumkum Bonnerjee; (second row, seated) Kay Wagner, Eileen Cameron, Roy Hays, Nathan Gayheart, Marianna Ruggerio, Jamie Piper, Matt Bonges, Nathan Logan, Tim Stelzer, Devyn Shafer, Morten Lundsgaard, Hamideh Talafian, and Maggie Mahmood; (front row) Kunal Pujara, Jill McLean, and Alex Mraz. Photo courtesy of Maggie Mahmood



their students when things are really hard. They share materials and part of themselves. In this regard, this is not a typical professional development experience."

Kunal Pujara who has taught physics at Highland Park High School in Chicago's north suburbs for 29 years, was new to IPaSS in 2022. He says he has learned so much from other participants that he feels like a new teacher.

"I have already benefitted from the mentors I've met," he shares. "The iOLabs really engage students in a way I never did before. They lend themselves to student-led design, which is so important for creativity and exploration."

Stelzer says the team at Illinois will continue to expand the network of high school physics teachers and will maintain IPaSS as a teacher-driven program. He sees the team's job as listening to the teachers, understanding their concerns and the problems they face, and adapting tools and curricula based on their feedback. In addition to its immediate benefits for teachers and students, he hopes IPaSS will help school districts to retain quality high school physics teachers and will eventually lead to a more diverse network of physics educators.

IPaSS is funded by the National Science Foundation under Grant No. DRL 20-10188. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the study authors and do not necessarily reflect the views of the National Science Foundation.

A bridge to college physics: IPaSS fellow Marianna Ruggerio

As a physics and Advanced Placement (AP) Physics teacher at Auburn High School in Rockford, Marianna Ruggerio knows that physics is a gateway for careers in science, technology, engineering, and math (STEM). Yet only 15 to 25 percent of students in Ruggerio's region graduate with a physics course on their transcripts.

Like many other high school physics teachers, Ruggerio is the only physics faculty in her school, but thanks to the Illinois Physics and Secondary School Partnership (IPaSS) program, she has a network of peer support.

"I'm the 'only' in my building, so this program allows me to have an incredible, solid network of physics teachers, many of whom have a similar set of values and beliefs around teaching and learning," says Ruggerio, who was invited to join the first cohort of IPaSS teachers in 2020. "At that time, everything was virtual, and all of the resources were invaluable to running my AP Physics C course with all of the fidelity of a normal experience."

Ruggerio saw Morten Lundsgaard, coordinator of physics teacher development for Illinois Physics, run a workshop on the iOLab wireless laboratory device in 2018 at the fall meeting of the American Association of Physics Teachers (AAPT). She was intrigued enough by the device to spend a day visiting a Physics 101 lab at Illinois to learn more about improvements in lab instruction at her alma mater.

"For a long time, I have been frustrated by what seems like a chasm between university and high school physics that is bridged only by a rudimentary rope bridge," she comments. "This program seemed like exactly the kind of partnership that could strengthen both communities."

Ruggerio now uses iOLab devices, online lectures, and course materials developed at the university with her students. This introduction to university curricula at the high school level helps bridge that gap between high school and college physics education, she says.

"Using the iOLab has also allowed me to focus on more complex relationships and the actual physics rather than wrestling with technology logistics," she adds. "This has led to more sophisticated work in my regular-level classes as well. I've also had the wonderful opportunity to serve as a teacher leader by providing support and sharing my ideas with fellow teachers across the state."

As one of the first IPaSS teaching fellows and the winner of the 2021 Illinois Outstanding Physics Teacher of the Year award, presented by the Illinois Section of the AAPT, Ruggerio conducts IPaSS workshops during summer training sessions. At regular online meetings, she offers teaching strategies, curriculum ideas, and general support to other IPaSS teaching fellows. It's the kind of interaction among teachers that school districts encourage, but is difficult to find, given the scarcity of physics teachers, she says.

"For teachers, IPaSS is a network of support for one another in a field where we are very isolated," shares Ruggerio. "I also believe the university benefits. They get to see our work in action, rather than theorizing or focusing on one particular facet of the craft."

Opposite page, pictured left to right, IPaSS teaching fellows Marianna Ruggerio, Jamie Piper, Matt Bonges, Nathan Rassi, and Eric Potter debate the results of their iOLab experiment.

Right, IPaSS teaching fellows Jacob Rangel (right) and Brendan Aydt work on a physics problem during a summer workshop. Photo courtesy of Maggie Mahmood, Illinois Physics

Student engagement, quality teaching: IPaSS fellow Jacob Rangel

Jacob Rangel teaches physics in both English and Spanish at Curie Metropolitan High School, a predominantly Hispanic neighborhood school on the southwest side of Chicago. He also teaches Advanced Placement (AP) Physics.

He's a young teacher who now has four years of experience under his belt and two years as a participant in the Illinois Physics and Secondary Schools Partnership (IPaSS) program.

He learned about IPaSS when it was still being developed by Maggie Mahmood, the coordinator of secondary education partnerships for Illinois Physics, and Illinois Physics Professor Emeritus Mats Selen.

"They [Mahmood and Selen] were my graduate advisers during my time as a graduate student at UIUC, and Maggie was actively working on the grant-writing process for the IPaSS program," recalls Rangel, who earned both bachelor's and master's degrees from Illinois Physics. "Once the program was up and running, I asked to join and was welcomed into the group."

Rangel says he sought out IPaSS because he wanted to provide his students with access to cutting-edge technologies and laboratory equipment that generally are not available at Curie Metro High. He began using the iOLab hand-held wireless laboratory devices with his classes and noticed the impact on his students almost immediately.

"The iOLabs have helped make my class more hands-on, interactive, and engaging," comments Rangel. "Many of my students struggle with the math component of physics, and the iOLabs help bridge the gap between conceptual and mathematical learning in physics."

According to Rangel, the IPaSS program and the use of the iOLabs can transform how physics teachers present and structure their lab activities. The program stresses an inquiry-based approach to teaching physics, and the iOLabs encourage students to conduct real experiments, think for themselves, and develop problem-solving abilities.

"It's a way to bring physics to life for students," Rangel adds. "Rather than just telling them things, they are discovering for themselves. They are more interested, and they are not doing the work just because I said they have to."

Rangel remembers the time a student came to him with questions after a two-day activity that involved taking measurements with the iOLabs.

"This student genuinely asked me what physics is," he says. "After I explained that everything we had been doing was physics, she said, 'This stuff is cool. Can we do more of it?' It was the first day I saw her really interested in the material and not simply doing the work to get it done.

"The IPaSS Program has provided me with resources I would not otherwise have had. It's been a huge aid in improving the quality of my teaching and student engagement," he adds.

A taste of college-level physics: IPaSS fellow Jill McLean

As a 28-year veteran teacher at Champaign Centennial High School, Jill McLean has seen many of her physics students, including Advanced Placement (AP) Physics students, go on to study physics at UIUC, about four miles to the east of her high school campus.

“I was interested in sharing actual materials from UIUC with my AP students, because so many attend Illinois,” says McLean, herself an Illinois Physics alumnus. “They get to have the same experiences as in a first-semester class at Illinois. They can earn AP credit and measure themselves at the college level.”

McLean, who teaches Physics, AP Prep Physics, AP Physics, and Mechanics, joined the first cohort of teachers in the Illinois Physics and Secondary Schools (IPaSS) program in 2020, after receiving an email inviting her to participate. She is the only full-time physics teacher at Centennial, which has a student population of about 1,400. And often teachers helping her in the classroom do not have a physics background.

During the pandemic, McLean was able to keep her students engaged by giving them the handheld wireless laboratory devices called iOLabs. The iOLabs allowed her students to design their own experiments at a time when getting together as a class was impossible. IPaSS also introduced McLean to high school physics teachers across Illinois, who regularly share ideas and offer support.

“The most useful thing has been meeting and collaborating with so many other physics teachers throughout the state,” she says. “I really learn a lot from others, but also from helping others. As a veteran teacher, it’s nice to share what I’ve done successfully to help other teachers.”

According to McLean, introducing her students to the iOLab has transformed physics lab work for her students. They can design their own experiments and have more control of their classroom experiences.

“Learning to use this technology and learning how to set up and conduct experiments has probably had the biggest impact on my students,” she says. “They come up with the experiments. They look at the data. It’s real science, and they are doing it.”

Diversity in science is important, notes McLean, and tackling that problem means giving students from under-resourced high schools the chance to get a high-quality physics education. The tools and resources provided through the IPaSS program give students across Illinois the opportunity to experience a hands-on physics curriculum similar to a college curriculum, she adds.

Like so many other IPaSS teachers, McLean values the chance to collaborate with her peers, share ideas and experiences, and use her own expertise to help other teachers solve problems, cope with challenges, and develop into better teachers.

“The collaboration in general has been so useful,” McLean concludes. “Physics and science teachers are really good at stealing ideas from each other.”

Opposite page, IPaSS teaching fellow Jill McLean (seated, center) collaborates on an iOLab activity with Illinois Physics Professor Tim Stelzer (standing, center), IPass coordinator Maggie Mahmood (standing, right), Illinois Physics graduate student Devyn Shafer (standing, left), and IPaSS teaching fellow Rodger Baldwin (seated, left). Photo by Michelle Hassel, University of Illinois Urbana-Champaign

Right, IPaSS teaching fellow Kunal Pujara participates in a group discussion during a summer workshop. Photos by Michelle Hassel, University of Illinois Urbana-Champaign

New tricks for an 'old dog': IPaSS fellow Kunal Pujara

Now in his 29th year of teaching, Kunal Pujara could have chosen to cruise into retirement. Instead, he chose to become involved with the Illinois Physics and Secondary Schools Partnership (IPaSS) program.

"I learned so much over the summer and benefitted so much from my mentors that I feel like a first-year teacher," says Kunal, who teaches Honors Physics and Advanced Placement (AP) Physics at Highland Park High School in Chicago's north suburbs.

A former student nominated Kunal for IPaSS. He applied and was accepted into the third cohort of teachers in Spring 2022. First, he attended in-person workshops on campus in June and August. These workshops connected him with other teachers and introduced him to IPaSS

A former student nominated Kunal for IPaSS. He applied and was accepted into the third cohort of teachers in Spring 2022. First, he attended in-person workshops on campus in June and August. These workshops connected him with other teachers and introduced him to IPaSS teaching resources, including the iOLab handheld wireless lab system, student engagement through whiteboarding, and the concept of flipped learning, where students familiarize themselves with concepts by watching pre-lectures as homework and then apply what they've learned in group classroom activities.

"I didn't realize what I was missing until I joined this program," says Pujara, who has incorporated iOLab activities, smartPhysics homework assignments developed at Illinois Physics, whiteboard engagement, and flipped classroom activities into all his AP and Honors Physics classes. "All of these are new ways of approaching topics and I believe they engage students better than the ways I'd been teaching for the past 28 years."

Pujara teaches at a school where the vast majority of students are college bound and motivated to do well in school. Nevertheless, by updating his teaching practices and adding new tools and resources to the curricula, his students are more engaged and more involved in the learning process, he notes.

"The iOLabs and the resources and ideas for improved teaching really lend themselves to student-led design in the classroom," shares Pujara. "That is so important for creativity and exploration, and it doesn't happen in a structured, cookbook-style lab."

A self-described "old dog" veteran teacher, Pujara says his primary motivation for joining the IPaSS program is to become a better teacher. He looks forward to continued growth during his four years in the program, along with collaboration and building relationships with some of the best high school physics teachers in Illinois.

He considers himself lucky to have Marianna Ruggerio—a teacher from the first IPaSS cohort who was named the 2021 Illinois Outstanding Physics Teacher of the Year by the Illinois Section of the American Association of Physics Teachers (AAPT)—as one of his mentors and collaborators.

"I am a big fan of Marianna, and she has taught me so much in just a short time," he says. "I look forward to her mentorship and working with her and other cohort mentor teachers in the IPaSS program over the next four years." ■

HANS FRAUENFELDER
1922–2022

PETER GUY WOLYNES
Rice University Bullard-Welch Foundation Professor of Science and Professor of Chemistry

Hans Frauenfelder, a physicist whose landmark contributions spanned from elementary particles to biomolecules, died at his home in Tesuque, New Mexico on July 10, a few weeks short of his 100th birthday. Having come to Illinois Physics as a postdoctoral fellow in the 1950s, Frauenfelder stayed on as a faculty member, eventually becoming one of its most distinguished professors and a permanent member of the Center for Advanced Study, UIUC's highest recognition of scholarly work. After officially retiring from UIUC in 1992, at age 70, Frauenfelder took up a position as a staff member at the Los Alamos National Laboratory (LANL). In 1997, he became the director of the laboratory's Center for Nonlinear Studies, which he led into complexity science. In 2004, he moved to the Theoretical Biology and Biophysics Group at LANL, where he continued to work, publishing his last paper in 2017.

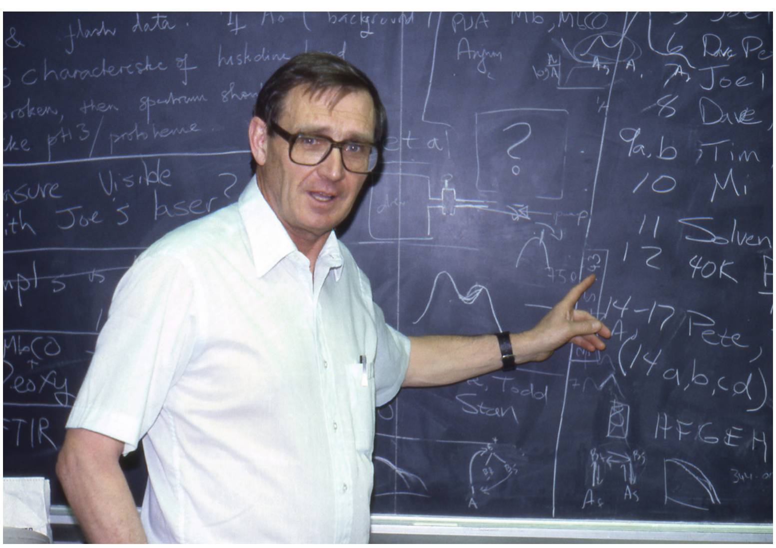
Like Einstein, Frauenfelder was trained at the *Eidgenössische Technische Hochschule* (ETH) in Zurich, Switzerland. Nominally under the supervision of Paul Scherer, a student of Peter Debye, Frauenfelder pursued several fundamental problems merging nuclear and solid-state physics. By studying the capture of K-shell electrons in radioactive thin films, he was able to show that after an electron was absorbed and a neutrino was emitted (but not directly detected), the emitting nucleus recoiled, thereby establishing the reality of the neutrino in a new way. In Frauenfelder's PhD thesis, the same technique, while being unable to establish the neutrino rest mass, did prove capable of giving fundamental information on how atoms moved on solid surfaces. At the ETH, Frauenfelder also studied the correlation between successive decays of radioactive nuclei. This correlation is perturbed by the nucleus's condensed phase environment, and Frauenfelder showed how to use the so-called perturbed angular correlation to study condensed phase dynamics.

In Urbana, using such correlations, Frauenfelder's group became one of several experimental groups that were able to confirm within the same short timespan Yang and Lee's idea of parity violation in the weak interaction, which later won them the Nobel Prize. Symmetry remained one of Frauenfelder's lifelong passions, and he later probed for parity violation in the strong interactions in nuclei. For a time, Frauenfelder's experiments also held the record for establishing limits on the lifetime of the proton, which some modern theories suggest should be able to decay, but so far appears to be completely stable.

Frauenfelder was among the first to appreciate the importance of the Mössbauer effect and championed Mössbauer, who later won a Nobel Prize. The Mössbauer effect led Frauenfelder into the world of biochemistry. Collaborating with Irwin Gunsalus, a member of the UIUC Biochemistry Department, he showed how the

Mössbauer effect could be used to characterize the dynamics of heme proteins. He quickly appreciated the limitation of existing biochemical experiments performed at near room temperature, which could not address very fundamental mechanistic questions about how proteins work. He studied a seemingly very simple biochemical reaction, the binding of a molecular ligand (carbon monoxide) to myoglobin. At room temperature, this recombination event seemed very simple, but surprises awaited when Frauenfelder explored the reaction at cryogenic temperatures. At the lowest temperatures, the reaction still occurred with no apparent thermal activation energy. This was the clearest proof that a chemical reaction could occur exclusively by quantum mechanical tunneling. More surprising, at higher temperatures, the reaction required thermal activation, as expected, but the kinetics of recombination manifested a wide distribution of activation energies. This was the beginning of the energy landscape concept: a protein molecule does not have a unique structure, but ranges over many such structures with widely differing energies; the dynamics of moving between different structures determines the protein function. Later, with Petsko and Tsernoglou, Frauenfelder explored protein X-ray crystallography at a range of low temperatures and showed the dynamics at room temperature was frozen in, proving the existence of a landscape. These results, along with the emergence of molecular-dynamics computer simulations, after considerable debate in the biology community, revolutionized how we look at biomolecules, seeing them now as complex systems.

In taking up the problems of biology, Frauenfelder insisted that his goal was to find new physics, not just to bring technical tools to biology. This insistence, along with his leadership, inspired many young physicists to take up this quest and has led to the emergence of a new field of “biological physics” as a branch of the sciences of complexity.



Frauenfelder’s scientific contributions were recognized in many ways. He received the American Physical Society’s Max Delbrück Prize for Biological Physics in 1992. He was elected a member of the U.S. National Academy of Sciences, the American Academy of Arts and Sciences, the American Philosophical Society, and the German National Academy of Sciences (*Deutsche Akademie der Naturforscher Leopoldina*). He was elected a foreign member of the Royal Swedish Academy of Sciences. He received honorary doctorates from the University of Pennsylvania and the University of Zürich.

Frauenfelder is also remembered as an inspiring teacher, both in lectures and in his mentoring of graduate students, postdocs, and younger faculty, who have also become leaders in physics. With Ernest Henley, a theorist, he wrote the textbook, *Subatomic Physics*, which through several editions, has become a mainstay of advanced undergraduate instruction across the country.

Frauenfelder is survived by his wife of 72 years, Verena, along with his son Ulrich, a now-retired professor of psychology, and his daughters, Katterli, who is a movie producer in Los Angeles and Anne, who is a teacher in Portland, Oregon. He also had four grandchildren and two great-grandchildren. ■

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