FALL 2024

ILLINOIS PHYSICS

Condensate

The News Magazine of the Department of Physics

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

PHYSICS.ILLINOIS.EDU

Contributors

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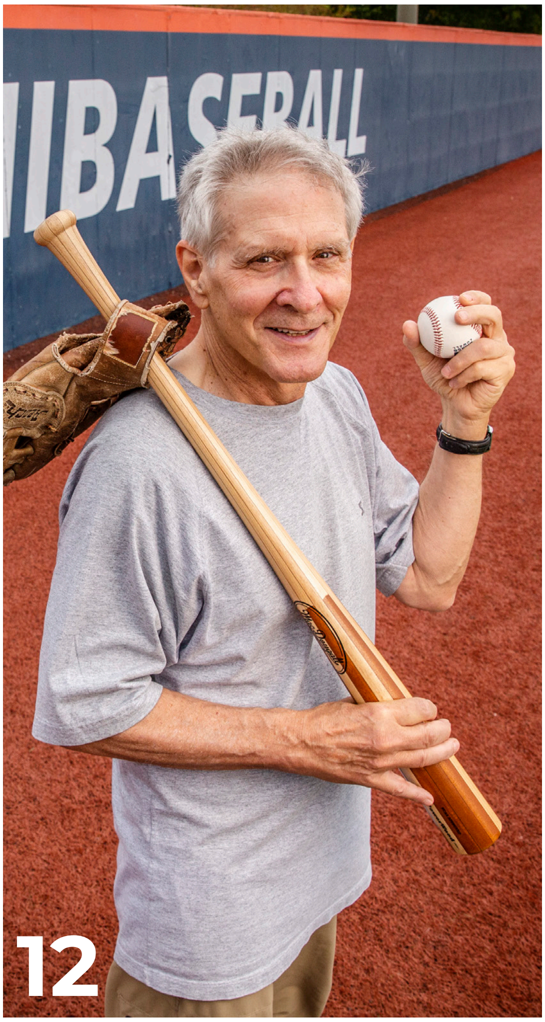

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The Grainger College of Engineering
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

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

Stay in touch!

To get our latest news, please update your contact information at

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Illinois Physics Condensate

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WELCOME

FROM OUR

Department Head

MATTHIAS GROSSE PERDEKAMP

Dear Physics Family,

This semester, we welcomed the inaugural class of 45 students to our CS + Physics undergraduate degree program. Combined with our 564 physics bachelor's students, our undergraduate program is now among the largest in the country—only UC Santa Barbara has comparable numbers. We also admitted 76 graduate students to our doctoral program, now the largest in the nation with 359 students. The program recently broke a barrier: we have 100 women Ph.D. students. For comparison, of the 240 doctoral programs in the country, fewer than 50 have more than 100 graduate students. The department is lively and colorful. And we speak many languages: 50 percent of our graduate students and about 40 percent of the incoming undergraduate class are international students.

Sadly, the hopeful beginning to the semester was overshadowed by the unexpected death of our dear friend and colleague, Emeritus and Research Professor Dale Van Harlingen, who had served 12 years as department head. It was a difficult loss. Dale is remembered fondly for his dedication, vision, and service-style leadership that maintained and contributed to the department's stature as a world leader in physics research and education. Our thoughts are with Dale's family and friends.

Faculty and staff news

I am grateful to our faculty and staff for maintaining our high standards through this period of growth and change. This is especially impressive given that our support staff has not grown. Meanwhile, our enrollment numbers are breaking records. Our hardworking staff also sustains a large and dynamic research program and has met the demands of increased faculty hiring, purchasing, travel reimbursement, and remodeling projects.

The face of our faculty has changed considerably: a quarter of our faculty has retired in the last six years, including Jim Eckstein and Russ Gianetta this year. At the same time, we have welcomed Pengjie Wang from Princeton University, Rafael Fernandes from the University of Minnesota, Jong Yeon Lee from the Kavli Institute

at UC Santa Barbara, and Hector Okada DaSilva from the Albert Einstein Institute in Potsdam. We are also hosting two scholars at risk: Elena Koptieva from Ukraine and Sami Muslih from Al-Azhar University.

The caliber of our new faculty is reflected in the near doubling of our department's research revenue to $40.7 million in FY24. Many of our new hires are active members of our newest research centers, the Illinois Center for Advanced Studies of the Universe (ICASU) and the Illinois Quantum Information Science and Technology Center (IQUIST). ICASU comprises 44 core and affiliate faculty members, 88 graduate students, and 44 postdocs from five campus units. Since its founding, ICASU faculty have successfully solicited nearly $57 million in new grants. IQUIST numbers 68 faculty members and senior research members and affiliates, more than 200 graduate students, and more than 45 postdocs from 11 academic departments and interdisciplinary research centers on campus. It has brought in over $160 million in active grants.

Many of our faculty members have recently been recognized for their excellence. Most notably, Chen-Yu Liu was elected to the National Academy of Sciences, and Charles Gammie and Paul Selvin were elected to the American Academy of Arts and Sciences. Gammie was also named the university's Ikenberry Endowed Chair. Vidya Madhavan was named a Donald Biggar Willett Professor in Engineering. Taylor Hughes is now an APS Fellow, and Eduardo Fradkin was awarded the Eugene Feenberg Memorial Medal. Aleksei Aksimentiev and Brian DeMarco were named Bardeen Faculty Scholars, Christopher Weaver has been appointed a Fortner Scholar, and Fahad Mahmood and Yoni Kahn were named Compton Scholars. Jake Covey recently was awarded the NSF CAREER Award, having earlier obtained career awards from the DOE, the Air Force, and the Navy.

Much help from our friends

I am thankful for several significant financial contributions that have strengthened the department's ability to invest in the future. When we renamed the ICMT the Anthony J. Leggett Institute, both the Office of the Provost and the Office of the Dean agreed to fund in perpetuity the Anthony J. Leggett Postdoctoral Fellowship. The first fellow, Kyung-Su Kim, joined us this year after finishing his Ph.D. at Stanford. Furthermore, Illinois Grainger Engineering has restructured the department's budget to resolve its longstanding operational deficit.

We are grateful for the continued generous support of our Illinois Physics alumni and friends. Among the many, I would like to extend special thanks for two generous estate gifts. Alumnus Bob Uyetani's gift will fund the Anthony J. Leggett Professorship in Physics, and alumnus Dr. Paul Parks has given $4 million to initiate the Dr. Paul Parks Physics Laboratory Support Fund.

These are exciting times in the field of physics, and our department is poised to continue its legacy of seminal contributions to the global scientific endeavor. If your travels take you to the Urbana area, I hope you'll get in touch and plan a visit. You will always be welcomed home at Illinois Physics!

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 leading physicists are working on.

KARIN DAHMEN

THEORETICAL CONDENSED MATTER PHYSICS

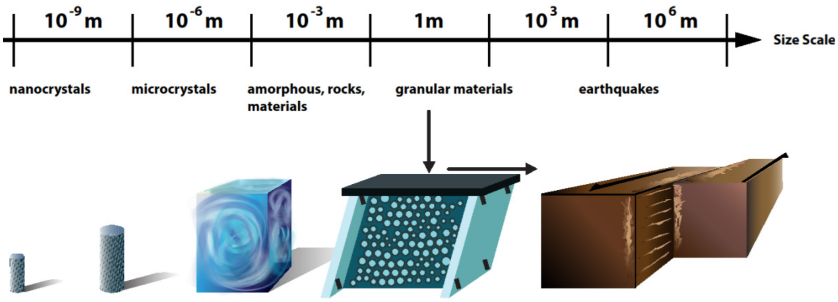
Illinois Physics Professor Karin Dahmen
Photo by Fred Zwicky, University of Illinois Urbana-Champaign

My research group maintains wide-ranging interests in non-equilibrium dynamical systems, including pattern formation, memory in materials, and avalanches in homogeneous and inhomogeneous systems having quenched disorder. We are especially interested in recent experiments that show intriguing far-from-equilibrium phenomena.

In physical systems consisting of a large number of atoms or molecules, statistical fluctuations often become small and consequently the signals we perceive are mostly averages over the complex microscopic behavior of the system. However, large classes of systems show fluctuations also on macroscopic scales. We extract information from the statistics of the fluctuations to predict aspects of the systems' future behavior.

For example, many systems respond to small forcing with sudden pops, snaps, or crackles, which often span many orders of magnitude in size. Examples range from the atomic to the tectonic (see figure). They include daily experiences such as the crackling noise of milk invading Rice Crispies and devastating events, such as earthquakes, landslides, power-grid blackouts, and stock-market crashes. At the scale of systems studied in laboratories, they include slips in crystals, glasses, and densely packed granular materials (such as powders, sand, or grain), magnetization avalanches in magnetic materials, resistivity fluctuations in superconductors, decision-making processes, and neuron-firing avalanches in the brain. On astronomical scales, they may include solar flares and the dimming events of Tabby's star and other stellar objects.

Our group aims to explain the complex response of these systems to slow forcing, to predict their future behavior, and to discover fundamental connections between different scales and systems. This knowledge is crucial for nondestructive testing and for transferring results from one system to another and from one scale to another (e.g., from lab scales to earthquakes). To achieve these goals, we employ tools from condensed matter physics, statistical physics, computational physics, biophysics, geophysics, astrophysics, and mathematical physics, especially the theory of phase transitions and the renormalization group. We are most grateful to our experimental collaborators, who generously share their data with us to see if our models' predictions match reality.



Sketch of size scales of samples, spanning 12–13 decades in length and showing surprisingly similar slip-avalanche statistics under slow shear, in agreement with our model predictions [from Scientific Reports 5, 16493 (2015)].

Research in the Dahmen group is supported by the U.S. Department of Energy and Sandia National Laboratories' Directed Research and Development program, Project No. 233080; and by the National Science Foundation under Grant Nos. 2123781 and 2014027. Additional support comes from the University of Illinois Campus Research Board. 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.

JOAQUIN VIEIRA
OBSERVATIONAL COSMOLOGY

My research aims to understand the physical origins of our universe. To this end, I develop instrumentation and conduct observations to study how the early universe and the first galaxies formed and evolved over cosmic time.

Early in my career, as a graduate student, I helped build the South Pole Telescope to study the cosmic microwave background (CMB). In the course of our work, we discovered a population of high-redshift and strong gravitationally lensed dusty starforming galaxies. That's a mouthful. More simply stated, there are galaxies in the universe's early history that formed stars at a prodigious rate but were completely enshrouded in dust and thus invisible at optical wavelengths of light. Averaged over the entire history of the universe, dust absorbs about half the radiation energy ever produced by stars and then reradiates in the infrared. Studying these galaxies in the infrared lets us see the hidden half of galaxy formation and evolution over cosmic time. In a happy coincidence, some of these galaxies perfectly align with a foreground galaxy, which magnifies them by gravitational lensing. First predicted by Einstein's general theory of relativity, gravitational lensing is a powerful tool in cosmology, serving to magnify the light from otherwise faint galaxies. When combined with the world's most powerful telescopes, gravitational lensing allows us to study these galaxies in unprecedented detail.

Illinois Physics Professor Joaquin Vieira poses in front of TIM's test launch at Fort Sumner in New Mexico in September 2024, conducted in coordination with NASA's Balloon Program Office. This flight tested TIM's payload systems in advance of the science flight from Antarctica, slated for 2026. Photo courtesy of Joaquin Vieira

My group has been using the Large Atacama Millimeter/Submillimeter Array (ALMA) and the James Webb Space Telescope (JWST) to do just that. We conducted the first spectroscopic redshift survey with ALMA and detected dusty gravitationally lensed galaxies out to a redshift of $z=6.9$, where z represents the fractional change in wavelength due to the expansion of the universe. The galaxies we observed date to when our universe was less than a billion years old—the universe is now 13.8 billion years old. We have also studied water and lately even rare isotopes of carbon and oxygen in these galaxies, so we are literally doing chemistry in the early universe. More recently, my group was among the first to observe with JWST, and we have been studying dust and the stellar populations in these distant galaxies.

I am the principal investigator of a NASA experiment called the Terahertz Intensity Mapper (TIM), designed to make 3D maps of the universe. TIM comprises a novel camera attached to a 2-meter-diameter telescope, which we will fly by helium balloon above Antarctica to map the distribution of ionized carbon in the redshift range of $z=0.5$–1.5 (that's when the universe was from 4 to 8 billion years old). We plan to study the history of cosmic star formation with this instrument, which also serves as a prototype for a larger future NASA space mission.

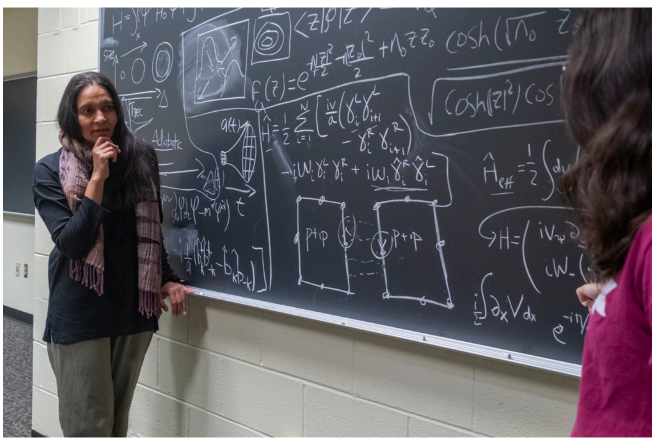
On even longer time scales, I am involved in the next-generation CMB experiment, called CMB Stage-IV (CMB-S4), which aims to constrain the epoch of inflation in the first instants of the universe. Along the way, we will do a lot of other exciting science, including studying how the millimeter sky changes on short time scales—from minutes to months. In this research, we'll tend to look at nearby objects, such as stars in our own galaxy. This is fun for me. It's a rare and exciting opportunity to think about objects and processes in the nearby universe.

Research in the Vieira group related to the Terahertz Intensity Mapper experiment is supported by NASA under Grant No. 80NSSC24K1881. Additional funding for research related to the South Pole Telescope comes from the National Science Foundation under Grant Nos. 1852617 and 2332483. 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.

SMITHA VISHVESHWARA

THEORETICAL CONDENSED MATTER PHYSICS

Suppose you knew how an individual behaved, be it an electron, a grain of sand, or a child on a soccer field. Now ask yourself how a collection of such individuals who are strongly interacting with each other would act as a whole. It's a challenging question. Collective behavior—be it the coordinated dance of electric current in metals, dunes changing shape in a desert, or the creation of a stadium wave—may bear no resemblance to the behavior of the individual. As condensed matter physicists, it is the collective behavior that we study (though rarely in the mind-boggling human realm), and a good fraction of us add the mysteries of quantum physics to the mix. As a pen-and-paper theorist, I equally love letting imagination run unfettered by reality and working with experimental colleagues who show us the magic of quantum matter that can actually be realized.



Illinois Physics Professor Smitha Vishveshwara (left) meets with graduate student Ellen Gulian at the Anthony J. Leggett Institute for Condensed Matter Theory. Photo by Bill Wiegand for Illinois Physics

The principles of condensed matter physics have enabled my group and collaborators to explore a range of phenomena from the atomic to the cosmic scales, both in and out of equilibrium. Quantum-ordered states of matter traverse these scales. In some cases, the order is local, as in magnets where large collections of spins primarily point in the same direction, or in superconductors and superfluids. In other cases, the order is hidden, as in quantum Hall systems, hailed for their ability to measure a combination of fundamental constants of Nature, or other topological states that have recently come into the limelight. Of the various features we study in these states, one of my favorites involves fractionalization. In strongly correlated systems—quantum Hall fluids or nanotubes, for instance—collective behavior gives rise to quasiparticles that are composed of the underlying soup of particles but appear nothing like them. An orthogonality catastrophe, as it is dramatically referred to, the quasiparticles could have a fraction of an electron's charge or quantum statistics different from those of the fermions and bosons composing the universe. Such quasiparticles, known as anyons, could bear good promise for topological quantum computation. After decades of work, experiments have recently detected these anyons, leading our community to explore these quasiparticles with renewed verve.

In another line of study, we are investigating superfluids, specifically Bose-Einstein condensates in shell-shaped geometries. In the past decades, experimentalists have mastered creating the coldest spaces in the universe right here on Earth, to host condensates. Now they are doing so aboard the International Space Station. Among these experimentalists, our own experimental collaborators have succeeded in creating these ultracold shell condensates away from gravity's grip. In addition to the thrill of these studies, I have had the privilege of working with my parents, both scientists. With my mother, we have applied principles of percolation (yes, also common to coffee-making) to understand protein structure, lately focusing on the spike protein associated with COVID-19. In my correspondence with my late father, a general relativist, he inspired me to draw parallels between black-hole-based gravitational waves and condensed matter physics. A popular-science book we began on quantum physics and relativity, written as letters between father and daughter, is slated to be published in January 2025.

As another major chapter, I am now on a euphoric journey, collaboratively melding my two passions—physics and the arts. Works that we scientists and artists have created include the theater piece *Quantum Voyages*, the circus performance *Cosmic Tumbles, Quantum Leaps,* and the short film *Solaria*. In a project-based interdisciplinary course that I developed and that is now part of our curriculum, *Where the Arts Meets Physics*, students unleash the imagination and give rise to marvelous creations. Our communities have celebrated physics-art-culture confluences by organizing art-science festivals and outreach events, including special programming with the American Physical Society; big festivities are in store for the 2025 International Year of the Quantum. My collaborators and I have now come together on campus as CASCaDe, the Collective for Art-Science, Creativity, and Discovery, etc.

Research in the Smitha Vishveshwara group is supported by NASA under Jet Propulsion Laboratory Research Support Agreement No. 1699891; and by the National Science Foundation under Grant No. DMR-2004825. 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.

HAMIDEH TALAFIAN

PHYSICS EDUCATION RESEARCH

I am a postdoctoral research associate who earned my Ph.D. in 2020 in educational leadership and learning technologies with a concentration in STEM education. Currently, I work with the physics education research group on multiple projects aimed at enhancing the quality of physics instruction in both high schools and higher education. My research integrates STEM education, learning sciences, educational psychology, and educational technologies. Over the past decade, I have designed and evaluated K–12 physics and chemistry curricula, facilitated professional development for teachers, developed informal learning programs for minoritized students, and leveraged digital technologies to enhance science instruction.

One of my significant projects involves working with the Illinois Physics and Secondary Science (IPaSS) program, a partnership between Illinois Physics and high school teachers across the state. The IPaSS community supports teachers in diverse geographic, ethnic, and cultural settings by facilitating the design and implementation of high-quality, university-aligned instructional materials. My research examines how professional development structures and mentoring support novice and out-of-field teachers in implementing reform-based instruction. Our findings highlight the effectiveness of a responsive professional development model, where teachers actively participate in collaborative problem-solving sessions and co-design workshops. This approach shifts teachers from passive knowledge recipients to socially active learners, fostering inquiry-oriented teaching identities and ultimately empowering students with greater agency in experimental design.

Addressing the nationwide shortage of physics teachers is another critical focus of my work. Through the Noyce Teacher Scholarship program, I investigate factors that attract or deter undergraduates from pursuing careers in the physics teaching profession. Despite being one of the world's leading physics departments, we currently produce very few physics teachers—a trend mirrored across the country. The shortage leads to understaffing, assigning physics courses to teachers without appropriate backgrounds, or even eliminating physics from curricula, particularly at smaller schools. In my research, I design and implement robust support structures within the physics department to create clear and sustainable pathways for students interested in high school teaching careers. These structures include fostering peer-support communities, organizing regular monthly meetings, and inviting guest speakers to share real-world insights and experiences. Additionally, I introduce and promote retention initiatives, such as the IPaSS program within our department, which provides ongoing mentorship and resources to guide and support in-service teachers throughout their journey. These efforts aim to build a comprehensive and research-driven framework that empowers future educators and ensures their long-term success in the field.

Illinois Physics postdoctoral researcher Hamideh Talafian collaborates with Illinois Physics IPaSS coordinator Maggie Mahmood in Loomis Lab. Photo by Bill Wiegand for Illinois Physics

Another key focus of my work is enhancing the quality of introductory physics courses for both physics majors and non-majors. These courses serve as critical gateway experiences for engineering students, making their improvement essential to supporting student success and retention. We are enhancing the occurrence and quality of students' interactions in these courses by introducing whiteboards as shared displays and improving TA training to foster better group interactions during discussions. While reform-based practices have made strides, there is still significant room for improvement in the implementation of collaborative problem-solving exercises. My research focuses on developing students' collaborative, cognitive, and metacognitive skills and equipping TAs to support these skills. This approach better prepares students for collaborative learning and problem-solving, both in academic settings and future professional environments.

The ultimate goal of my research is to foster a more robust and equitable physics education landscape. My research bridges theory and practice, contributing to sustainable solutions that advance science teaching and learning in diverse educational settings.

Hamideh Talafian's research is supported by the National Science Foundation under Grant Nos. 2010188 and 2345132. 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 agency.

Photo courtesy of Eun-Ah Kim

ALUMNA EUN-AH KIM:

AT THE BRINK IN QUANTUM COMPUTING

BILL BELL *for Illinois Physics Condensate*

Work by Eun-Ah Kim, an Illinois Physics alumna and professor at Cornell University, helps prove the feasibility of using non-Abelian anyons in quantum computing.

Professor Eun-Ah Kim has been keeping her eye on anyons for more than two decades. While completing her doctoral degree with Illinois Physics Professor Eduardo Fradkin in the early 2000s, she explored how anyons "see" each other. Like other quasiparticles, anyons are collections of fundamental subatomic particles that can be grouped and treated as a single particle. However, unlike fundamental particles, exchanging positions between a pair of anyons changes the state of the whole system.

"Anyons are a very intriguing notion," explains Kim, who is a professor at Cornell University. "There isn't anything that more dramatically speaks to the fact that when many bodies interact, something totally new can happen."

"Something totally new" can have very useful applications in quantum computing. Groups of anyons, for example, can serve as a qubit—the quantum-mechanical entity used as the basic unit of calculation in quantum computing.

The problem is that something totally new only happens under very particular circumstances that are difficult to create.

"I was always interested in seeing beautiful ideas manifested in the lab," says Kim. But during her doctoral studies, "how hard the experiments were going to be was beyond my grasp. And beyond the field at the time. It started to dawn on me, and to the field, that these things are very difficult to control to the degree you want to control. We started to do the engineering to build experiments that could capture the behavior of anyons and overestimated how much we could do at the time."

According to Kim, the time now seems to have come. "We appear to be at the brink of the control we need."

Kim, then-postdoctoral researcher Dr. Yuri Lensky, and colleagues at Google published a pair of papers in 2023. The first outlined a theoretical framework for using bulk anyons to encode a logical qubit and braid them to do a gate operation (that is, the switching from one state to another that is the basis for all digital and quantum computing). The second, published in *Nature*, implemented that protocol using what are known as non-Abelian Ising anyons for the first time.

After more than 20 years, this incredibly fruitful collaboration came together fast for Kim.

"From the outside view, it might have appeared I had moved on. But it is close to my heart, my first love. I was waiting for the right opportunity. Any time it seemed like something might work—a new type of superconductor or topological insulator or a new platform—I would look at it and write a paper on it. But I was never convinced I would see braiding in the immediate future on any of the previous platforms," she says.

That changed when the leader of Google's Quantum AI efforts, Dr. Pedram Roushan, presented at Cornell in February 2022. The team was touting their development of a quantum processor based on superconducting qubits that could move and braid Abelian anyons. Thus, they could begin to verify long-established theoretical predictions about how the anyons behaved.

Kim believed that the processor could be used to encode a logical state non-locally among non-Abelian anyons and change the quasiparticles' logical state by braiding them. By May, Lensky had developed a proposal for how to do that work and was in Santa Barbara pitching the idea to Google Quantum AI.

"He developed a roadmap for how to make this all happen," says Kim. "He went there thinking that this would probably be too hard. But he talked to the experimentalists and came back so energized. 'Eun-Ah, this can be done!'"

Lensky and Kim then began implementing the experiment with a large team from the company. They released their successful results on arXiv.org in October 2022, and the journal articles were published in May 2023. Lensky has since gone to work at Google Quantum AI. Kim and her team continue to investigate the space as well, including the one additional logical gate that would be needed to build a fully functional universal quantum computer from non-Abelian anyons.

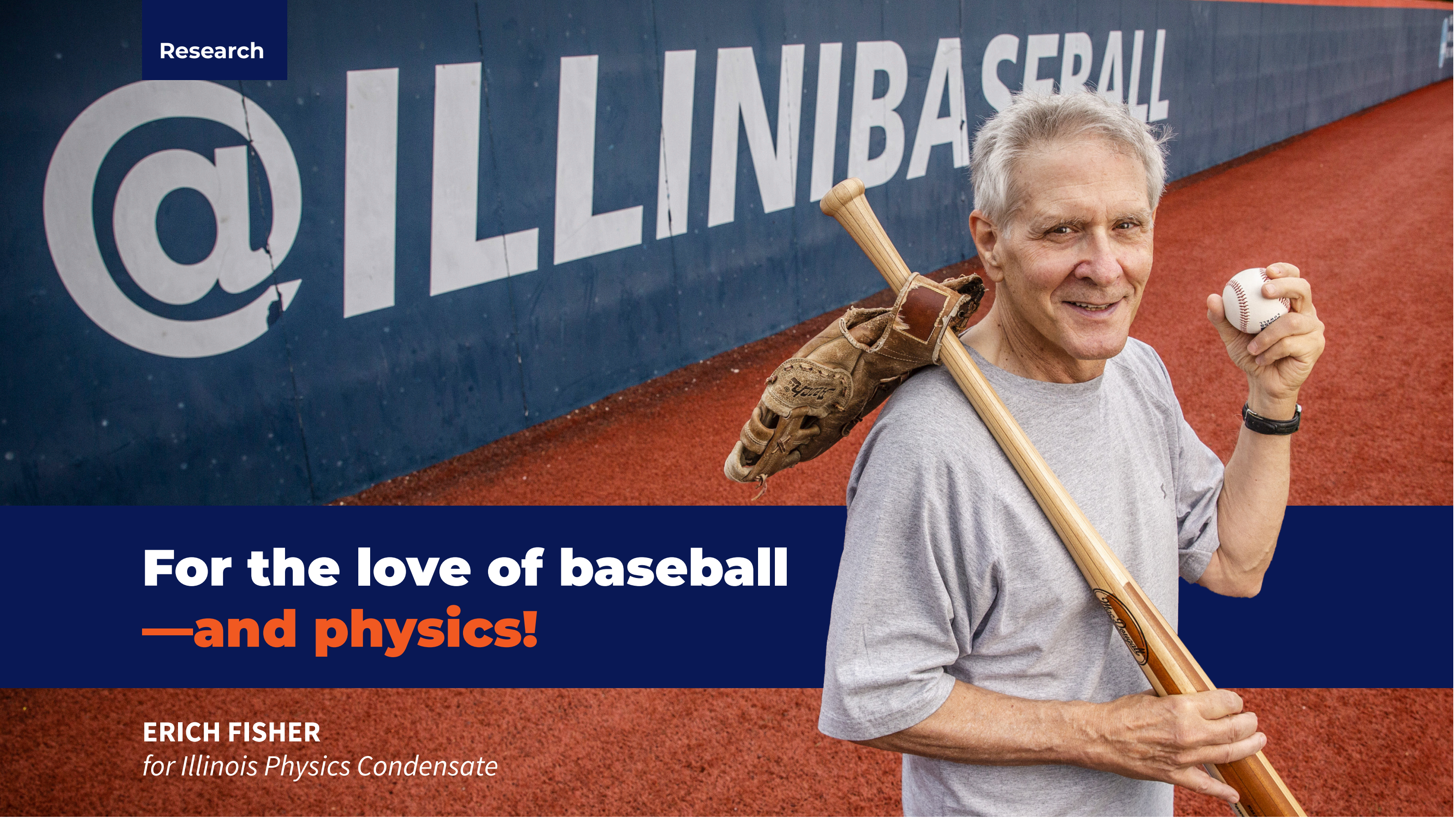
Kim says the experiments embodied her early work with doctoral advisor Eduardo Fradkin, despite the fact that "Eduardo is on the other end of the spectrum from engineering." His influential work in lattice gauge theory was central to the approach Lensky took to his "experimental playbook" for non-Abelian anyon braiding, especially in the efficient and robust protocols for moving anyons. Because of inherent noise and decoherence, the efficiency of the move was critical for reaching the intended outcome.

"We are trying to manipulate a very complex wave function by manipulating each physical qubit," Kim explains. "Each time we do something to a qubit, we are giving it time to decohere. The quality deteriorates with time. If we wanted to see what we were envisioning, we needed a robust and efficient way to get to the goalpost. Thinking about it from a gauge-theory perspective allowed Yuri to invent a protocol that was explicitly efficient and robust."

The work was also a terrific example of one of the reasons Kim became a teacher and mentor like Fradkin. Seeing Lensky return from his first visit to Google so excited "was pivotal for me in my career," says Kim. "I became more hopeful than ever that this dream of anyonic braiding done predictably can possibly come true. But it was also the moment of witnessing non-linear growth in a young person.

"Yuri became a different person after that visit. That's the reward of being in academia. Seeing talented young people and trying to find ways for their potential to burst. When I manage to help make that happen, it is so rewarding. I have always known that Yuri is really brilliant. But the world can only see results. He was able to connect that brilliance—what is really special about him—to an obviously valuable outcome. And that's what it takes for a young person to make it in the world." ■

Read about the quasiparticles that researchers are exploring as a basis for quantum computing—including a discussion of Eun-Ah Kim's work—in a December 2023 *Science* article, "The Quantum Phantom."



For the love of baseball —and physics!

ERICH FISHER
for Illinois Physics Condensate

Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

For 28 years, experimental nuclear physicist Alan Nathan has exercised his fascination with baseball by studying the physics of ball-bat collisions, baseballs in flight, and other intriguing physics questions. His work has benefitted the NCAA and the MLB and has helped to build a community around baseball data analysis.

Illinois Physics Emeritus Professor Alan Nathan's office sits in the middle of a nondescript hallway on the north side of Loomis Laboratory. Stopping in front of the door, I notice a Boston Red Sox sticker with his name on it. Those who aren't familiar with Nathan could guess at the very least that he likes the Red Sox. Entering his office, they'd quickly realize that "likes" is an understatement.

Everywhere you look is baseball memorabilia. To the left, wooden baseball bats lean against the wall under a chalkboard. To the right are a couple baseballs, one in a cup, one rolling around the desk. Hanging on the back wall is a 2018 Boston Red Sox World Series Championship banner.

And in the center is Nathan, sitting in his swivel chair with his legs crossed, his right arm propping his chin up from the arm rest. He confidently answers a series of questions he's probably been asked at some point before. It's not the first time he's been asked to communicate his expertise in the physics of baseball in an interview.

But before too long, one of my questions catches him off guard: "Why do you love the game of baseball?"

It seems an obvious enough question—Nathan's office decor clearly illustrates that he loves the sport. A lot. And everything he has shared points to the same thing: Nathan's passion for the game has driven him to research baseball in its closest details for over a quarter-century.

Nathan sits back in his chair and looks up at the ceiling, as though pondering a complex physics problem. He noticeably takes more time to craft this response.

"There's a tremendous amount of subtlety to the game of baseball," Nathan proffers. "It looks simple on the face of it. But if you try to explain the rules of the game to someone who's never watched it before, you realize how subtle it is. It's that subtlety that I find the most charming part about it.

"The fact that no two baseball stadiums are alike—I find that fascinating. The fact that you can do a statistical analysis on a particular question, and there's a lot of noise in that analysis—finding the signal among all the noise is an interesting kind of problem."

Solving these kinds of problems has made Nathan one of the leading experts in the country on the physics of baseball. Over the years, he has been interviewed countless times, for news articles, podcasts, video series, and TV.

The ball-bat collision

So how did it all begin? Before Nathan was heading Major League Baseball (MLB) research committees and working on baseball's most pressing physics questions, his research focus was experimental nuclear physics. He joined the faculty at Illinois Physics in 1977.

It wasn't until just before the autumn of 1996 that Nathan began researching the game's physics. The Rumford, Maine native reviewed work being done by early pioneers in the physics of baseball for a public lecture he gave as part of the Saturday Physics for Everyone series, titled "When Ash Meets Cowhide: The Physics of Baseball." Nathan had come across a seminal 1991 article by the late Purdue University Physics Professor Lonnie Van Zandt and was intrigued. He began reading the paper, all the while trying to derive the same results himself—which he was able to do, up to a point.

"I worked through all the details of the Van Zandt paper that treat the bat as a dynamic object that is capable of vibrations," Nathan recalls. "I then worked out an extension of his work to include the effect of those vibrations during the ball-bat collision."

In response to Van Zandt's paper, Nathan published an article accounting for energy conservation in the calculations.

"The initial energy of the ball coming off the bat must go somewhere, whether some of it goes into the ball, or some of it goes into the bat," explains Nathan.

Switching up the rules

Nathan's paper on ball-bat collisions garnered some public attention and led to Nathan being asked to serve on an NCAA committee tasked with establishing techniques for regulating the performance of aluminum bats.

"This involved understanding what makes aluminum bats perform better than wood bats, a problem well suited to a physics-based analysis," notes Nathan. "Once those differences are understood, coming up with a performance metric that can be used to regulate the bats is straightforward."

The committee met once or twice a year, and Nathan was for the most part working independently on his research into the matter, having an occasional phone conversation with other committee members on technical aspects here and there. It happened that the other members of the committee were taking a different tack than Nathan, one that wouldn't provide the clarity needed to write the NCAA regulations.

"They had already gone off in a certain direction, and the more I thought about it, the more I felt like that was the wrong direction. It's not that they were wrong, it was more that it was more complicated than it needed to be," Nathan remembers. "So, I steered them in another direction, proposing a new technique and some new analyses. And in the end, we advised the adoption of a different performance standard than the one that was used at that time. I wrote a detailed position paper on the subject and distributed it to the members of the committee. Ultimately, the committee thought it was a good idea."

The NCAA Baseball Rules Committee also thought it was a good idea. The new bats, which are now used in both the NCAA and high school baseball, must adhere to the so-called "BBCOR specification," which essentially makes aluminum bats perform similarly to wood bats.

"It seems to have stood the test of time," notes Nathan. "This work was done in 2008, and 16 years later, they're still using it."

A new data source and new connections

Another major vein of Nathan's research into the physics of baseball began in 2006, when the PITCHf/x pitch-tracking system was first introduced by MLB. The technology employed cameras to measure the full trajectory of every pitch, providing real data for analysis, such as velocity, position, and break.

The new technology piqued Nathan's curiosity. In fact, he was so intrigued by Sportvision's innovation that he reached out to the company. He discovered that the brains behind the system, Marv White, received his bachelor's degree from Illinois Physics in 1969. Nathan recognized that he wasn't the only one who had taken the initiative to study the data the pitch tracker was generating in an attempt to understand what the device was teaching them—and the new technology was calling for specialized input.

"There were all kinds of people during the 2007 season who were doing analyses of the data—I was doing some, and other people were doing some. That led me to the idea we should have a conference devoted to just this topic. I proposed the idea to Marv White, and he agreed to sponsor it," Nathan shares. "It was a great opportunity—I was talking to baseball people, including people from Major League teams."

Nathan attended the conference on the pitch tracker system over the four years it was held, publishing several articles in that time.

"They were absolutely superb experiences," Nathan says of his work with the pitch-tracker conferences. "These meetings were highly focused and just a lot of fun."

A proliferation of home runs

More recently, Nathan's physics-of-baseball research has focused on a question that had baffled MLB officials: what caused the increase in home run rates in the 2015 to 2019 seasons?

It was in 2017 that Nathan received a phone call from an unfamiliar area code. He didn't hesitate to answer—at this point, he was regularly getting inquiries from across the country. Never could he have imagined the opportunity being offered from the other end of the line.

Morgan Sword, MLB's senior vice president in charge of league economics and operations, was calling to ask Nathan to chair an MLB committee to investigate the increase of home runs over the previous three seasons.

"When they asked me if I wanted to chair the committee, it was like, 'Yeah, yeah, twist my arm more.' Yeah, how could I not be interested in chairing this committee? It's almost like this whole problem was created just for me. I really felt that way," Nathan says.

Nathan's task on the committee wasn't to analyze the data. He says there were members better at digging into the data at a more efficient rate. Where Nathan excels is in interpreting the information.

Others brought him their findings—a year's worth of data and research—and he stitched the results together to find their significance. It took him over a month to compile the findings into a report sent to MLB on December 31, 2017—the deadline given to the committee.

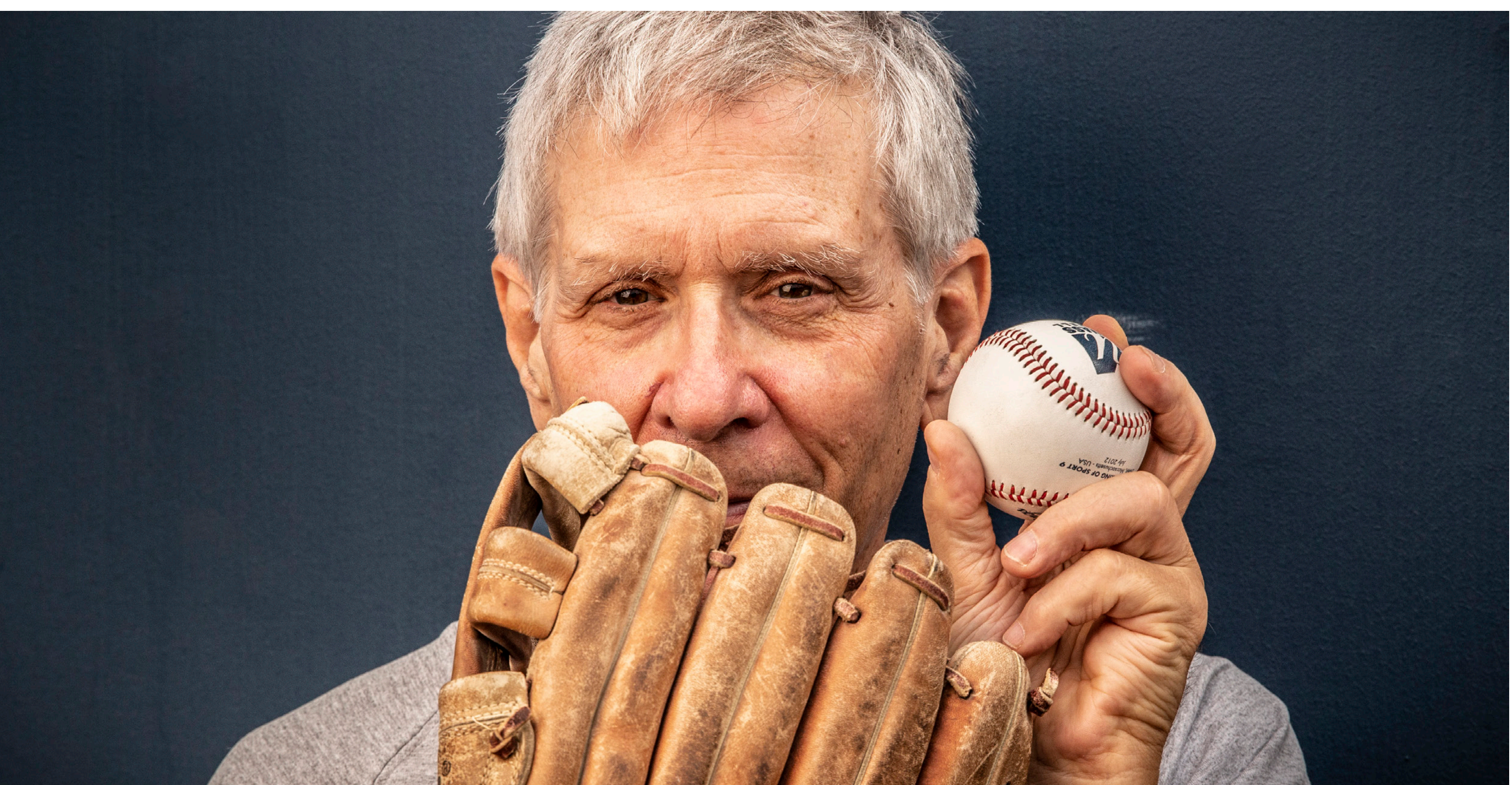
So, what did the report say?

"We figured out that it wasn't the launch conditions that had changed. They stayed on average the same. It was how the ball carries through the air that changed," Nathan explains. "We determined that the so-called drag coefficient is the thing that had changed, and we measured how much it changed. To draw the connection to how the change in drag coefficient affects the change in home runs is a physics problem. My major contribution was showing that the change in drag coefficient was consistent with and could explain the change in home runs. This was the crowning achievement of the project."

But there's more to the story. As Nathan explains it, "As often happens with research, problems get solved and new problems get uncovered. The solved problem is that the changes in home runs could be explained by variation of the drag coefficient of the ball. The new problem is that we can't really figure out how two baseballs that look and feel essentially identical could have different drag coefficients. It almost certainly has to do with subtle features of the seams, but we haven't been able to figure it out yet. That work is ongoing."

When Nathan talks about his work with MLB, he perks up in his seat and smiles constantly.

"You know, when this home-run increase happened and I got the call, I was almost too willing to chair this committee—and why not? For me, this is the dream job. The two major things I've worked on are the physics of the ball-bat collision and the physics of the flight of the ball through the air, and this involved both of those. It was definitely a fun project to work on."



Mentoring the next generation

In addition to his work with baseball organizations, Nathan has mentored undergraduate students in the physics of baseball. One such student, then-freshman Charlie Young, contacted him in 2016 about working on various projects on the physics and analytics of baseball. Over the next four years, Nathan and Young grew from mentor and mentee into equal coworkers and wrote several papers together. Nathan connected Young to Illini baseball coaches, leading him to organize a group of like-minded undergraduates to do baseball analytics for the team. Young now works as an analyst for the Houston Astros, and he even has a World Series ring.

Currently, Nathan is working with physics major Riku Komatani, who is on the same trajectory. He will graduate in May and shortly thereafter begin working with the Seattle Mariners. Comments Nathan, “Needless to say, both experiences have been personally very rewarding.”

Nathan admits that when he first started researching the physics of baseball, it wasn’t to benefit the baseball fans or to have an impact on the Major Leagues—it was really for himself. He wanted to understand the sport in all of its subtleties.

In the intricacies of baseball’s physics, Nathan’s love of the sport has evolved into something far more than what he could have imagined, and this is what pushes him to continue trying to unlock the mysteries of baseball.

“I started doing this for my own interest. And I went many years doing this because it was fun and interesting for me to do. No one was paying me to do it. They are now,” Nathan laughs. “But I was just doing it as a little side hobby in addition to all the other little things I was doing. So yeah, I never thought it would lead to this at all.”

“At some point, I’ll stop doing this,” Nathan adds.

Is that what he tells himself?

“It is inevitable. And I would certainly like to think that when I’ve finished doing this, I have either dropped dead or moved on to something else—and that I have made useful contributions to the sport.” ■

For more information about Nathan’s research in the physics of baseball or to learn about the pioneers of this field, please visit his homepage on the Illinois Physics website, at baseball.physics.illinois.edu.

Photos by L. Brian Stauffer, University of Illinois Urbana-Champaign

THE LOOMIS CONFESSIONS

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

These interview questions are inspired by the "confession album," a Victorian parlor game. It later became known as the Proust questionnaire after French writer Marcel Proust's thoughtful and witty answers were discovered and published in the French literary journal *Les Cahiers du Mois* in 1924. 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 ANGELA KOU

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

When I was younger, I wanted to have a new job every day (not realizing that every job requires a level of expertise not gained in a day). Probably the closest option to that would be working as a documentary photographer, where I would get to do lots of different projects in different situations.

What is your favorite place?

New York, the South Island of New Zealand, and Lander, Wyoming.

What is the greatest scientific blunder in history?

I don't think we need to look for great blunders; little scientific blunders can have big consequences.

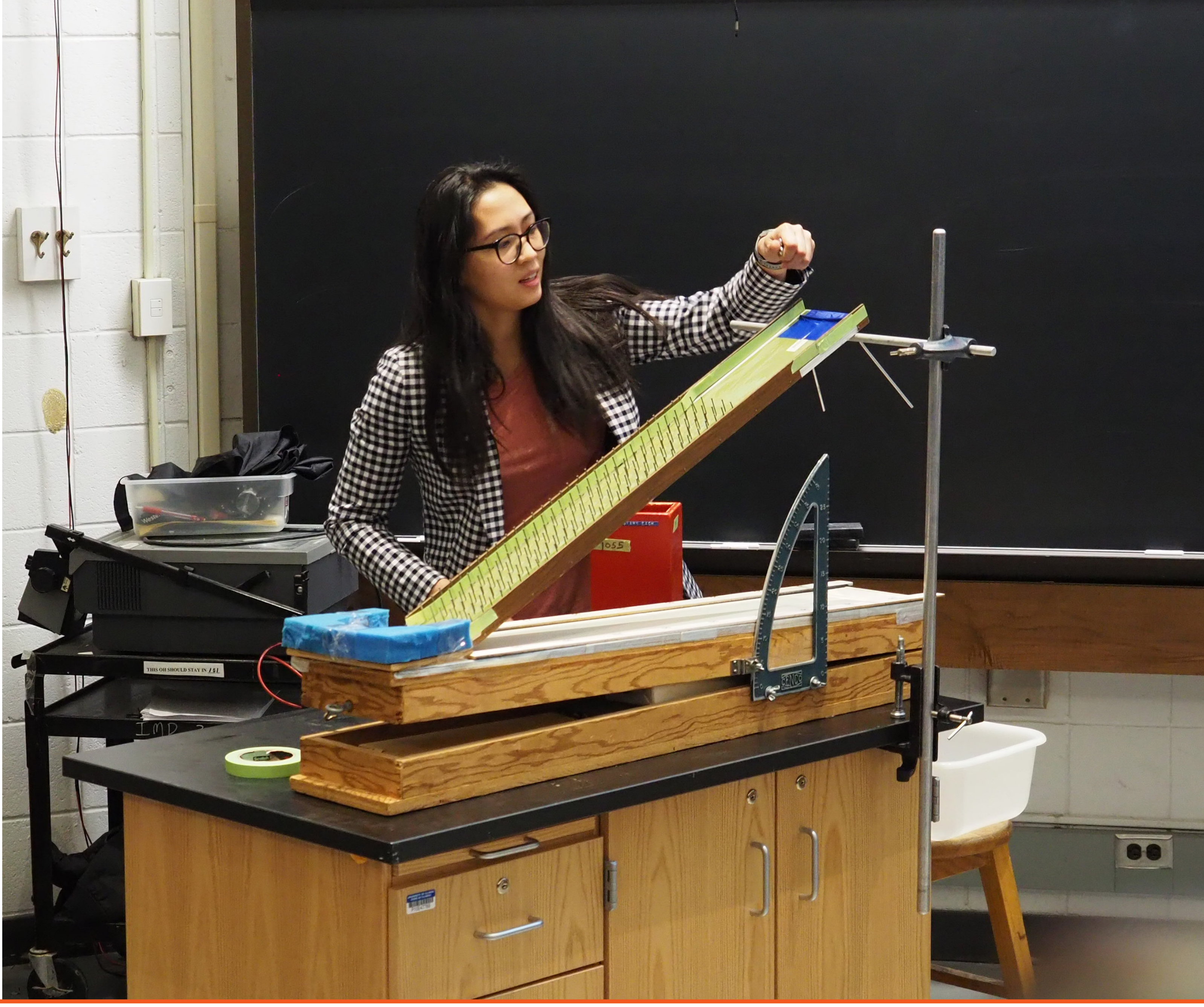
Who is/are your favorite artist(s) in any medium—painters, composers, authors, filmmakers?

Artists: Bruce Nauman, Robert Frank, Iris van Herpen

Musicians: Max Richter, GoGo Penguin, Billie Eilish

Authors: Ted Chiang, Amor Towles, N.K. Jemisin

Theater: Ivo van Hove, Third Rail Projects



Illinois Physics Professor Angela Kou performs a demo during her Saturday Physics for Everyone lecture. Kou is an experimentalist in condensed matter physics and quantum information. Photo by Nathan Carlberg for Illinois Physics

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

Addie LaRue from The Invisible Life of Addie LaRue. Elizabeth Zott from Lessons in Chemistry. All of the women in House of Spirits.

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

I'm too lazy to hate anyone.

What is your idea of happiness?

Lying on an empty, sandy beach in front of a clear blue ocean with only the sound of ocean waves. In daily life, learning something new and tasty food.

What is your idea of misery?

Being cold.

What quality do you most admire in others?

Creativity. Equanimity.

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

Related to my work, how to build a quantum computer. More generally, how does consciousness arise.

A Strange Alchemy

BILL BELL *for Illinois Physics Condensate*

Illinois Physics Professor Philip Phillips brings his unshakeable focus and wide-ranging curiosity to opera.

Find Professor Philip Phillips seated in the auditorium at Smith Hall on a Sunday night. Professor Casey Robards is at the piano, accompanying renowned baritone Kenneth Overton. They are premiering an excerpt from a song cycle by Anthony Patterson called "Lyrics of Love and Laughter."

The four are friends. Robards and Patterson are, in fact, married. In their various ways, they've bonded over a passion for this music: art song. Poetry set to a nuanced style of opera. Intimate rather than bombastic. Performed with a piano rather than an orchestra.

Phillips is intent as Overton sings the words of Paul Laurence Dunbar. He's set aside his pre-show snack and folded in on himself. Arms and legs crossed, one hand supports his chin. He doesn't move—no toe tap or head bob.

'Philip Phillips: Opera and Physics'
Original artwork by Yasmine Steele for Illinois Physics

Intermission comes. Phillips is up. He greets Patterson in the aisle and offers a hug. "Tony! Bring it in! Extraordinary! Absolutely great."

Phillips is so much bigger when he speaks. Booming.

After some questions about Patterson's process for selecting the poems used in "Lyrics of Love and Laughter," Phillips returns to his seat. Overton and Robards continue with selections from other composers and close with Duke Ellington's standard, "Come Sunday." Overton ends with a beautifully controlled decrescendo from a high note. As the crowd begins to applaud, Phillips whispers an obviously impressed "Whoa!"

He appreciates how technically challenging the moment is. In addition to being a globally recognized condensed matter physicist, he's a singer himself.

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Find Professor Philip Phillips on stage in the summer of 2022. The past six weeks have been a flurry of rehearsals, recitals, and classes. He is now performing Colline in a production of Puccini's *La bohème*. The character is "a philosopher type," he later explains, who famously sings a farewell aria ("Vecchia Zimarra Senti") to a coat that he must pawn. It's Phillips' first time in a role at the Bay View Music Festival in Michigan. Bay View is the longest continuously operating chamber music festival in the United States. Overton, Patterson, and Robards are all faculty artists there.

"Your work ethic has to be incredible" for a Bay View-caliber performance, according to Phillips. As in any opera production, "You have to be ready to deliver a line regardless of what you hear or don't hear, which requires intense focus. There's a similar thing when you derive an equation. But this is much more immediate and tactile. If you lose focus, it's curtains. You can't come back to the moment."

The equations he derives off-stage often involve unorthodox approaches to the Mott problem. (The Mott problem, very basically, represents the failure of the standard theory of metals to explain electron motion in transition metal oxides, such as the copper-oxide high-temperature superconductors. Read more about Phillips' research on Mott physics in *Nature Communications* and *Nature Physics*.) His breakthroughs in applying the random dimer model—the exception to Anderson's localization theorem—to explain conducting polymers, meanwhile, are what led Illinois Physics to recruit him from the Massachusetts Institute of Technology.

Illinois Physics Professor Philip Phillips as the Commendatore in Wolfgang Amadeus Mozart's Don Giovanni.
Photo courtesy of the Krannert Center for the Performing Arts

Illinois Physics Professor Philip Phillips plays Alcindoro in the Cafe Momus scene in Giacomo Puccini's La Bohème.
Photo courtesy of the Krannert Center for the Performing Arts

"I wanted to know what happens to an electron when it has a random potential in low dimensions," Phillips says in a recent interview. "I knew the standard result, that disorder would preclude conduction in one dimension. But I also knew that there were conducting polymers and that diffusion poles were hard to kill regardless of dimension. So I knew there had to be an exception. That's the random dimer model.

"Exceptions to dogma. That's the sort of thing I do."

Phillips came from MIT 30 years ago, but his love of opera goes back even further. It played in his family home growing up in Tobago, Boston, and Washington state. It was practically all he listened to in college. During his postdoc at Berkeley, he was fortunate enough to see Leontyne Price's final performance as Aida at the San Francisco Opera. "Wow. What a production," he recalls.

The desire to sing was "always under the surface," says Phillips. He had performed with the University of Illinois' Lyric Theatre, playing Commendatore in *Don Giovanni* and Alcindoro in *La bohème*, for example. But the summer gig doing *La bohème* in Michigan was intimidating, nonetheless.

"I ended up at Bay View sort of accidentally," he says. "In my first coaching session with Casey in February 2022, she asked me if I would send in audition tapes for a role at Bay View. The rest is history: I was cast as Colline."

"I was by far the oldest performer at Bay View. It's mostly college and grad students. But it's all about singing there. It's irrelevant that you're a physicist. You put your ego somewhere else. You have to be completely open and imbibe everything they have to say."

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Find Professor Philip Phillips entering Professor Casey Robards' office in the Music Building with Kenneth Overton. A beat-up baby grand piano takes up half the room. Scores of scores line metal bookshelves and pile on the desk that fills the other end of Robards' office.

In addition to being let's-grab-dinner friends, Robards and Overton double as vocal coach and voice teacher, respectively, for Phillips. He sees Robards often in person, and Overton, who performs around the world, is catch-as-catch-can both in person and via Zoom.

Phillips, a bass, performed a recital with pieces by Verdi, Rossini, Mozart, and others in January. Today, the group is refining one of the recital pieces. It's Schubert's *Erlkönig*, or *The Elf King*. He starts their session with a run-through of the song. In it, a father ignores his son's warnings that they are being chased by a demon.

Phillips voices narrator, son, and child alike, pleading: "*Mein Vater, mein Vater, und siehst du nicht dort Erlkönigs Töchter am düstern Ort?*" ("Father, father, can you not see Erlkönig's daughters there in the darkness?") As Phillips finishes, the father cradles his dead son in his arms, and Overton begins sharing his thoughts quickly and candidly.

They explore ways to embody the different characters in the song. They practice diction and musical phrasing. Overton touches Phillips' face—at various moments, his cheek, his temple, the back of his head—to remind him where he should be feeling the sound. At one point, they pull against opposite ends of a scarf to encourage Phillips to sustain a given note.

"Make that as legato as molasses," Overton prompts. "The narrator is matter of fact, mysterious.

"Air is free. Audiences will forgive you for taking a breath if you make the rest of the phrase beautiful." Robards consistently lays in a bit of piano at just the right moment to illustrate a point or to help Phillips stay on track.

There's a debate about what key Phillips should be singing *Erlkönig* in. Robards has been encouraging him to move it up. Overton agrees, strongly. Phillips acquiesces and runs it in the higher key.

"It's a strange alchemy, this training for operatic singing," Robards explains.

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Illinois Physics Professor Philip Phillips plays the Commendatore in Wolfgang Amadeus Mozart's Don Giovanni. *Photo courtesy of the Krannert Center for the Performing Arts*

Find Professor Philip Phillips in his own office at the Anthony J. Leggett Institute for Condensed Matter Theory. A poster of The Clash's *London Calling* hangs on the wall; Schubert and Handel aren't the only things spinning on his turntable.

He's just back from teaching his *Philosophy of Physics* course. One of the topics covered was 19th-century debate on the aether as the medium for transporting electromagnetic waves. All of the problems this posed weren't properly resolved until general relativity emerged. For decades, some of the world's brightest minds ground away to upturn orthodoxies. Surely, the work was driven by a combination of intuition and technical skill, intense personal focus and powerful collaboration, obstinate beliefs and complete openness, moments of quibbling and moments of ego put aside.

Another kind of strange alchemy, perhaps.

"The problem I've chosen as my life's work is the Mott problem," he says with a laugh. "And, really, most people would walk. For years, it was too controversial. People's opinions were set. But new doors opened as we gained new insights. You have to be open to changing your view. If it's smooth sailing, you're not working hard enough."

Whether picking a key or picking apart a long-standing puzzle in physics, "some people naturally want to do things their own way. It may seem that's what I'm doing, but it's not," he says. "My work is sometimes viewed as nontraditional, but I feel I understand profoundly what others have done. I understand what's in the box before I step outside of it."

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.

Coinfecting viruses impede each other's ability to enter cells

ANANYA SEN *for the Carl R. Woese Institute for Genomic Biology*

Aug 4—Illinois Physics Professor Ido Golding and postdoctoral researcher Thu Nguyen, together with researchers at Texas A&M University, have found that a phage's ability to infect a living cell by injecting its genetic material could be impeded by the presence of other coinfecting phages attached to the surface of a cell. The team used cutting-edge techniques to study this process at the level of a single cell.

Eduardo Fradkin awarded Feenberg Memorial Medal

2024 Recent Progress in Many-Body Theories 22 conference news

Aug 5—Illinois Physics Professor Eduardo Fradkin was awarded the Feenberg Medal "for pioneering applications of quantum field theory to the understanding of emergent many-body physics of quantum systems, in particular composite fermions and electronic liquid crystalline and pair–density wave phases of correlated electronic systems." The Feenberg Medal is awarded for work that is firmly established and that can be demonstrated to have significantly advanced the field of many-body physics.

Gravitational waves unveil previously unseen properties of neutron stars

LOIS YOKSOULIAN *for the University of Illinois News Bureau*

Sept 5—Illinois Physics Professor Nicolás Yunes, along with Illinois Physics postdoctoral researcher Justin Ripley and Illinois Physics graduate students Abhishek Hegade and Rohit Chandramouli, have verified that out-of-equilibrium dissipative tidal forces within binary neutron star systems are detectable via gravitational waves. The team studied data from the gravitational wave event identified as GW170817, using computer simulations, analytical models, and sophisticated data-analysis algorithms.

Mystery in the Mass Gap

MADELINE STOVER *for Illinois Physics*

Oct 3—Illinois Physics Professor Jaki Noronha-Hostler, together with collaborators at the University of Washington and Kent University in Ohio, has confirmed that a class of mysterious astronomical objects falling within the "mass gap"—the range of 2.3 to 5 solar masses, wherein very few astrophysical objects have been observed—could indeed be ultradense neutron stars. The team developed a method to systematically reconcile the equation of state for an ultradense neutron star with heavy-ion collision data, bridging astrophysics and nuclear physics.

New study: Earthquake prediction techniques lend quick insight into strength, reliability of materials

LOIS YOKSOULIAN *for the University of Illinois News Bureau*

Nov 6—Illinois Physics Professor Karin Dahmen, in collaboration with researchers at Sandia National Laboratories and Bucknell University, has shown that the amount of deformation caused by stress applied locally to the surface of muscovite mica is controlled by the physical condition of the mineral's surface and follows the same statistical dynamics observed in earthquakes and avalanches. Materials scientists can now use this insight to quantify how hostile environmental interactions may impact the degradation and failure of materials used for advanced solar panels, geological carbon sequestration, and infrastructure such as buildings, roads, and bridges.

Down the Escher staircase and into the quantum realm

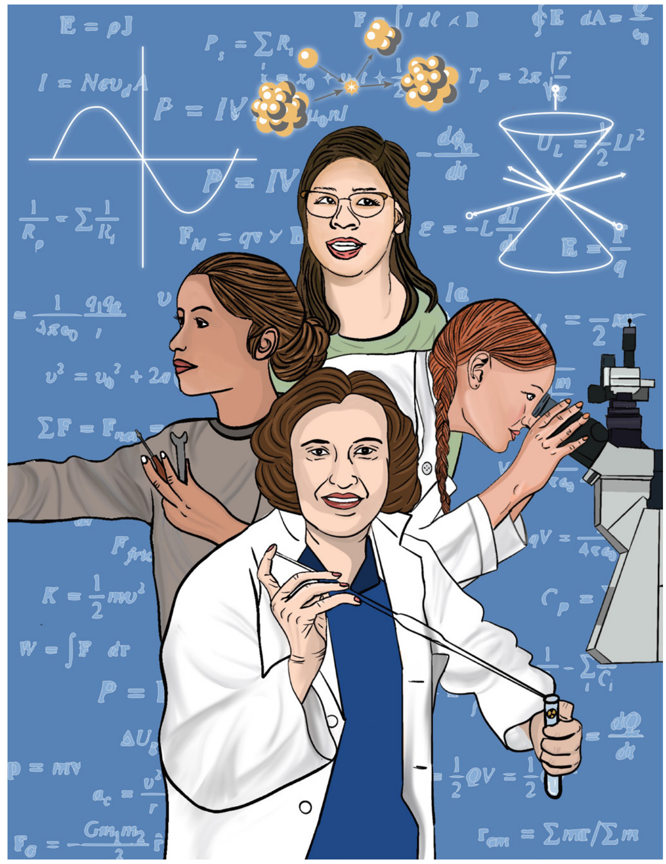
MADELINE STOVER *for Illinois Physics*

Nov 12—Illinois Physics Professor Jacob Covey and his team have built a cutting-edge quantum simulator using synthetic dimensions represented by internal states of an atom. Within these synthetic dimensions, the team was able to create geometries that cannot exist in real space and use these geometries to capture the complex dynamics of strongly interacting quantum particles. The team's novel approach to reproducing small-scale quantum phenomena enables the study of previously unobserved quantum systems.

100 years of women Ph.D.s continued:

First-person profiles of alumnae **Laurie McNeil** and **Yulia Maximenko**

In the 2024/2025 academic year, 100 women were enrolled in the Illinois Physics graduate program—a new record. These two profiles, written in the first person by outstanding women physicists and Illinois Physics alumnae, reflect the contributions and value added by women to the field of physics. These profiles are the second part of the *100 years of women Ph.D.s* article published in the Fall 2022 issue of *Condensate*.



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

ALUMNA LAURIE MCNEIL

Laurie McNeil is the Bernard Gray Distinguished Professor in the Department of Physics and Astronomy at the University of North Carolina at Chapel Hill. In her research as a condensed matter and materials physicist, she specializes in optical spectroscopy of semiconductors and insulators.

I arrived at Illinois as a new graduate student in 1977, one of two women in an unusually large entering class (62, if memory serves). I had been a chemistry and physics major at Harvard and had fallen in love with solid state physics. When I asked Harvard faculty members where I should go to graduate school to pursue this passion, they all replied, "Well, besides Illinois, you should also consider…" I got the message.

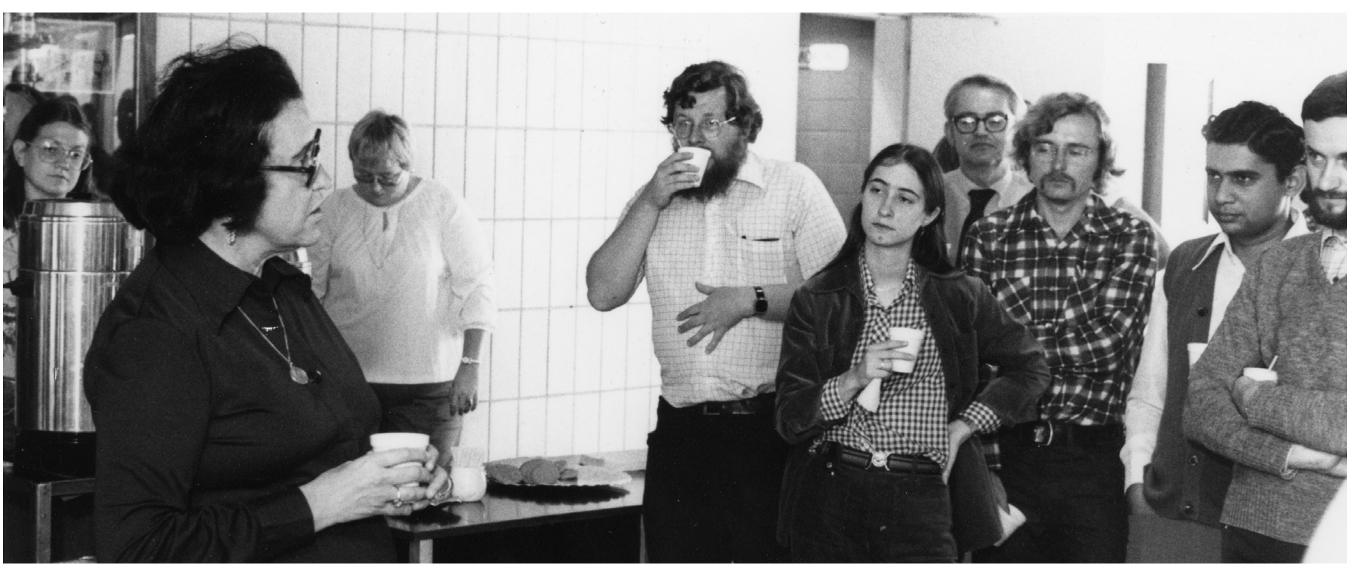
The department at Illinois (students, faculty, staff) was generally welcoming, though the extreme gender imbalance did contribute to some peculiar moments. A classmate asked me why the Susan B. Anthony dollar coin had 13 sides—apparently being female made me an expert on that subject (and it actually had 11 sides). Older male faculty members accustomed to calling students by their surnames felt uncomfortable addressing a woman that way, and so didn't quite know what to call me. I joined a wonderful research group led by David Lazarus, who couldn't have been more supportive of his female (and male) students even while he took on the role of editor in chief of the *Physical Review* journals. By the time I finished my studies in December 1982, Dave had been in touch with his graduate school classmate Millie Dresselhaus at MIT, who agreed to take me on as a postdoc. Her mentorship had an enormous influence on my career. Besides the scientific growth she supported me to achieve, she also taught me what being a leader in the physics community looks like, and that we all have an obligation to serve. In subsequent years, she provided opportunities for leadership by recommending me for various roles when she thought I could learn something from them.

After a year and a half at MIT, I became an assistant professor in the Physics and Astronomy Department at the University of North Carolina, and except for sabbaticals at Argonne National Lab, DuPont Central Research & Development lab, and Nanyang Technological University in Singapore, I have been here ever since. I was the first female faculty member in my department—and for six years the only one. When I arrived in 1984, the department hadn't hired anybody in seven years, so I was also very much the youngest member of the department. The other faculty members seemed pleased that I had joined them, but many were unsure how to treat a colleague who resembled their daughters. The second female faculty member came as a senior professor, and fourteen years after that, a third woman joined us as an assistant professor (my joke was that the department hired a woman on average once per decade). Soon thereafter, I became chair of the department and was able to hire several faculty members, including two women. I did my best to provide them with the kind of mentoring my senior colleagues had not been able to give me, including regarding conflicts with difficult coworkers (sometimes tinged with sexism). We now have 11 women among our 36 faculty members, and I'm proud of the hand I had in that, especially considering how successful they have all been.

In my lab at UNC, I undertook research using optical techniques (mostly Raman scattering) to study various phenomena in semiconductors and insulators. Over the years, I have done some very interesting science with many wonderful students who went on to careers in academia, industry, and national labs. Working with them has been a joy, even if we generally had to go through ten drafts of their dissertations and scientific papers before the writing met my standards. As my first grad student told me, by their junior year, most physics majors aren't writing anything longer than letters to their mothers. (That was back when students wrote letters to their mothers rather than just texting them.)

While I was chair, I also undertook to transform the classroom teaching in my department to incorporate active student engagement. My efforts were inspired and informed in part by what Illinois had done in its introductory courses, which served as a wonderful model of how a physics department could make a profound change even to such a big enterprise. With the help of a dedicated and skilled team (and two NSF grants), I was able to convert all of our introductory physics courses to a lecture/studio model, with outstanding results in learning outcomes and student satisfaction. Now faculty members in the teaching teams of these courses carry the same active engagement pedagogy into other courses, so all of our teaching is being modernized and made more effective. In 2014, UNC bestowed on me the Bernard Gray Distinguished Professorship "for outstanding scholarship, creativity and teaching," and in 2019 the Southeastern Section of the American Physical Society (APS) honored me with the George B. Pegram Award for "Excellence in Physics Education in the Southeast." Most recently, I received the 2025 John David Jackson Award for Excellence in Graduate Physics Education from the American Association of Physics Teachers.

Following Dave and Millie's examples (though not at their level), I have sought to make a difference in the broader physics community by taking on a range of leadership roles in the APS. I have served as chair on the Committee on the Status of Women



Then–graduate student Laurie McNeil (center right) and other members of Illinois Physics visit with Nobel laureate Rosalyn Sussman Yalow (left) during a pre-colloquium tea in 1978. Yalow is wearing her Nobel Prize medal, conferred in 1977 for her development of radioimmunoassays of peptide hormones. She was the first-ever American woman to be presented with this prize, which she shared with her colleague Solomon Berson. Photo scanned at the Emilio Segrè Visual Archives.

in Physics, the Forum on Education, and the Southeastern Section; participated in or led the task forces that produced the *SPIN-UP Project Report* on thriving physics departments and *Phys21: Preparing Physics Students for 21st-Century Careers*; participated in or led dozens of "climate for women" site visits to physics departments; am a member of the leadership team for the Physics and Astronomy New Faculty Workshop (now the Faculty Teaching Institute); and currently serve as a member of the Council of Representatives and the Board of Directors of the APS. These and other activities have given me a chance to work with many dedicated people on important tasks, and I sometimes have the pleasure of intersecting with friends from Illinois.

All of the experiences and successes I have had throughout my career as a physicist are rooted in the excellent education (in all senses) that I received at Illinois. When Dave Lazarus decided to retire in 1987, he said, "this department has been good to me." My time there lasted fewer than six years compared to his 38, but I agree with him wholeheartedly. For one thing, I met my husband, Pat Wallace, when we shared a TA office in Loomis Lab!

Laurie McNeil (center) and husband Pat Wallace (left) celebrate her 60th birthday with a hot air balloon ride. The couple met as graduate students at Illinois Physics. Photo courtesy of Laurie McNeil

Photo courtesy of Yulia Maximenko

ALUMNA YULIA MAXIMENKO

Yulia Maximenko is a professor at Colorado State University. In her research, she studies many-body quantum effects and seeks novel electromagnetic properties having applications in device engineering.

If I must characterize myself in a few words—which, don't get me wrong, is terribly hard—the words would be *physicist, educator, explorer, creator,* and *humanist*. I strongly believe in human rights and equitable access to education, I love adventures and concocting scientific and artistic creations, I am passionate about mentoring students, and I aspire to become a great teacher. But first and foremost, I am a physicist. It could easily be considered a sort of acquired neurodivergence. My life partner, a musician, showed me the extent of how weird we physicists are. In casual conversations, I constantly subject them to words like *interactions*, *suboptimal*, *phase space*, *potential barrier*, *local minimum*, and oh so many more, and to them it's like I'm speaking in tongues. It is absolutely a lens through which I see the world: I think in terms of interdependent variables, dimensionality, symmetry, and modeling, while visualizing 3D movies in my head. Without a doubt, I thoroughly enjoy being a physicist. (But before you get too excited, be ready to spend about 20 years in "school" to get there.)

My path to experimental physics, sadly, didn't involve exploding chemicals or flying rockets or any other favorite hands-on activities of middle-schoolers. I grew up in Russia, where you have to take a test in math—and chess, and ice skating, and ballet—before they even cut your umbilical cord. (Luckily, heavy drinking wasn't one of the requirements.) So, I came to science by way of abstract math and logic rather than tinkering. I had a resolute father who pushed me to pursue intellectual challenges, excel in school so I could skip out on house chores, and, for good measure, run and ski long and boring trails in the woods. Even though Russia was and still is a lot more traditional in its gender roles and expectations, some local stereotypes benefited me: "girls are hardworking and responsible," "being smart is cool," "being good at math and physics will guarantee you a job," etc. Before I got any silly notions about what girls must and must not do, I already knew that I enjoyed math, and no one could convince me otherwise.

Physics, on the other hand, was a different story. It didn't make any sense to me when I first encountered it at the age of 11–12, and yes, that's how early students start physics in Russia. What turned it around was one very special person, Lyudmila Pravdina—the best physics teacher the world has ever seen! She was so excellent and inspiring that physics suddenly clicked and became my lifelong passion. By then I knew more of the world to see that women aren't particularly welcome in science, but I was stubborn enough to continue down that path no matter what. I am not usually plagued by impostor syndrome, possibly because my expectations were so low that the only outcome was defying them. I do not recommend the hungry-'90s Russian pessimism as a life philosophy, but I do believe that overcoming reasonable challenges while having a solid support structure is the path to growth, adulthood, and independence, as a scientist and as a person.

After high school and college, I came to the US for a Ph.D., and after a postdoc landed a faculty position, which is a traditional track. As a woman in physics, I've had my share of *suboptimal* experiences, ranging from insinuations to blatant harassment. In Russia, I existed in a constant ready-to-fight mode, but I was propelled by my ambition and desire to prove to the world that women can be good physicists. The US is a cut above Russia in terms of gender equality, but systemic sexism still exists in all spheres, and sustained effort is needed for improvement.[1] It's easier to persevere with some grit and resolve, a healthy degree of arrogance, and a knack for finding supportive mentors who will teach you and root for you. I was lucky enough to have all of the above.

Having said that, my strong belief is that these specific traits should not be a *necessary condition*—the last mathy reference, promise—to succeed in science. Precisely because of my struggles, I am trying to make the physics world better for future generations, to the best of my ability: all personalities and backgrounds belong and are invaluable! Here's the conspiracy: I try to meet more women, gender/ethnic minorities, and allies at all stages of science careers and facilitate mutually supportive networking—all in hopes of subverting toxic authorities and abandoning inequitable practices. So, shoot me a message if you are in!

So, in August 2023, I became an independent group leader in the field of quantum 2D materials and tunneling microscopy. This was not the end goal, but rather another step in the process of doing something meaningful and gratifying. Sure, there are challenges and responsibilities, but also lots of excitement, freedom, rewarding mentoring, learning, growth, and building new connections. The setbacks and frustrations along the way seem worth it now, but you can also minimize their effect on you. Before we fix the world, that is.

If I were to give a recipe on how to convert a passion for science into academic success, it would be this:

1. Nurture your passion in whatever way works for you, whether it's reading books, talking to other scientists, mentoring, or working on specific topics.
2. Prioritize your health, sleep, and exercise! Being healthy is a privilege, and it is much harder to function as a scientist without it.
3. Find the right environment where you feel valued and can grow and thrive. Leave toxic places as soon as you can. They are not worth your time and effort.
4. Find allies, mentors, and supporters wherever you go; keep growing that professional network and don't be shy about asking for help and advice.
5. Value your personal connections and rely on people close to you for support.

Sounds easy, right? In the end, as sad as it is, there is a lot of luck involved in becoming successful in any field, no matter what history textbooks and news tell us. The most successful humans are unique in one and only one way: they got lucky [1]. However, your own belief in your success is a better predictor of excellence than privilege or talent [2]. You can use these facts to your advantage by proactively seeking opportunities and taking chances and by building a support network that helps you believe in yourself. And it never hurts to take more naps! ■

Footnote:

[1]If you are interested in rigorous data and statistics on the subject, I strongly recommend reading *Invisible Women* by C. Criado Perez.

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Quantum science and the arts —a beautiful entanglement

DANIEL INAFUKU *for Illinois Physics Condensate*

Illinois Physics Professor Smitha Vishveshwara and her longtime creative collaborators, Illinois Theatre Professor Latrelle Bright and Illinois Music Professor Stephen Taylor, launched the Collective for Art-Science, Creativity, and Discovery, etc. (CASCaDe) in April 2024 with a performance of the first scene of *Quantum Voyages* at the Krannert Center for the Performing Arts. Now the team of art-science creatives is preparing a reimagined full production of *Quantum Voyages*—including performances by Le PeTiT CiRqUe, a youth circus group directed by Nathalie Yves Gaulthier—for the largest gathering of physicists in history, coming up this March.

The first seeds of the art-science collaboration now known as CASCaDe were planted in 2016, when Illinois Physics Professor Smitha Vishveshwara first met Illinois Theatre Professor Latrelle Bright.

Vishveshwara's science spans the quantum to the cosmic. She studies everything from exotic quantum systems—ultracold Bose-Einstein condensates, superfluids, and superconductors—to black holes and even protein networks. Yet she's always had a deep affinity for the arts and envisioned a space where she could blend these two interests into one.

"Art has always been a part of my life," reflects Vishveshwara. "My grandfather was a playwright, and my father, a black-hole physicist and planetarium director, scripted shows with musicians and visual artists. So I grew up in that environment."

Bright, a prolific director, uses theatre and storytelling to build community in a unique approach she calls "theatre-making." She traces her journey in science back to her interests in nature and in humans' relationship to the environment.

"Making new things with a group of people really feels like the way I want the world to work," shares Bright. "I use these devised performance pieces to continue learning. After undergrad, when I found myself in charge of my continued education, I was eventually drawn to nature and the environment. This turned into a fascination with water over time—water in our region, our state, our country, and the world."

Vishveshwara and Bright's first meeting sparked a creative flame. The two together devised the performance piece *Quantum Voyages*, bringing it to the stage in 2018 at a conference honoring Illinois Physics' resident Nobel laureate Tony Leggett. Additional

Shown Left: *Pictured left to right, Illinois Physics Professor Smitha Vishveshwara, Illinois Theater Professor Latrelle Bright, and Illinois Music Professor Stephen Taylor speak at the CASCaDe launch at the Krannert Center for the Performing Arts last April. Photo by Nic Morse, Illinois Grainger Engineering*

performances followed at the Beckman Institute in 2018, at the 2019 APS March Meeting in Boston, and over Zoom in 2020 when the pandemic first struck.

Their work soon brought them into the orbit of Illinois Music Professor Stephen Taylor, a composer who collaborates with scientists to interpret genetic, protein, and astronomical data through sound.

"I'd been writing pieces inspired by science and science fiction for a long time—I even wrote an entire opera," says Taylor. "After that, I thought about having the music actually do the thing that it's about, and not just in a metaphorical sense. We call this 'data-driven' music, or sonification.

"I got into art-science through biology, inspired by the idea of DNA as a recipe for life," Taylor continues. "I've also always been interested in outer space. Thinking about the tininess of the atom, the vastness of the universe, and how these aren't yet reconciled gives you fertile ground to explore. We don't know, for example, what the relationship is between quantum physics and general relativity."

The trio have enjoyed a productive collaboration. And audiences have responded enthusiastically. *Quantum Voyages* debuted to an audience of approximately 400 at the I-Hotel. Later, the multimedia performance piece *Quantum Rhapsodies* played to a standing-room-only audience of over 100, the virtual art-science festival *The Illuminated Universe* drew almost 100 attendees each day across its 3-day run, the multimedia performance piece *Joy of Regathering* filled KCPA's nearly 650-seat Colwell Playhouse to capacity, and the physics-plus-circus collaboration *Cosmic Tumbles, Quantum Leaps* premiered to an audience 2,000 strong at the 2023 APS March Meeting's Kavli Symposium.

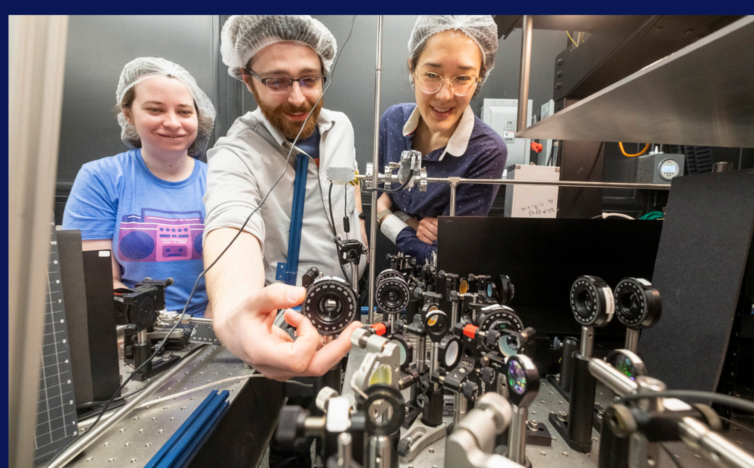
Energized by these successes, Vishveshwara, Bright, and Taylor formalized their collaboration, bringing their prior stand-alone projects under one cohesive identity: CASCaDe. CASCaDe now unites over 100 U. of I. faculty, staff, students, and community members across multiple campus departments in celebration of quantum science, the cosmos, and the role of science in deciphering nature's mysteries.

Bright comments, "The motivation behind CASCaDe was the realization that our pieces didn't have a permanent home. CASCaDe is now the umbrella under which these pieces exist. It's beneficial to fund an initiative rather than individual works."

For CASCaDe's launch in April 2024, the trio staged *Quantum Voyages*'s opening scene, entitled "Light; What does it mean to see?" at the Krannert Center for the Performing Arts.

Vishveshwara notes, "So many sagas begin with the emergence of light. It seemed apt to bring CASCaDe into the world through the opening scene of *Quantum Voyages*, which celebrates light."

Quantum Voyages follows explorers Terra and Akash as they venture into a quantum world. Echoing the journey of Dante in *The Divine Comedy*, the explorers, led by the Virgilian figure Sapienza, dance with light, swim in a sea of electrons, and even play a quantum version of the board game Clue. Along the way, they encounter so-called Quantum Sages, real-life physicists who act as guides during the voyagers' trek.



Members of the Gina Lorenz research group collaborate in her quantum optics lab. Photo by Bill Wiegand for Illinois Physics

At Illinois Physics and around the globe, quantum scientists and engineers are working toward a new generation of quantum-based technologies that would revolutionize society. For example, quantum computers could help us to find solutions to complex problems in agriculture, food and water security, medicine, climate change mitigation, sustainability, cybersecurity, and more.

Illinois Physics Professor Gina Lorenz, an optical physicist, has been part of *Quantum Voyages* since its first production in 2018. She portrays the Quantum Sage of Light, who teaches Terra and Akash about photons—quantum particles of light—speaking in iambic pentameter.

"The radiation quanta that you see … from depths of purest nothing come to be," incants Lorenz as she describes the birth of photons from immaterial nothingness. "They travel fast, make distance short. As Hermes, they—pure information—fly."

Lorenz penned the monologue herself.

For this most recent iteration of *Quantum Voyages*, Taylor composed new, original music. Vishveshwara and Bright credit Taylor for giving the piece new depth.

Says Vishveshwara, "The music Steve wrote added a completely new dimension. A renewed dialogue took place between theatre, physics, and music."

Vishveshwara, Bright, and Taylor are ready to kick art-science activity into high gear in the coming months. The trio have been workshopping *Quantum Voyages* with Le PeTiT CiRqUe, a children's circus, and its director Nathalie Yves Gaulthier ahead of the APS Global Physics Summit in March 2025. There will be a new full-scale production of *Quantum Voyages* at Krannert's newly renovated Colwell Playhouse, planned for April 2025.

By making esoteric science more accessible and engaging to the public, CASCaDE organizers are working to broaden conceptions of who gets to engage in science.

"Let's dispel the stereotype about who a scientist is and what a scientist looks like," Bright asserts.

And that's built into the creative process.

Asks Bright, "How do we tell the story of different scientific concepts so that they're not scary but accessible? One thing that's evident from everything we've done is how fun and creative physicists are.

"This CASCaDe community is growing and getting bigger and bigger," Bright continues. "It's a place where I can share the fullness of myself—my academic brain, my creative heart, the boots on the ground making things happen. That's what brings me to CASCaDe."

Vishveshwara agrees. "There's this common ground that we and our extended community have built together. We deeply resonate with each other. This is my happy space." ■

Celebrating 100 years of quantum mechanics

On June 7, 2024, the United Nations formally declared 2025 the International Year of Quantum Science & Technology (IYQ). The new designation commemorates the 100th anniversary of the development of quantum mechanics in the 1920s, a decade when many of the field's fundamental concepts were placed on firm mathematical foundations.

IYQ's year-long international celebration will bring the strange world of quantum phenomena to the masses through greater access to quantum education globally and through public engagement. IYQ events already in the making also promise greater opportunities for networking and collaboration among quantum scientists, energizing progress toward new quantum technologies. The IYQ is now endorsed by over 75 major scientific bodies, including the American Physical Society (APS), the Institute of Physics (IOP), and the International Union of Pure and Applied Physics (IUPAP). The APS is set to celebrate IYQ at its first-ever Global Physics Summit, a combined March Meeting and April Meeting that is shaping up to be the largest gathering of physicists in history.

Illinois Physics Professor Smitha Vishveshwara, a member of the APS's IYQ Steering Committee, had a head start on the celebrations. Her artistic collaborations on the topic of quantum science, described in this article, will coalesce in a performance of *Quantum Voyages* in conjunction with the APS Global Physics Summit. The performance will be part of a week-long IYQ celebration called "QuantumFest," which Vishveshwara is co-organizing and which will feature quantum-themed performances, interactive installations, talks, and demonstrations. And Vishveshwara won't be the only Illinois physicist joining in.

"Many of our own Illinois faculty and community members are involved as well," Vishveshwara notes. "For example, Ben Hooberman, Helvi Witek, Gina Lorenz, and Paul Kwiat are among the faculty participating in the festivities, and so many of our marvelous students and staff are joining us in creating the magic."

Other faculty and staff at Illinois Physics and at the Illinois Quantum Information Science and Technology Center are likewise gearing up for new IYQ outreach efforts and educational opportunities. We hope you'll stay tuned and take part!

Illinois Physics Professor Gina Lorenz rehearses her role as the Quantum Sage of Light ahead of the CASCaDe launch. Photo by Nic Morse, Illinois Grainger Engineering

Surkhab Kaur (left) plays Terra, and Jon Faw (right) plays Akash in the opening scene of Quantum Voyages, staged in April 2024. Photo by Nic Morse, Illinois Grainger Engineering

Among her recent creative exploits, Illinois Physics Professor Smitha Vishveshwara will soon publish a memoir co-authored with her late father and renowned black-hole physicist C.V. Vishveshwara. The book presents conversations between father and daughter, tracing the history behind two pillars of modern physics: general relativity and quantum mechanics. The memoir, entitled “Two Revolutions: Einstein’s Relativity and Quantum Physics,” is slated for a January 2025 release.

DIRECT AND RAPID IMPACT

BILL BELL *for Illinois Physics Condensate*

Illinois Physics alumnus Dustin Wooten describes his work tracing the effects of therapeutic candidates through the human body and his route to a career in medical imaging.

Before a pharmaceutical company can heal people and make their lives better, before it can market its next blockbuster medicine, before it can run a clinical trial, before it even identifies a way of attacking an illness or develops a drug in the first place—there's basic science to be done. The company has to know how those medicines will interact with the body and see what's going on at the chemical level. And that involves some serious physics.

That's where Dustin Wooten comes in. Wooten earned a bachelor's degree from Illinois Physics in 2008. He is now principal research scientist and head of image analysis within the Translational Imaging Group at AbbVie, the 50,000-person, $250 billion-firm based in northern Illinois, which spun off from Abbott Laboratories about a decade ago.

Wooten's team takes images generated by non-invasive imaging techniques like PET scans or MRIs and derives quantifiable data that can be used in clinical trials and other studies. In other words, they write the code and establish the image-processing steps used to assess a few to thousands of scans consistently, allowing researchers to determine how and how well potential therapies are working.

It's a tricky business. Molecules that are drug candidates or that can measure physiological effects of drug candidates are labeled with radioactive atoms like Fluorine-18, which decay rapidly by emitting low-energy positrons. The radioisotopes that result can be imaged by a PET scanner but, importantly, they remain physiologically identical to their non-radioactive equivalent. The positrons that they emit collide with electrons in other molecules, releasing a pair of gamma photons.

Wooten explains, "The PET scanner detects these gamma rays, and because we know they are traveling in opposite directions along a straight line, we know the positron emission had to happen somewhere along that straight line. This gives us the spatial information we need about where the radioactive molecule was located. By combining all this data and making some corrections, we can generate a 3D—or even 4D, including time—distribution of the radioactive molecules in the subject."

Expert image analysis by Wooten's team allows researchers to determine characteristics like where a therapeutic drug travels, how quickly it moves through the body, how long it lasts, or even pharmacodynamics.

Imagine the sort of selective serotonin reuptake inhibitors (SSRIs) that are often used to treat depression. They are taken orally, absorbed by the body, carried to the brain, bind to the proteins that carry messages among nerve cells, and are finally flushed from the body. PET scan imaging and image analysis could be used to track parts of that process and identify which candidate drugs most effectively bind to the proteins and are effective for the longest period of time. Those insights allow researchers to pick the most promising candidates and develop the most appropriate clinical trials to test them.

The technique can be applied to both the candidate therapeutics being tested and their targets—in our example, either the SSRI or the neurotransmitter protein.

"Say we have a receptor that is abundant in the brain, and we've developed a therapeutic that targets that receptor," says Wooten. "It would be great if we could show that our therapeutic is engaging that receptor. There are potentially *in vitro* methods of detecting this, but it's always more reassuring to know target engagement is happening *in vivo*. Thus, if we have a PET radiotracer that engages that same receptor, we, in theory, have our solution, which would involve several PET scanning sessions.

"In the first scan, we inject only radiotracer, and we see high uptake in the brain. In the second scan, we inject a small dose of the therapeutic prior to the radiotracer injection and PET imaging, and we see less radiotracer uptake. In the last scan, we inject a large amount of the therapeutic prior to the radiotracer injection and PET imaging, and this time we see little to no uptake of the radiotracer in the brain. This demonstrates target engagement because the therapeutic is reducing the number of available receptors for the radiotracer to bind to."

Ultimately, these types of studies can help determine which candidates are most promising, as well as other factors like what doses of the candidates should be used in clinical trials.

Wooten worked in PET imaging long before joining AbbVie, first as a doctoral student at the University of Wisconsin. He had considered medical school but stumbled on medical physics and imaging while an undergrad at Illinois.

"In my research on various medical schools, I came across the field of medical physics, and it piqued my interest—this would allow me to remain grounded in physics," Wooten recalls. "I honestly didn't know the field existed before coming across it in an online search. It came up in Google's search suggestion after typing 'medical'. UW-Madison had pioneered one of the most prestigious medical physics programs in the country and was right next door."

After earning his doctoral degree, Wooten continued his training in Boston. He served as a postdoc and faculty member at Harvard Medical School (HMS) and Massachusetts General Hospital (MGH). His work was focused on medical imaging in research, while he also spent time in the clinic and teaching.

A growing family brought Wooten back home to Illinois. (Family is obviously important to Wooten. We conducted our interview in two parts, just before and just after a vacation to Table Rock Lake, Missouri, with his wife and three sons. No interruptions while on the lake!)

"My wife and I had been in Boston for 4 years," says Wooten. "My wife was a speech and language pathologist at a local nonprofit hospital. I was junior faculty at MGH and HMS, conducting research, performing clinic work, and teaching. We both loved our careers, positions, mentors, colleagues, and the Boston area.

"However, around this time, we found out we were adding our first addition to our family. We were very excited about this, but the thought of expanding our new family while being so far from our own families seemed a bit daunting."

AbbVie offered many of the same charms as academic life and a home base back in Illinois. For Wooten, it's been a great fit—and an opportunity to do good.

Wooten reflects, "To me, one of the draws of the medical field is having more of a direct and rapid impact on people's lives." ■

Illinois Physics alumnus Dustin Wooten poses at the AbbVie facilities in north Chicago. Wooten is the principal research scientist and head of image analysis within the Translational Imaging Group at AbbVie. Photos by Bill Wiegand for Illinois Physics

Research

Next-generation gravitational-wave detector will orbit the Sun

SYDNEE O'DONNELL *for Illinois Physics Condensate*

Scientists around the globe are preparing for the upcoming LISA mission, which will launch a detector into space capable of discovering gravitational waves emanating from merging galaxies and colliding supermassive black holes. Illinois Physics is contributing expertise in theoretical astrophysics, relativity, and advanced computational modeling and data analysis.

To call the international Laser Interferometer Space Antenna (LISA) project ambitious is almost an understatement. Funded by the European Space Agency (ESA) in collaboration with NASA, the estimated $1.5 billion mission will extend our gravitational-wave observational capabilities into space, providing an unprecedented view into the universe and shedding light on some of the most profound as-yet-unanswered questions in astrophysics. Scientists around the globe are working to prepare for LISA's planned launch in the mid-2030s. At Illinois Physics, scientists are preparing for the enormous data LISA will generate by developing the theoretical framework and technology needed to identify the signatures of gravitational waves and their sources.

Gravitational waves are ripples in the fabric of spacetime originating from the universe's most violent events, such as collisions of black holes or neutron stars. The first direct detection of gravitational waves was achieved in 2015 when Advanced LIGO (the Advanced Laser Interferometer Gravitational-Wave Observatory) detected waves from a pair of merging black holes. This discovery confirmed a major prediction of Einstein's theory of general relativity and opened a new era in physics and astronomy. Since then, ground-based detectors in the LIGO-Virgo-KAGRA collaboration have detected numerous gravitational-wave events, providing insights into the properties and behaviors of black holes and neutron stars.

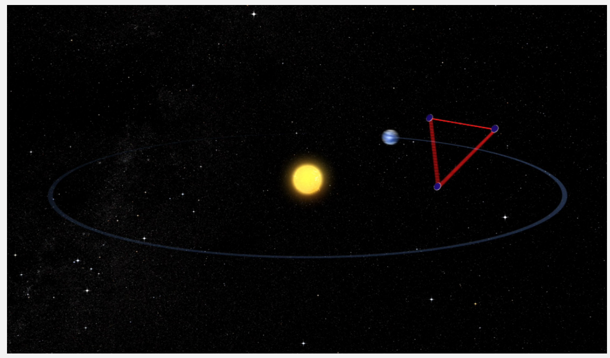
Shown Left: *The Helvi Witek research group poses for a photo in the ICASU meeting space at Loomis Laboratory of Physics. Pictured are (front row, seated, left to right) Illinois Physics graduate student Chloe Richards, Professor Helvi Witek, and graduate students Domenica Garzon and Noora Ghadiri; (back row, standing, left to right) Illinois Physics graduate student Cheng-Hsin Cheng, visiting research scholar Elena Koptieva, senior research programmer Roland Haas, postdoctoral researcher Deborah Ferguson, graduate student Fredric Hancock, undergraduate student Yi Zhang, and graduate student Frederick Pardoe. Not pictured but also a member of the group is undergraduate student Udit Ohri. Photo by Bill Wiegand for Illinois Physics*

The LISA mission will deploy three spacecraft positioned precisely 2.5 million kilometers apart, forming an equilateral triangle that will trail Earth in its orbit around the Sun. Each spacecraft will emit and receive laser beams from the others, detecting minute changes in distance caused by passing gravitational waves. The instrumentation build is set to begin in January 2025.

Why put a detector in space? Illinois Physics Professor Helvi Witek, co-chair of the LISA Waveform Working Group from 2018–2024 and in this role co-lead author of a white paper, explains, “Ground-based instruments have detected gravitational waves in the few hundred hertz range, produced by neutron stars or light black holes. LISA, being in space, will be sensitive to millihertz frequencies and will allow us to detect waves from supermassive black holes, the kind that live in the center of galaxies and are a hundred thousand to a million times as massive as our Sun.”

The complexity of the signals being measured and the sheer volume of data being collected mean that data processing and analysis will be enormous undertakings requiring sophisticated algorithms and computing techniques. Witek and her team at Illinois are already applying their specialized understanding of relativity and their expertise in generating numerical relativistic models toward LISA’s scientific goals.

Witek’s group is generating complex computer simulations that will serve as templates for interpreting signals in the LISA data. To achieve this, they are simulating the dynamics of the inspiral and merger of binary black holes of varied masses and the gravitational waves their collision emits, as described by general relativity or its extensions. By creating highly accurate source-specific models, the Witek group aims to provide a comprehensive template bank for interpreting LISA data. Once LISA is operational, these templates will enable scientists to identify the sources of gravitational waves—supermassive black holes or other violent cosmic phenomena—and to determine their properties, including mass, spin, and distance from Earth. The comparison of computational models to LISA’s physical observations will provide a test of Einstein’s theory of general relativity and will give LISA researchers the opportunity to explore dense dark-matter environments.



Max Planck Institute for Gravitational Physics (Albert Einstein Institute) / Milde Marketing Science Communication / Exozet Effects

The LISA mission consists of three spacecraft orbiting the Sun in a triangular configuration. The three satellites are separated by a distance of 2.5 Mio km. Ground-based detectors are limited by their sensitivity to high-frequency gravitational waves, typically in the range of tens to thousands of hertz. LISA’s position in space will allow it to detect much lower-frequency waves, in the millihertz range, which are produced by different types of astrophysical events, including the inspiral and merger of supermassive black holes. LISA’s observations will complement those made by ground-based detectors, providing a more complete picture of the gravitational-wave background (GWB)—the constant rippling of spacetime.

Illinois Physics Professor Nicolás Yunes, director of the Illinois Center for Advanced Studies of the Universe (ICASU), recently served as co-chair of LISA's Fundamental Physics Working Group. In this role, he co-led the writing of a white paper, published in the journal *Living Reviews in Relativity*, on our ability to test general relativity and extract fundamental physics from future LISA data.

Yunes's team at Illinois is leveraging its expertise in gravitational physics—within and beyond Einstein's theory—and its proficiency in analytical and semi-numerical methods to help achieve LISA's goals. The group uses post-Newtonian theory and black-hole perturbation theory to create highly precise models of the inspiral and merger of coalescing binaries and the gravitational waves they emit. His group is also developing sophisticated data-analysis tools to study synthetic LISA data and predict the physics that future LISA data will demonstrate.

Recently, the Yunes group has focused on making gravitational-wave models more realistic by accounting for the astrophysical environments in which binaries exist. This work will minimize the introduction of systematic errors that would be introduced by incorrect models.

Yunes comments, "Our ability to extract robust science from the data hinges on being able to model realistic signals and control systematic errors. I first became interested in these problems about two decades ago, and we have made a lot of progress toward this objective."

Illinois Physics and Astronomy Professor Stuart Shapiro and his group, as well as Illinois Physics Research Professor Antonios Tsokaros, were the first at Illinois to join the LISA collaboration. They are members of several LISA working groups, including LISA's Theoretical Astrophysics Working Group. Additionally, a new faculty member, Illinois Physics Professor Hector Okada da Silva, an expert on black holes and gravitational-wave science, will soon form his research group and will contribute to the Illinois LISA effort.

Shapiro is a pioneer in the physics of compact objects (black holes, white dwarfs, and neutron stars). He helped to develop the tools of numerical relativity that enable scientists to solve Einstein's equations of general relativity computationally and to simulate the exotic cosmic scenarios that LISA hopes to detect. Shapiro's research group was among the first to simulate the merger of binary compact objects and the subsequent generation of gravitational waves.

Shapiro comments, "The gravitational waves LISA will measure may provide clues to the type of environment in which really big black holes reside and help us solve the mysteries of exactly how and when supermassive black holes form—what are their seeds and how do they grow? LISA may also help us unlock the nature of ever-present dark matter, which may affect the mergers and resulting waveforms. Most importantly, the waves we measure will test our fundamental theory of relativistic gravitation—that is, general relativity—as well as our ideas about cosmological structure formation. It is all very exciting."

The LISA experiment is perhaps most exciting to early-career physicists. Witek's postdoctoral research associate Deborah Ferguson chairs the LISA Early-Career Scientist Group. She emphasizes the mission's significance for up-and-coming gravitational-wave scientists.

Ferguson says, "Given its timeline, the adoption of LISA is particularly important for early-career scientists in the field. Many current graduate students and postdocs will be forming their own research groups around the time LISA launches, so this experiment will really define our careers."

To view simulation videos from the Shapiro group, please visit http://tinyurl.com/shapiromovies.

Research in the Helvi Witek group related to the LISA Mission is supported by the National Science Foundation (NSF) under Grant Nos. PHY-2409726, OAC-2004879, and OAC-2411068. Research in the Shapiro group related to the LISA Mission is funded by the NSF under Grant Nos. PHY-2308242 and PHY-2006066. Research in the Yunes group related to the LISA Mission is supported by NASA under Grant No. 80NSSC22K0806 and by the Simons Foundaton through a grant shared with Brown University. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies.

Illinois Physics Professors Helvi Witek (left), Nicolás Yunes (center), and Stu Shapiro (right) sit and chat in Loomis Lab. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

LISA demands innovations

Building and deploying LISA presents numerous technological challenges. One of the most significant is the need for extreme precision in measuring the distances between the spacecraft. The laser interferometry technique used by LISA must detect changes in distance as small as a few picometers—less than the diameter of an atom—over a baseline of 2.5 million kilometers. This requires incredibly stable and precise instrumentation.

Additionally, the spacecraft must maintain formation with a high degree of accuracy, despite the influences of solar radiation, gravitational forces, and other environmental factors in space. Advanced propulsion and navigation systems will be employed to keep the three spacecraft in the correct positions relative to one another.

Another challenge is the transmission of data from the spacecraft to Earth. Given the vast amount of data that will be collected, sophisticated data processing and compression techniques will be necessary to ensure that the most critical information is transmitted efficiently. Ground stations on Earth will have to be equipped with advanced receivers to handle the data flow and to integrate it into the scientific analysis.

A rigorous threshold of evidence must be met before a gravitational wave can be considered discovered. The process includes cross-verifying signals with multiple templates, ensuring that the detected signals are not contaminated by instrumental noise, and controlling other systematics introduced by astrophysical environments or other artifacts.

Dale J. Van Harlingen

1950–2024

Dale Van Harlingen, professor emeritus of physics and the Donald Biggar Willett Professor Emeritus of Engineering at the University of Illinois Urbana-Champaign, died on Saturday, July 20, 2024, of complications from multiple myeloma. He was surrounded by his loved ones.

Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

A renowned experimental condensed matter physicist, Van Harlingen contributed to our understanding of a broad range of superconductors, both classic and unconventional. Among the many techniques he employed in his laboratory, he is perhaps best known for developing phase-sensitive probes based on Josephson and SQUID interferometry for measuring the pairing symmetry of unconventional superconductors. He also contributed to the development and use of scanning SQUID microscopy and related scanning probes and was a proponent of using noise spectroscopy to reveal dynamical information. More recently, he investigated topological excitations such as Majorana fermion states in hybrid superconductor-topological insulator Josephson junctions.

Van Harlingen served Illinois Physics as its 10th head of the department from 2006 to 2018. He described his own leadership style as an inverted pyramid with him at the bottom, providing faculty and staff with the support and the resources to do their best. His accomplishments in those 12 years benefited Illinois Physics in all its aspects: he tirelessly advocated for its people and research programs, pushed to modernize and upgrade its facilities, and supported evidence-based teaching innovations in its classrooms. He fostered the department's strong sense of community and the collaborative "Urbana-style" intellectual culture that underpins its research successes. He supported diversity-building initiatives.

And at every opportunity, he voiced to the campus community and to the broader academic community what he held to be true, that this department is “the best place in the world to do physics.”

Van Harlingen was a member of the National Academy of Sciences, elected in 2003, and of the American Academy of Arts and Sciences, elected in 1999. He was a Fellow of the American Physical Society. He was a recipient of the 1998 Oliver E. Buckley Prize in Condensed Matter Physics of the American Physical Society.

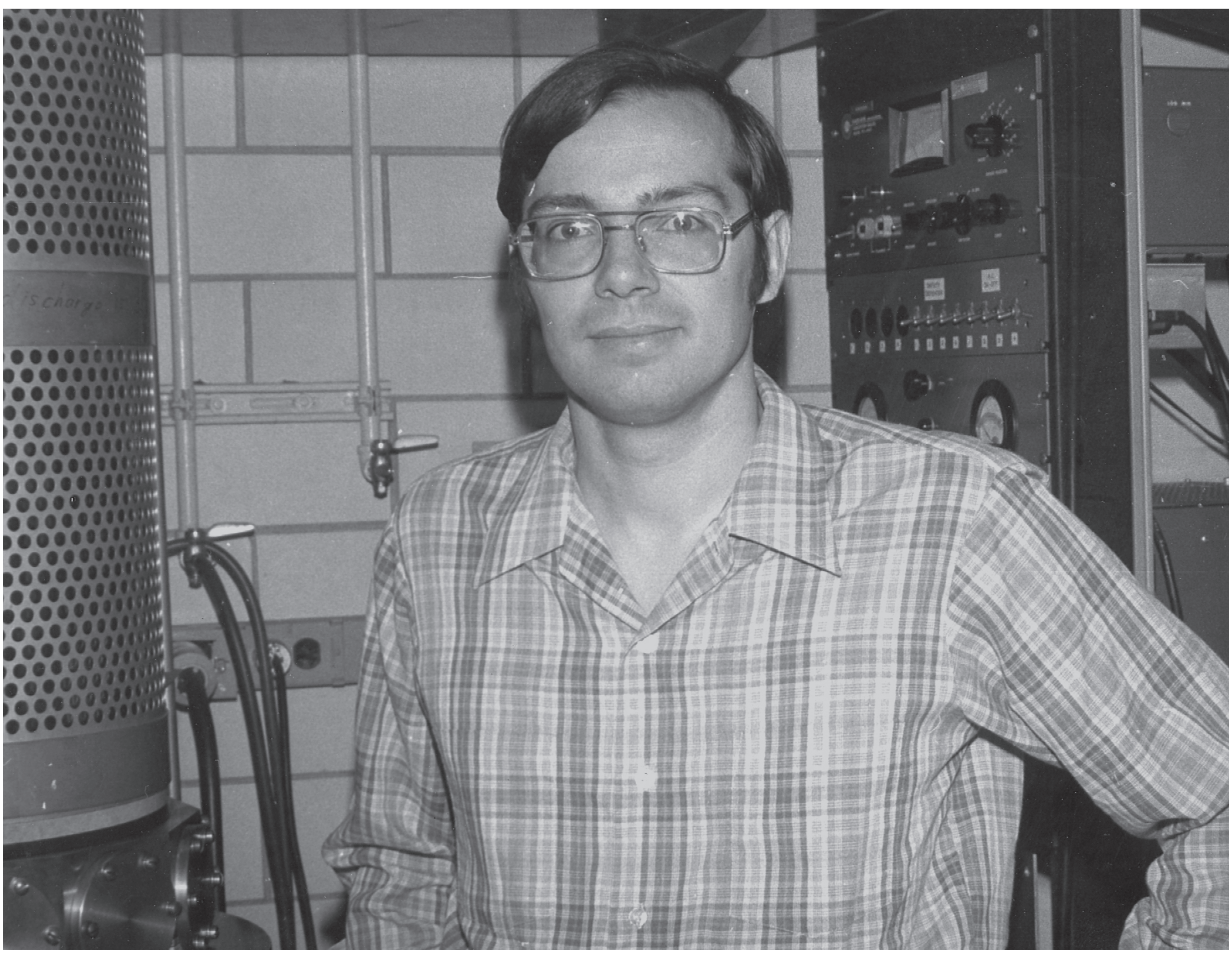
At Illinois, he received the 2016 Campus Executive Officer Distinguished Leadership Award. He was elected a Center for Advanced Study Professor in 2005. Van Harlingen retired from teaching in 2023, but continued to hold a research appointment up until his death.

Van Harlingen received a B.S. in physics in 1972 and a Ph.D. in physics in 1977, both from The Ohio State University. After a year as a NATO postdoctoral fellow at the University of Cambridge, England, he held a postdoctoral research position at the University of California, Berkeley for three years. He joined the faculty at Illinois Physics in 1981.

Beyond his professional achievements, Van Harlingen was known for his kind and gentle nature, his sense of humor and his ability to connect with others. He was a passionate sports fan, fervently supporting Ohio State football, Illinois basketball, and Chicago’s professional teams—the Cubs, the Bears, and the Blackhawks. He recently rediscovered his joy of golf as well. Dale loved to travel and was lucky to have spent time in countless cities and countries. He was a devoted wine enthusiast, often visiting Napa Valley and Sonoma’s vineyards.

Van Harlingen is survived by his wife, Judy Vandenberg; by his children, Jeffrey (Amanda) Van Harlingen, Rebecca (Jacob) Gray, and Erin (Jason) Vandenberg; and by his grandchildren, Ayden and Reese Van Harlingen and Makenna and Landon Gray.

Van Harlingen’s legacy of curiosity, education, and joy in life’s simple pleasures will be remembered by all who knew him.



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No reservation required.
Questions or special requests?

Contact Celia Elliott, cmelliot@illinois.edu
or phone (217) 244-7725

Tuesday, March 18
6–8 p.m.

Gala venue: Marquis Ballroom Northwest
Anaheim Marriott
700 West Convention Way, Anaheim

Summit venues: Anaheim Convention Center, Anaheim Marriott, and Hilton Anaheim