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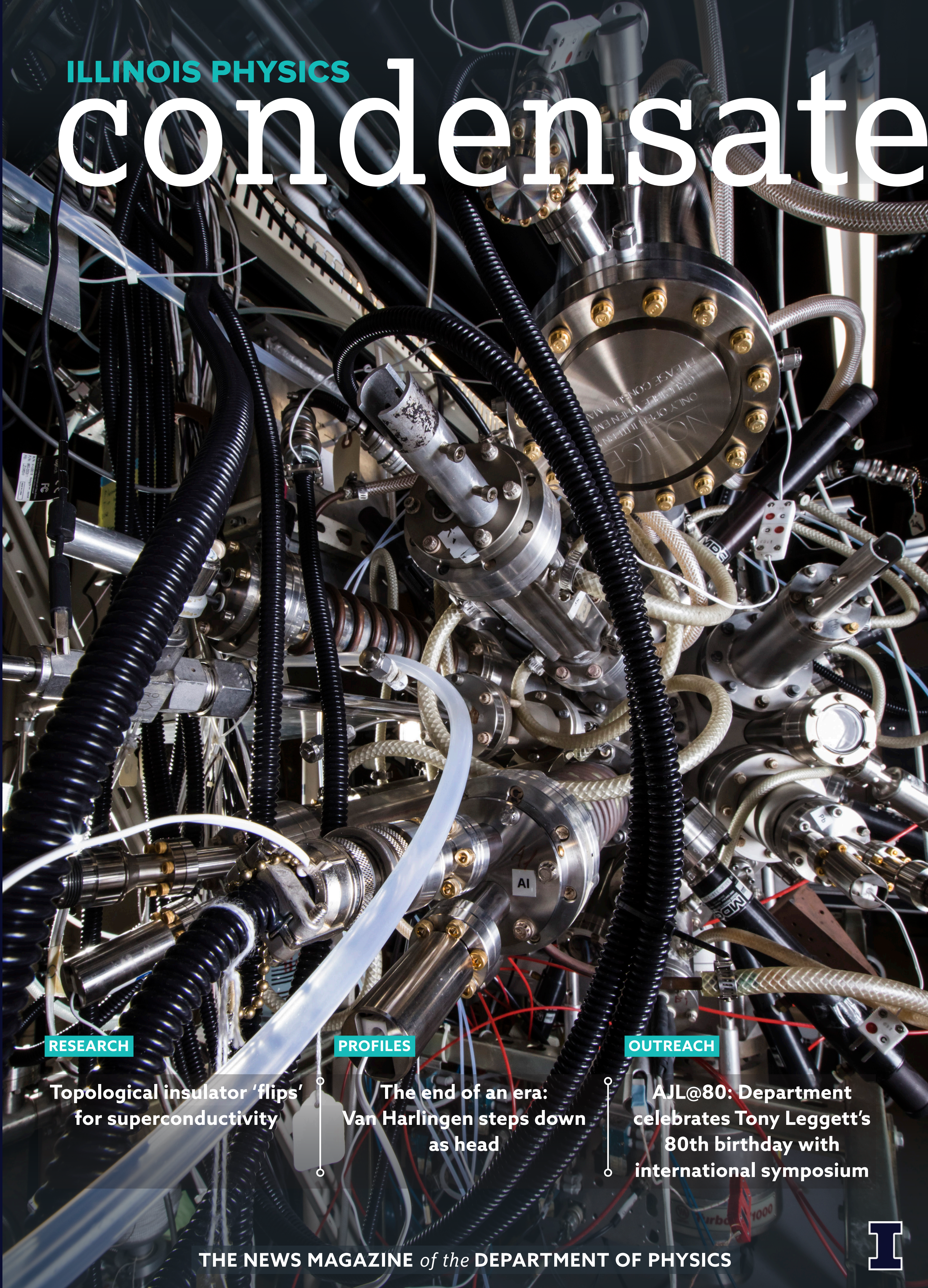

RESEARCH

Topological insulator 'flips' for superconductivity

PROFILES

The end of an era: Van Harlingen steps down as head

OUTREACH

AJL@80: Department celebrates Tony Leggett's 80th birthday with international symposium

THE NEWS MAGAZINE *of the* DEPARTMENT OF PHYSICS

ILLINOIS PHYSICS
CONDENSATE

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Cover image: A close-up shot of the atomic layer-by-layer molecular beam epitaxy system used to grow topological insulator thin-film samples in a new 'flip-chip' method, located in the Eckstein laboratory at the University of Illinois. Professors Tai-Chang Chiang and James Eckstein successfully engineered a superconducting topological insulator. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Back cover image: Materials Science and Engineering Building, view from Mathews Street, showing original "Physics" lintel. Completed in 1909 as the Physics Laboratory, it was the first dedicated physics building on the U of I campus. Photo by Siv Schwink for Illinois Physics

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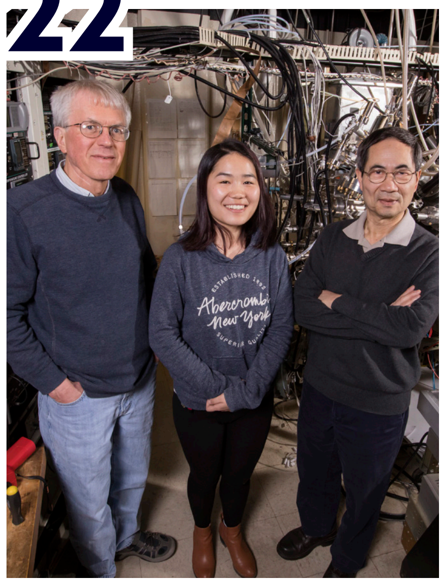

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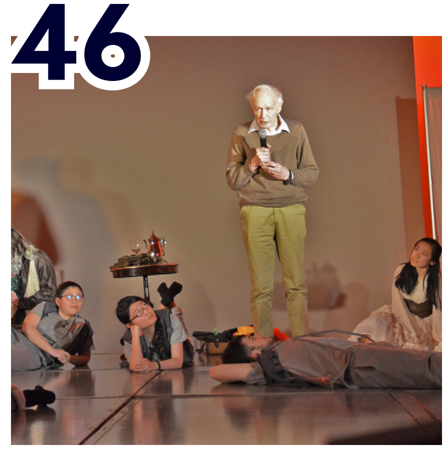

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WELCOME

FROM OUR *Department Head*

DALE VAN HARLINGEN

Unfinished business

My next life adventure is about to begin as I assume my new role as a Professor in the Department of Physics at the University of Illinois, a title I have held for nearly 37 years, but which for the past 12 years has been followed in my signature by "... and Head." In my last few days in this position, a number of emotions and reflections are emerging.

One looming question is what will happen next for me. I know I will be going back to my lab to focus on some projects in collaboration with my colleagues here at Illinois and around the world, starting with taking a sabbatical in the fall semester in Northern California (to no one's surprise) to focus and energize my research program over a glass of wine, or two (also pretty obvious to those who know me). What I do know is that I hope to work less and enjoy life more by spending more time with family and friends and traveling to places I have always wanted to see. But beyond that, the road is open, the path is uncertain, and I plan to "always take the long way home," in reference to one of my favorite songs by Norah Jones.

Another reflection is the discrepancy between how long I have been Head and yet how fast it has all gone. It seems only a short time ago that Ade (aka Dean Adesida) phoned me as I sat on a plane at O'Hare Airport about to leave for a conference in Russia and asked me to take on this role, and that Jeremiah Sullivan, the previous Head, sat with me to pass on his knowledge and wisdom of the internal workings of our department, as I am about to do with the next Head. I am aware that it has been a lot of work and a lot of late nights, but what I tend to remember is that it has mostly been a very exciting and rewarding experience and a lot of fun. Happily, life has a way of letting you remember the best days!

It is natural as well to reflect on how much we have accomplished over the past 12 years. I am very proud of that we have achieved, much of which is documented in the article about my tenure as Head that Siv Schwink has written for this newsletter.

But in this last letter from the Head that I will get to write, I want instead to mention some of the things I did not finish and some of the goals I set that remain unreached, in hopes that the new Head will read this. None of these comments will come as a surprise—I have always openly shared my dreams and ambitions, no matter how unattainable they seemed, with the faculty, staff, administration, and anyone who would listen. Wishing is always the first step toward happening.

One of my favorite passions has been to improve the physical infrastructure of the department, in terms of both expanding our capabilities and enhancing the appearance, functionality, and *feng shui* of our space. Several projects we have started are already well underway, such as the ESCO project that will actually end someday (I am told), the long-overdue 4th-floor particle physics theory suite, and the Loomis patio, whose plantings are just now beginning to bloom. Other endeavors are just getting started, most notably the extensive remodeling of the 4th floor of the Engineering Sciences Building (ESB) for new upper-level instructional labs, the parallel expansion of the Institute for Condensed Matter Theory (ICMT) on the 1st floor, and the newly conceived undergraduate-course Help Room on the 2nd floor of Loomis, an idea born from our experiences during the graduate-student teaching-assistant strike. And there remains a list of ambitious plans that are still in the dreaming stage—particularly the west-side addition to Loomis Laboratory above the lecture halls, which would include an open atrium, new lecture halls, new faculty offices, new elevators, new restrooms, a rooftop patio, and a coffee shop; and the proposed Advanced Experimental Research Facility adjacent to MRL, which would provide high-bay, environmentally controlled space for cutting-edge experimental research. These two projects offer creative designs that await equally creative investments. I would love to see progress continue toward these and other infrastructure projects—our talented faculty, staff, and students deserve an environment that is modern, enabling, and elegant in its appearance and functionality.

In the last couple of years, one of the highest priorities of the department has been to improve the quality of

our undergraduate programs and the opportunities we offer undergraduate students. This has been driven in part by the rapid growth in the number of our physics majors and by the intense pressure this has put on our courses, space, and budget, but equally by the change we have recognized in what our students want and need to successfully pursue their chosen careers in the present scientific and technical world. The plan we have crafted to create a new College of Engineering undergraduate degree program in Applied Physics is one of the most innovative and transformative paths we have adopted in recent years. It is exciting to watch how this idea is emerging from the collective input and creative brainstorming of faculty, staff, students, and outside consultants and is evolving into a vibrant coherent plan. I look forward to seeing the ultimate launch and evolution of this program over time, hoping that it will indeed achieve the success, impact, and visibility that we envision. Along the way, we hope also to address what have been two of the most difficult challenges our department has faced in the last decade, still needing attention: how to achieve significant increases in the diversity and inclusivity of our undergraduate major population; and how to increase the number of students that we can engage in useful undergraduate research opportunities and internships. I think we will get there.

On the research side, throughout my own academic career and especially as Head, I have been a strong proponent of teams and centers to enhance productivity, visibility, and the training of scientists. The Institute for Condensed Matter Theory (ICMT) and the Center for the Physics of Living Cells (CPLC) have been highly successful and serve as models for how such organizations can enhance our programs in specific areas and reinforce the "Urbana style" of interactive research that has become a hallmark and guiding principle of our program. Over the past few years, many of us have been advocating for starting collective efforts in Quantum Information Science (which connects our Condensed Matter and AMO Physics programs to interdisciplinary efforts in this field across campus), Fundamental Physics (which connects our programs in High Energy Physics, Nuclear Physics, Astrophysics, and Cosmology to efforts in Astronomy and to computational and "big data" science), and a broadened Biological Physics and Quantitative Biology theme (that couples our Biological Physics program to other life sciences programs on campus and to the new Carle Illinois College of Medicine). These agendas are currently in various stages of conception and implementation, and it would be great to see all of them come to fruition in the future.

Finally, I think the need has never been greater to focus as much on teaching Physics as we do on doing Physics. That includes extending the reach of our stellar Physics Education Research program, disseminating the effective pedagogical techniques and content they have developed to more places, to more age groups, and to more STEM disciplines. It also includes finding creative ways to convey the appreciation of science and its beauty and elegance to the broader population—this is particularly critical now with incompetent and misguided national leaders who do not understand the reality and importance of science and seek to suppress the truth and reality for political gain. In the last few years, my colleague Smitha Vishveshwara and I have been working on an approach with the working title of "Physics, Art, and Wine" or PAW, by which we hope to teach Physics "P", symbolic of truth and scientific knowledge, and Wine "W", symbolic of what can be created by scientists, engineers, and talented people of all disciplines (and what we enjoy while pondering all of this), via the Arts "A", which represents the beauty and elegance of life and learning. We physicists must step up and take the lead in propagating and preserving the reality and elegance of science.

You might say that I have had 12 years to do all of this so why didn't I finish it? All I can say is that the beauty and enjoyment of physics and of life is not where you have been or what you have done, it is about where you are going and who you are going with. There are no better travel companions than my colleagues and friends in our Physics Illinois family, and I look forward to the journey ahead.

ILLINOIS PHYSICS

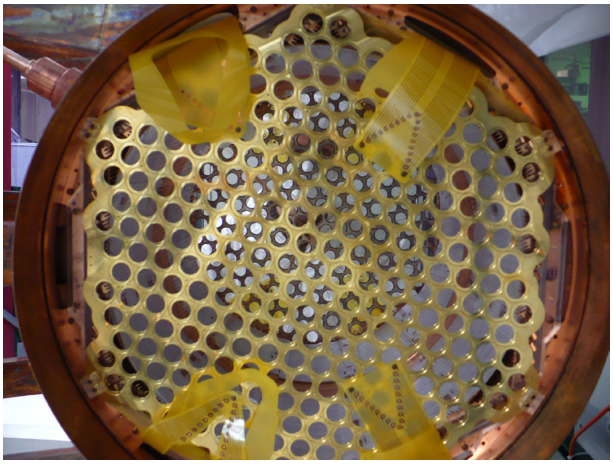
Spectrum

The Department of Physics at the University of Illinois at Urbana-Champaign is known for its collegial style of research—the "Urbana style"—that often involves collaborations across research areas and among theoretical and experimental physicists. Here is an inside glimpse of what some of our leading physicists are working on.

LIANG YANG

NUCLEAR PHYSICS

My research centers on understanding the fundamental properties of the neutrino, one of the most elusive and mysterious elementary particles in the universe. Neutrinos are tiny and have almost no interactions with ordinary matter. Physicists initially thought they were massless, like photons. But experimentalists discovered that some neutrinos produced by the Sun "disappear" when they reach Earth; it turns out that the "missing" neutrinos have oscillated into other types of neutrinos. The oscillation phenomenon implies that neutrinos do have small masses. The non-zero neutrino mass is an indication of new physics beyond the standard model of particle physics. Oscillation experiments can measure the mass differences between different types of neutrinos, but we still don't know the absolute mass scale of neutrinos nor why their masses are less than one-millionth the mass of an electron. Recent theories suggest neutrino mass is deeply connected to the dominance of matter in the universe.



The time projection chamber (TPC) of the EXO-200 detector. Photo courtesy of EXO-200.

To study neutrinos, we built state-of-the-art particle detectors deep underground, either in mines or tunnels inside tall mountains. The overburden in the underground locations shields the detectors from the harmful influence of high-energy cosmic rays. Using a combination of shielding techniques, we've created inside our experiments the most radio-quiet environment on Earth. The detectors themselves are constructed with specially chosen materials having ultra-low radioactive impurities.

My group plays a leadership role in the EXO-200 experiment, which utilizes enriched liquid xenon to study a very rare decay process, neutrinoless double beta decay. In this hypothetical process, two neutrons insides a nucleus decay into two protons with no emission of neutrinos. The discovery of this decay would signify that neutrinos are their own anti particles and illuminate the neutrino mass generation mechanisms. We are currently focused on developing new analysis techniques to perform the most sensitive searches with the EXO-200 data. We are also heavily involved in the R&D for the next-generation detector, nEXO, which promises to unravel the mystery surrounding the origin of the neutrino mass.

JESSIE SHELTON

PARTICLE PHYSICS

I'm a theoretical particle physicist, and this is a really exciting, if puzzling, time to be working in the field. The cosmological history of our universe tells us unambiguously that there must be physics beyond what we currently understand. We have an enormous amount of evidence for some unknown form of dark matter from its gravitational pull on ordinary matter. Additionally, the cosmos shows a mysterious preference for matter over antimatter that ensures that we are all here today. These two observations mean that new particle physics has to be out there somewhere, but the real challenge right now is to figure out exactly where is the best place to look—we have very few hints from experiment as to what form any of this new physics should take.

Jessie Shelton and Aida El-Khadra collaborate in Shelton's office in Loomis Laboratory. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

One cornerstone of my current research is to come up with new ways to understand the footprints of dark matter in the cosmos. If dark matter happens to live off in its own shadow world, interacting with us (and our experiments) only rarely, these kinds of astrophysical footprints might be our best shot for unraveling the particle physics behind dark matter. I'm also very interested in making sure we take full advantage of the amazing discovery opportunities offered by the Large Hadron Collider. This is the only place in the world where Higgs bosons can be made, and we still have a lot to learn about this particle. The Higgs boson is one of our best windows into the kinds of shadow worlds where dark matter might live. I've thought a lot about what possible decays of the Higgs boson into shadow particles would look like—these would be rare, weird events, and a real challenge experimentally, but the insight they could offer into the Higgs boson, dark matter, and the structure of our universe would be profound.

ALEKSEI AKSIMENTIEV

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

BIOLOGICAL PHYSICS

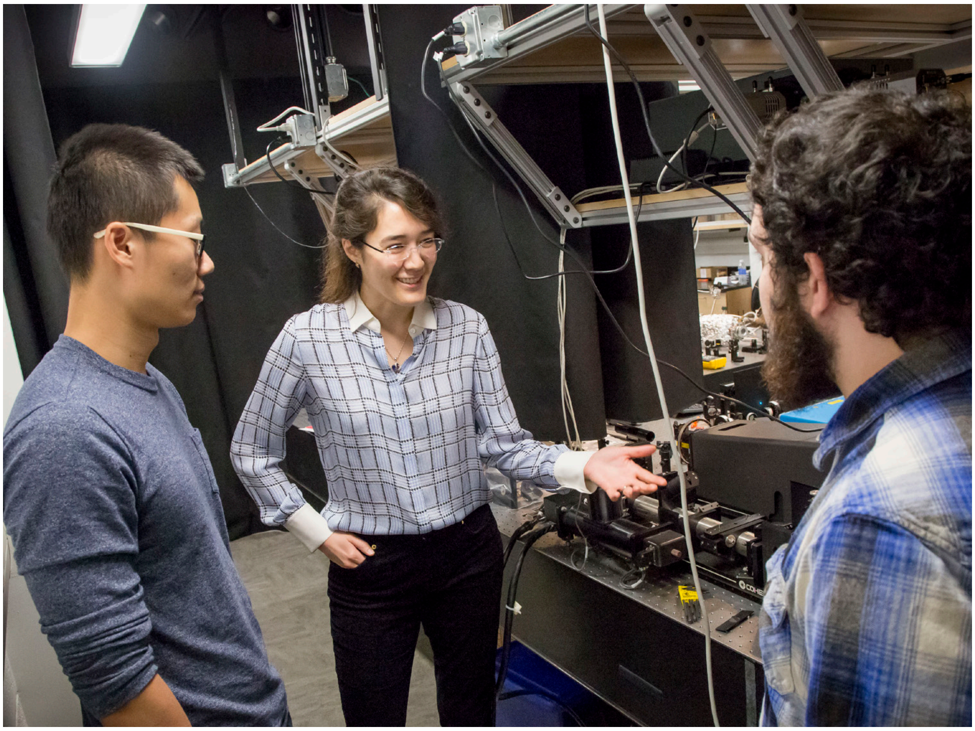
My group is using supercomputers to unravel the inner workings of biological cells and to design synthetic molecular machines that outperform their biological prototypes. Recent advances in biological sciences have provided a nearly complete list of biomolecules that make up a living cell. But how exactly that collection of molecules becomes a living being remains to be determined. Using computer models, my group is elucidating how biological phenomena originate from physical interactions between biomolecules. For example, we recently discovered that physical forces between DNA molecules depend on the genetic code they carry and can promote spatial segregation of DNA in a cell's nucleolus, controlling which genes turn on and off.

Complementing theoretical studies of biological processes, my group is using computer simulations to advance applications of nanotechnology in medicine. In collaboration with experimental groups from around the world, we are developing nanopore readers of biological information, the nucleotide sequence of DNA and RNA and the amino-acid sequence of proteins, to be used in clinical diagnostics and basic research. We are exploiting the self-assembly properties of DNA to build synthetic analogs of biological nanomachines, such as membrane channels and rotary electromotors. Recently, we demonstrated a synthetic DNA nanostructure that flips lipids of a cell membrane thousands of times faster than any biological or synthetic system known to date.

VIRGINIA LORENZ

ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

The ever-decreasing size of electronic components is leading to a fundamental change in the way computers operate. But at the few-nanometer scale, resistive heating and quantum mechanics prohibit efficient and stable operation. One of the most promising next-generation computing paradigms is spintronics, which uses the spin of the electron to manipulate and store information in the form of magnetic thin films. Although electron spin is a quantum-mechanical property, spintronics relies on macroscopic magnetization and thus does not take advantage of quantum mechanics in the algorithms used to encode and transmit information. Part of my group's research focuses on optical studies of the fundamental mechanisms by which we can efficiently manipulate magnetization using electric current. We developed an optical magnetometer capable of sensitively measuring current-induced magnetization changes using a technique complementary to electrical measurement techniques. It allows us to study the magnetization changes that occur just a few nanometers beneath the surface of these materials.



Virginia Lorenz works with grad students in her lab in Loomis Laboratory.. Image by L. Brian Stauffer, University of Illinois at Urbana-Champaign

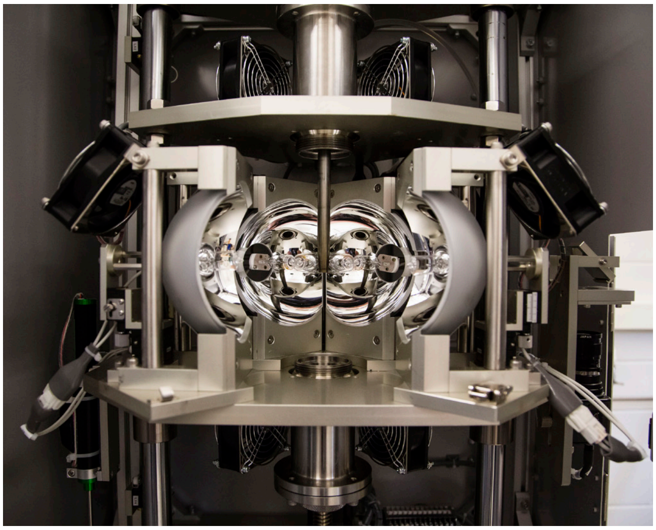
My group also works on problems related to new computing and communication technologies based on the quantum mechanical properties of photons. Quantum technologies often require the carriers of information, or qubits, to have specific properties. Photonic quantum states are good information carriers because they travel fast and are robust to environmental fluctuations, but characterizing and controlling photonic sources so the photons have just the right properties is still a challenge. We are working to develop efficient techniques for determining the properties of the photonic quantum states as well as methods to control these properties. Examples include using stimulated emission, the basis of laser technologies, to enhance the signal-to-noise ratio of characterization measurements as well as developing devices to store and retrieve the information encoded in photons via material excitations, such as the excited states of atoms and solids.

GREG MACDOUGALL

CONDENSED MATTER PHYSICS

My research group studies quantum materials and is dedicated to the discovery and exploration of exotic states of matter inside solids. In this branch of condensed matter physics, we study emergent phenomena in many-body systems—the amazing collective behavior of large numbers of particles working together that make these systems more than the sum of their parts. Illinois Physics has long been a world leader in this field, with an impressive level of expertise across a wide range of experimental and theoretical techniques held by talented researchers, working together inside a uniquely collaborative culture. My contribution is an expertise in the technique of neutron scattering.

Additionally, I maintain two laboratories at Illinois dedicated to materials discovery and crystal growth. Using our knowledge of the periodic table of elements and a toolbox of chemistry and crystal-growing techniques, we work to modify the properties of existing materials or to create entirely new materials, in a way that encourages unconventional behaviors. This includes materials that exhibit novel forms of superconductivity, interesting topological behaviors, and exotic forms of magnetism. One example is our recent discovery of material containing a so-called "spin-ice" state, wherein spins freeze into a non-equilibrium configuration with excitations that look like magnetic monopoles, but with additional evidence for strong quantum fluctuations. These properties raise the possibility at lower temperatures of a "quantum spin liquid" phase containing a long-ranged entanglement between magnetic moments. Another example is our work on manganese ferrimagnets, where we have seen that strong coupling between electron spins and atom positions allows us to create a state that self-separates into ordered and disordered regions separated by "domain walls," which themselves order on the microscale and can be moved around with applied magnetic fields. A third example is our work on high-temperature copper-oxide superconductors, wherein quasi-1D spin and charge orders coexist with a spatially modulated "pair density wave" superconducting condensate having unique properties. The novelty of these states is such that a complete understanding often requires exploration with a variety of different experimental techniques and frequent consultation with theorists. In light of this, my group often collaborates with our condensed matter colleagues in the department and makes great use of local facilities housed in the Fredrick Seitz Materials Research Laboratory.



A crystal growing chamber in one of Gregory MacDougall's labs in the Frederick Seitz Materials Research Laboratory. Image by L. Brian Stauffer, University of Illinois at Urbana-Champaign

My group is a prolific user of scattering instrumentation housed at national laboratories: most regularly, the neutron scattering instruments at the Spallation Neutron Source and High Flux Isotope Reactor at Oak Ridge National Laboratory, but also x-ray scattering facilities at Argonne National Laboratory and the Cornell High Energy Synchrotron Source and muon spin rotation spectrometers at the TRIUMF meson facility. In all cases, the ultimate goal of our research is not to understand the workings of any particular compound, but instead to illuminate the origin of novel and potentially useful behaviors that may extend to entire classes of materials.

Daniel Johnson, a Knight of St. Patrick

SIV SCHWINK
for Illinois Physics Condensate

Daniel Johnson, a graduating senior double majoring in engineering physics and computer science, was dubbed a 2018 Knight of St. Patrick, a high honor conferred through the College of Engineering at the University of Illinois at Urbana-Champaign. He is among 11 students knighted this year by a ceremonial St. Patrick at the annual Knights of St. Patrick Ball in March.

St. Patrick knighthood recognizes student contributions to the college and demonstration of leadership and character. The knights are selected by a special committee of past knights, honorary knights (faculty members) and "Golden Shamrocks" (staff).

"This honor means a lot to me," says Johnson. "I have worked hard to contribute to our community at Illinois over the past few years, and it shows that the College of Engineering has seen and recognizes my efforts. I'm very happy to represent the physics and computer science departments in this way."

An unofficial part of the tradition, the knight-elects play several pranks leading up to the night of the ball.

Johnson shares, "I personally like pranks that are dumb and don't hurt anyone. So I bought 150 fake skeleton keys and key tags. A friend and I wrote on every one of them, "Engineering Hall 206," which is undergraduate admissions, and we dropped these all over campus."

Johnson, who will start a doctoral program at Stanford University's Institute for Computational and Mathematical Engineering in the fall, having received a 12-quarter fellowship, says he values the opportunities he has had to participate in research as an undergraduate at the U of I. It's fair to say, he took these research opportunities and ran hard with them. Remarkably, he is first author on two journal articles published during his undergraduate years.

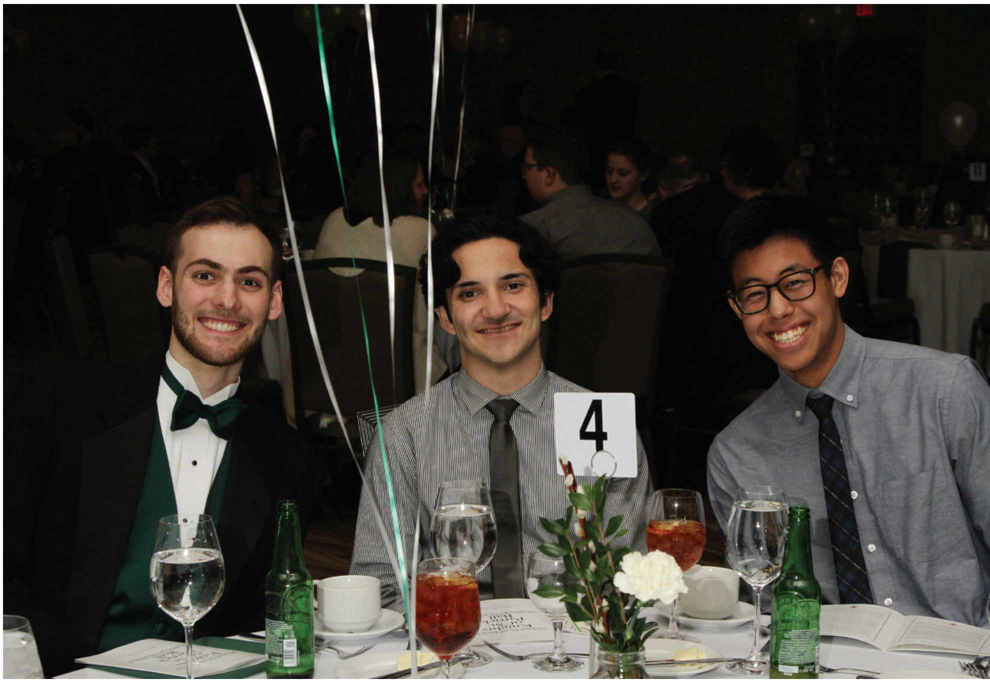
"Being able to be the first author on two papers for two different research groups, I attribute to the great environment of learning and research at Illinois," Johnson stresses. "I have definitely done a lot of hard work to accomplish this. But I recognize that wouldn't have meant anything if my mentors hadn't guided me and then set me loose. They allowed me to contribute in a real way as an undergraduate."

Last summer, working as a SPIN (Students Pushing INnovation) intern at the National Center for Supercomputing Applications, Johnson wrote a software program called Python Open Source Waveform ExtractoR (POWER) that has made post-processing of large-scale numerical relativity simulations on the Blue Waters supercomputer vastly more efficient. This work is published in the journal Classical and Quantum Gravity (19 Dec 2017, v. 35, no. 2).

"POWER software is able to take black-hole-simulation results and transform the data into physical strain—the push-pull on the fabric of spacetime," he explains.

As a SPIN intern, Johnson was mentored by Eliu Huerta, the research scientist who heads NCSA's Gravity Group.

"Eliu is so good at shepherding students' professional development," affirms Johnson. "My very first day at NCSA, I was running a binary black hole simulation. And as soon as you say you want to do something, he is encouraging and guiding you. He makes sure everyone gets a lot of opportunities.



Above, graduating senior Daniel Johnson (left) invited friends and family plus his physics academic adviser Merissa Jones to attend the Knights' Ball in March.

Left, the keys Johnson used in his Knight's prank.

Below, Johnson is knighted by St. Patrick during the Knights' Ball.

Photos courtesy of Scott Christenson, Memory Lane Photography.

"Eliu at one point made the comment, it would be nice if we had a python program that did this, this, and this. He had the mathematical method and wanted something that would do the work within that same high-performance computing environment—so there would be less porting of data. I thought, I know some numerical methods, I can do it. And I kind of went on a coding bender. Once I get in the zone, I don't want to stop. I have to say, I certainly couldn't have published the paper without Eliu and the SPIN program."

Daniel Johnson kisses the Blarney Stone during the Knights Ball ceremonies. Photo courtesy of Scott Christenson, Memory Lane Photography

An additional first-author paper came out of an earlier research experience, working for Illinois Research Professor Daniel Andruczyk; Johnson contributed to the startup of the HIDRA plasma/fusion facility, developing the software control system for the primary instrument formerly known as WEGA, donated by the Max Planck Institute to the Department of Nuclear, Plasma, and Radiological Engineering. Johnson started this work in the spring semester of freshman year and worked through the next summer following his sophomore year. This work is published in the journal *Fusion Engineering and Design* (March 2018).

Johnson additionally interned at Wolfram Research the fall of his freshman year and at Garmin in the summer following his sophomore year.

Looking back over his four years at Illinois, Johnson knows he made the most of it. Pairing physics with computer science was natural for Johnson, as his research exploits attest.

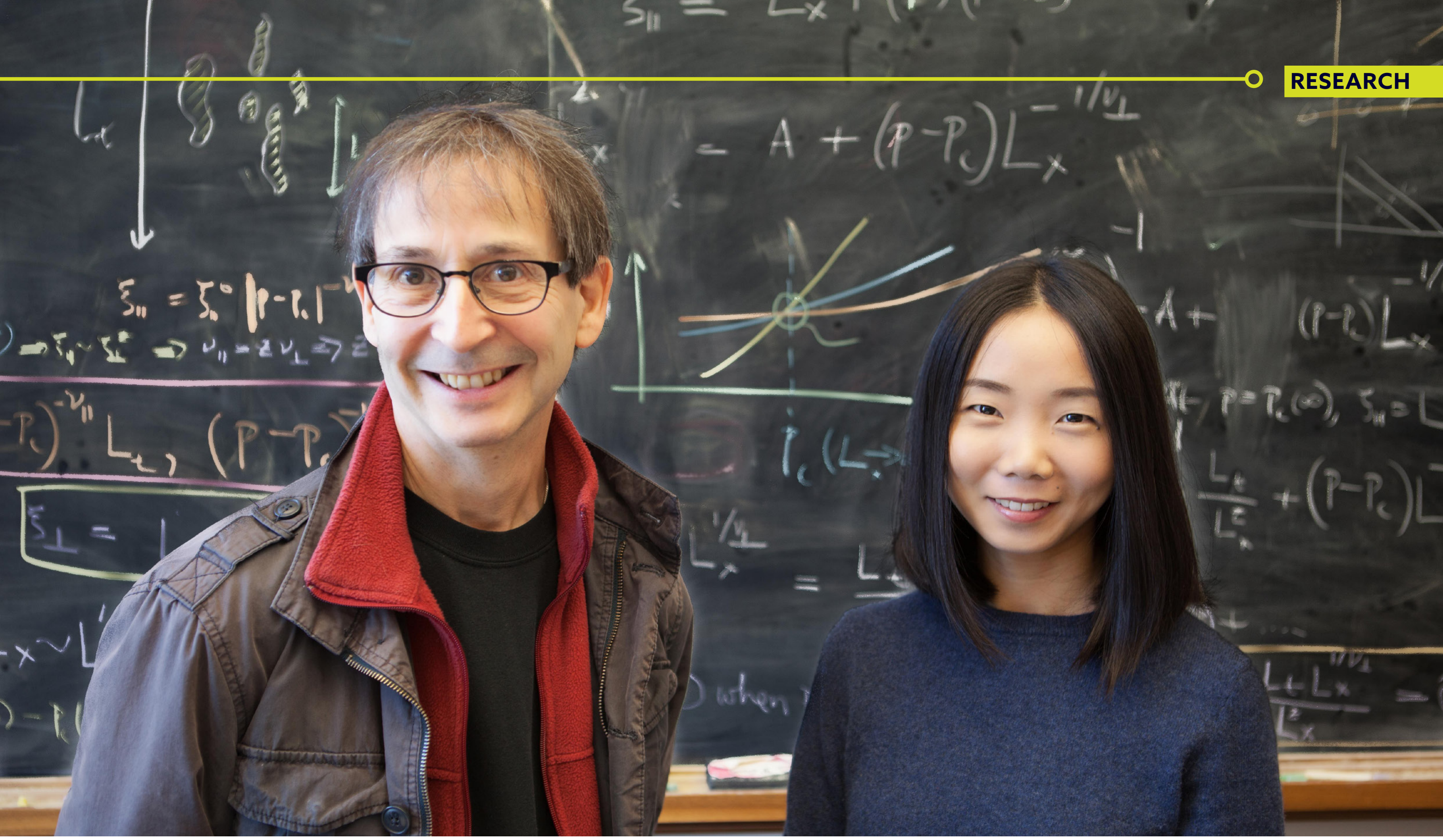
"I've really loved being in the physics department. I especially have fond memories of my physics study group—we were just 5 friends who took several upper-division physics courses together."

Johnson adds that his love of physics was first kindled in his junior year at William Fremd High School, in science teacher Matt Zimolzak's class.

Johnson said he also has great memories from the various student groups he was involved with over the four years at Illinois. Highlights include volunteer work through the student service organization Volunteer Illini Projects; teaching steganography and computational physics through the Computer Science Sail program, which invites high schoolers to take a day of courses taught by undergrads; and leading tours for the College of Engineering admitted student days.

Johnson shares that his ultimate career goals are still forming, and he is keeping all options open. He is at this point most interested in the fields of cosmology, computational physics, applied math, and pure computer science.

The Knights of St. Patrick tradition came to the U of I in 1950. According to the group's website, the tradition originally traces back to 1903 at the University of Missouri, Columbia. The story goes, students there claimed only an engineer could have accomplished the tremendous feat of driving the snakes out of Ireland, and therefore St. Patrick must have been an engineer. St. Patrick's Day was declared a day to celebrate engineering, and St. Patrick became a symbol of honor and achievement among engineering students.



A virus-bacteria coevolutionary 'arms race' solves the diversity paradox by 'killing the winner'

SIV SCHWINK
for Illinois Physics Condensate

There is remarkable biodiversity in all but the most extreme ecosystems on Earth. When many species are competing for the same finite resource, a theory called competitive exclusion suggests one species will outperform the others and drive them to extinction, limiting biodiversity. But this isn't what we observe in nature. Theoretical models of population dynamics have not presented a fully satisfactory explanation for what has come to be known as the diversity paradox.

Now researchers at the Carl R. Woese Institute for Genomic Biology at the University of Illinois at Urbana-Champaign have shed new light on this fundamental question in ecology, by improving a popular proposed scenario for diversity known as "Kill the Winner." Chi Xue and Nigel Goldenfeld, supported by the NASA Astrobiology Institute for Universal Biology, which Goldenfeld directs, approached the diversity paradox from the perspective of non-equilibrium statistical mechanics.

Goldenfeld and Xue developed a stochastic model that accounts for multiple factors observed in ecosystems, including competition among species and simultaneous predation on the competing species. Using bacteria and their host-specific viruses as an example, the researchers showed that as the bacteria evolve defenses against the virus, the virus population also evolves to combat the bacteria. This "arms race" leads to a diverse population of both and to boom-bust cycles when a particular species dominates the ecosystem and then collapses—the so-called "Kill the Winner" phenomenon. This coevolutionary arms race is sufficient to yield a possible solution to the diversity paradox.

These findings were published December 28, 2017, in *Physical Review Letters*, in the article, "Coevolution Maintains Diversity in the Stochastic 'kill the winner' Model." (PRL, 119, 268101, 2017).

Goldenfeld and Xue looked at a classic example of the diversity paradox from marine biology, the paradox of the plankton. In observed marine ecosystems, many plankton species and bacterial strains coexist and have high diversity.

Goldenfeld explains, "There any many tentative hypotheses to solve the paradox. The one we are interested in is the 'Kill the Winner' (KtW) hypothesis. In a nutshell, it says that the problem with the diversity paradox is the assumption of a steady state. A real ecosystem is never in a steady state, but undergoes population fluctuations from the interplay between predators and prey.

"Take for example competing strains of bacteria, each of which is prey to a host-specific virus. In this scenario, as soon as a particular bacterial species starts to dominate in the ecosystem, the virus (or bacterial phage) that preys preferentially on that host will have plenty of targets and so will proliferate, culling the host-bacteria population. After this viral attack, another bacterial species may emerge as the most abundant for a time, until its population is likewise diminished by its bacterial phage. This host-specific predation maintains the coexistence of competing species by preventing a winner from emerging, so that in a sense, species go through boom-bust cycles of abundance."

"Moreover," Xue adds, "in a system where plankton compete with bacteria for a resource, a protozoan group that hunts down all bacterial strains non-selectively suppresses the population of the entire bacterial community and thus leaves space for plankton species to survive. The KtW idea works on two layers here: the coexistence of bacteria and plankton as the first layer, and the coexistence of bacterial strains as the second. It's a very appealing theory and has become one of the most influential ideas in marine ecology."

However, the original formulation of KtW required a widely used technical simplification. Xue points out, "The original KtW model did not account for spatial variations or any fluctuation effects and was formulated in terms of continuous biomass concentrations and deterministic ordinary differential equations. The significance of this is that it incorrectly accounts for what happens when viruses attack bacteria, for example. In this formulation, the population of bacteria in a region of space can get smaller and smaller during viral predation, but never reaches zero. In a sense, the theory allows the number of bacteria to be a fraction, when in reality it must be an integer like zero, one, two, etc. So the theory under-estimates what happens during viral attack, and in particular cannot capture extinction."

To go beyond the simplified model, Xue and Goldenfeld developed a stochastic model of bacteria-virus interactions that could describe population fluctuations, in order to see whether the KtW scenario really emerged from calculations more detailed than those undertaken previously.

Their model described the outcome of the bacteria-virus encounters using a method similar to that used in statistical thermodynamics to describe colliding atoms in a gas. Just as the properties of gases—such as sound waves and thermal effects—can be computed from understanding the atomic collisions, Xue and Goldenfeld used statistical mechanics methods to compute the behavior of populations from understanding bacteria-virus encounters.

Goldenfeld explained that the KtW scenario was not put into their calculations by hand. Their goal was to model the bacteria-virus interactions at an individual level to see if KtW emerged. However, from their simulations, Xue and Goldenfeld were surprised to find that the species in their model didn't even coexist let alone exhibit KtW dynamics—they were driven to extinction!

Xue noted, "The breakdown of the original KtW model in the presence of stochasticity was a surprise to us. Stochasticity represents something closer to the randomness of nature. We hadn't expected this very reasonable model to fail."

The researchers realized that there is another way in which ecosystems are not in a steady state, separate from the population fluctuations that they had attempted to model. Real ecosystems are also evolving. Indeed, when they also included coevolution into their model, the model reproduced the biodiversity observed in nature.

Goldenfeld describes, "In the case of the ecosystem in our marine biology example, there is coevolution of each bacteria strain and its host-specific virus as they compete in what can be described as an arms race. As the bacteria find ways to evade the attack of viruses, the viruses evolve to counter the new defenses. In this coevolving KtW model, the arms race is driven by mutations that arise in both bacterial and viral strains."

Xue adds, this idea has support from genomics. "Researchers, especially in marine microbial ecology, have found that different bacterial strains show strong variation in regions of their genomes that are believed to be associated with phage resistance. This observation links the diversity of bacterial genomes to the virus predation and agreed with our coevolving KtW framework."

"And the extinction issue can now be avoided," Xue continues. "When a strain goes extinct, it, or something close to it, can still reemerge later as a mutant from another strain. This coevolutionary mechanism acts in addition to spatial heterogeneity, which also helps diversity: if a particular strain becomes extinct in a particular region of space, it is possible that it can be re-seeded by the migration or diffusion of that strain from somewhere else. Thus, at long time scales, the diversity of the system is maintained."

Goldenfeld says it was satisfying to see how the use of stochastic modeling enabled the team to include the already well-known coevolutionary arms race within a simple model, from which emerged Kill-the-Winner dynamics.

"The KtW model is a profoundly important idea," he asserts, "but it needs to be supplemented by additional factors such as coevolution and spatial variation. Our work demonstrates the breakdown of the simplest but most widely used version of the theory and presents a way to restore its explanatory power. It's exciting that our theoretical model not only captured the diversity that we were trying to explain, but also is consistent with a seemingly disconnected strand of data from the field of genomics, thus providing a satisfying narrative that works from the level of ecosystems down to the genome itself."

Goldenfeld and Xue plan to pursue this line of inquiry further. They speculate that diversity is generally related to how far away an ecosystem is from equilibrium. Future work will attempt to quantify the relationship between diversity and the distance from equilibrium.

The results of this theoretical study are in principle testable in experiments:

"I am most excited about the possibility that the coevolving KtW model can be tested by conducting experiments with coevolving bacteria and phages," Xue comments. "The short reproduction time and high mutation frequency make microbial systems a good candidate to test models in which evolutionary and ecological dynamics happen at the same time scale."

The researchers' interest in this problem arose from a seemingly different area of science. Goldenfeld explains that this work has implications for open questions in astrobiology and for detecting life on extraterrestrial worlds.

"The diversity of ecosystems, especially microbial ones, is a key factor in understanding the likelihood that life can gain enough of a toehold in a planetary environment not only to survive, but also to be detectable. With the groundbreaking discovery by the Cassini mission of global oceans of liquid water on Europa (moon of Jupiter) and Enceladus (moon of Saturn), marine microbial ecology is poised to become an even more active component of astrobiology. Understanding the fundamental mechanisms driving biodiversity—a pervasive feature of terrestrial ecosystems—will help us predict the observability of non-terrestrial life on worlds that will be within reach of our probes in the coming decades."

This work was supported by the National Aeronautics and Space Administration Astrobiology Institute (NAI) under Cooperative Agreement No. NNA13AA91A issued through the Science Mission Directorate. C.X. was partially supported by the L.S. Edelheit Family Biological Physics Fellowship from the Department of Physics, University of Illinois at Urbana-Champaign. The findings are those of the researchers and not necessarily those of the funding agency.

'Return to the Lab': LabEscape sequel opens in Urbana

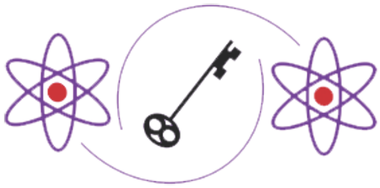
LABESCAPE AGENTS—WE NEED YOU (AGAIN)!!

PROFESSOR S. IS GONE, BUT HER RESEARCH LIVES ON AND HAS APPARENTLY FALLEN INTO THE WRONG HANDS. NOW THE SECURITY OF THE WHOLE PLANET HANGS IN THE BALANCE. ONLY YOU CAN DETERMINE THE ORIGIN OF THE STRANGE POWER SURGES FROM THE PROFESSOR'S OLD SECRET LAB AND WHO IS USING HER QUANTUM PROCESSOR TO HOLD THE ENTIRE COUNTRY HOSTAGE. BUT TIME'S RUNNING OUT, FOR YOU AND THE FREE WORLD!

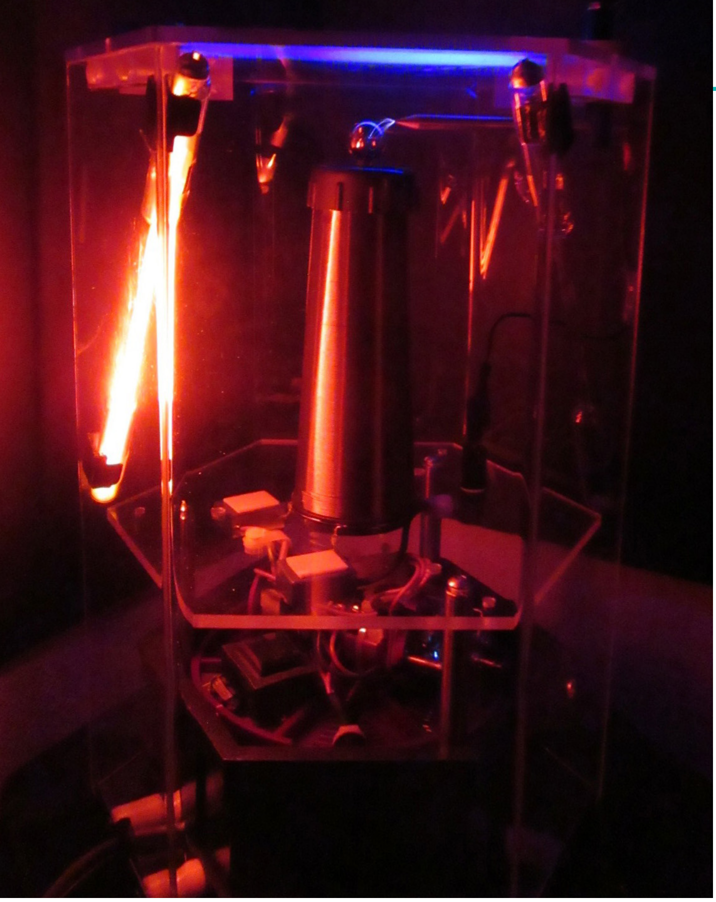
SIV SCHWINK
for Illinois Physics Condensate

LabEscape is calling all agents back to the lab to solve the continuing mystery of the disappearance of Professor Schrödenberg, a University of Illinois physicist who developed a top-secret quantum computer that can crack any digital-security encryption code in the world. Once again, it's up to you and your team to save the free world from evil forces plotting its destruction, and you have precisely 60 minutes to do it. Mysterious circumstances and new intelligence have reopened this investigation—unhackable messages were hacked three days ago, there are power surges coming from Dr. S's abandoned secret lab, and her missing technology and a hard drive that were lost before her disappearance have now resurfaced.

LabEscape, a science-themed escape room at Lincoln Square Mall in Urbana, first opened in January 2017. Paul Kwiat, a physics professor at the University of Illinois at Urbana-Champaign, initiated the nonprofit LabEscape project two years ago as a community outreach effort, with the goal of showing that science can be fun, beautiful, useful, and accessible to all.



To date, nearly 2,500 agents have passed through in groups of up to six participants at a time. The sequel adventure, "Return to the Lab," picks up the storyline three months after the first adventure. It features all new interactive



A Tesla coil produces voltages in excess of 50,000 volts that are able to arc through the air (the bright blue spark coming from the metal sphere at the top) and light up neon bulbs that aren't connected in any way. Photo by Paul Kwiat, Department of Physics, University of Illinois at Urbana-Champaign

puzzles that are based on amazing physics phenomena. Just like in the first adventure, no science knowledge is required—all information required to solve these puzzles is provided among the clues in the escape room.

"The sequel's storyline was already planned when we wrote the first adventure," shares Kwiat. "It's really important that the storyline make sense and that the puzzles fit the storyline. I'm excited about these new puzzles, because they really are jaw-dropping. The agents who have revisited the lab have enjoyed the sequel as much or more than the original. Both adventures have received rave reviews. We're particularly gratified that many of our attendees have described LabEscape as the best escape room they've ever done; this is nice testament to the many, many hours the puzzle development teams invested to create the space."

In his own leading-edge research, Kwiat develops techniques for secure communications with unbreakable encryption by manipulating the quantum behaviors of entangled photons—so he very much identifies with Dr. S's storyline.

Kwiat adds, "We've had a wonderful time exposing people to the joy of being a scientist, with the rewards for solving a difficult problem commensurate with the difficulty. It's been great to see directly how important diversity is, too—groups with a mix of backgrounds often have a much easier time, even over groups that are all scientists. In fact, one of our record times is held by a group with no technical background at all."

Day-to-day operations at LabEscape are handled by U of I undergraduate students who have completed introductory physics courses. Two levels of play are available in each storyline; the 'challenge' mode adds several puzzles beyond those in the 'novice' mode.

Kwiat plans to keep the escape room open for about two more years, after which he hopes to pack it up as a travelling exhibit on loan to science museums in major U.S. cities. In July, he and a graduate student teaching assistant will bring the LabEscape experience to the annual meeting of the American Association of Physics Teachers, being held in Washington, D.C.

Financial support for this outreach project has been provided by the National Science Foundation through the American Physical Society, and by the Department of Physics and the Academy for Excellence in Engineering Education at the U of I at Urbana-Champaign. Proceeds above the cost of development and operation will support Urbana-Champaign's STEM-related community outreach efforts.

> *"I've always thought that taking care of the people was the most important part of the job. That, coupled with upholding and preserving the values and the reputation of the department. That was easy for me, because I have believed in it."*

THE END OF AN ERA:

Van Harlingen steps down as head

SIV SCHWINK
for Illinois Physics Condensate

For 12 years, Head of Department and Professor Dale Van Harlingen has served the Department of Physics at the University of Illinois at Urbana-Champaign as its top administrator. The 10th department head in the department's 129-year history, he has capably maintained the department's long tradition of strong, impactful leadership. 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 has voiced to the campus community and to the broader academic community what he holds to be true, that this department is "the best place in the world to do physics."

On June 30, 2018, Van Harlingen will step down from his responsibilities as head of department. He has no plans to retire from the university. He intends to invest his regained time and energy into research, travelling, and enjoying his family.

Van Harlingen comments, "The time has gone really fast—I feel like I just started. It's an interesting job, every day there is something new, and most of it is fun. In 12 years, the landscape changes, but how I approached the job never did—I tried to take care of the people and to keep the department healthy in all aspects. I've heard people say it can be hard to manage faculty, but that's not the job—you don't manage faculty. For me, it's been gratifying to be able to work with people high enough in the university's administration to get stuff done and, at the same time, with the people who are actually doing the work of scholarship. I will definitely miss it."

U of I Vice Chancellor for Academic Affairs and Provost Andreas Cangellaris remarks, "In my role first as a fellow department head, then as a dean, and now as provost, I have been very fortunate to work closely with Dale. Through our many conversations and interactions, I have come to admire his unwavering commitment to the significance of physics and the sciences as a cornerstone of Illinois's global stature and impact. He has hired some incredible faculty members and has worked diligently and creatively to provide them with the resources they needed to succeed and to thrive. And he has looked after the entire Illinois Physics community with care, dedication, and diligence, fostering a dynamic, interdisciplinary culture of inquiry, discovery, and innovation, inspired by scholarly excellence and bold thinking. I commend him and I thank him for his outstanding service to the University of Illinois."

A 15-year member of the Illinois Physics Advisory Board, James Garland, professor of physics and president emeritus of Miami University, has known Van Harlingen since he was an undergraduate in Garland's physics classes at The Ohio State University. Garland, a condensed matter experimental physicist, later served as Van Harlingen's doctoral adviser.

Garland states, "Dale was a brilliant student at Ohio State, both at the undergraduate and graduate level. His doctoral dissertation research on the thermoelectric flux in superconducting toroidal rings was a remarkable and difficult project, far outside the boundary of most Ph.D. student capabilities.

"I feel enormously privileged to have worked with Dale and to have watched him rise through the ranks to become one of the most recognized and respected condensed matter physicists of his generation. But in addition to his research expertise, Dale is also known for his even-handedness and sensible judgment—traits that have served him well as department head. Successfully leading a large academic department is one of the most difficult challenges in academic administration (speaking from experience!). Few people have the requisite mix of interpersonal and organizational skills and intellectual depth that the job calls for. Dale's quiet and determined commitment to his departmental colleagues has paid large dividends for Illinois Physics. I know Illinois Physics well, and I continue to believe the department sets the standard for the entire physics world."

Illinois Physics Associate Head for Graduate Programs and Professor Lance Cooper has worked closely with Van Harlingen on departmental administrative matters. He adds, "Dale's tenure as head of department has left an indelible mark on the culture of Illinois Physics. Since 2006, Dale's sense of what is possible has continuously infused the department with optimism and has kept the faculty, staff, and students focused on sustaining excellence in research, teaching, and service. Even in the face of a challenging funding environment, Dale has maintained his ambitious vision for the department and has been tireless in his efforts to preserve the department's top-ten ranking and the number-one ranking of its flagship condensed matter physics program. His service to the department has been truly exemplary."

Illinois Physics Associate Head for Undergraduate Programs and Professor Mats Selen states, "The department has thrived under Dale's watchful and caring leadership. He is smart and decisive, but more than that, he is just a very kind person. Dale's warmth and good humor come through every time he addresses the faculty, staff, and students, whether he has prepared his words

28 FACULTY MEMBERS HIRED BY VAN HARLINGEN

Yann Chemla (2007)
Ido Golding (2007)
Mark Neubauer (2007)
Ben Lev (2008)
Taylor Hughes (2011)
Shinsei Ryu (2011)
Lucas Wagner (2011)
Thomas Kuhlman (2012)
Gregory MacDougall (2012)
Liang Yang (2012)
Caroline Riedl (2013)
Peter Adshead (2014)
Bryan Clark (2014)
Thomas Faulkner (2014)
Jeff Filippini (2014)
Bryce Gadway (2014)
Ben Hooberman (2014)
Vidya Madhavan (2014)
Verena Martinez Outschoorn (2014)
Julia "Jessie" Shelton (2014)
Anne Sickles (2014)
Jun Song (2014)
Virginia "Gina" Lorenz (2015)
Gilbert Holder (2016)
Seppe Kuehn (2016)
Barry Bradlyn (2018)
Patrick Draper (2018)
Fahad Mahmood (2019)
(2 additional Van Harlingen hires were pending at time of publication)

or is speaking off the cuff. His efforts on behalf of the department have lifted others up and enabled their accomplishments—he has always welcomed and supported others' ideas, without needing to claim recognition for himself. He has especially looked after our younger faculty members and helped them to be successful. And, as busy as he has been and as much as he has seamlessly juggled, he has always made himself available. He never showed the slightest irritation when I regularly poked into his office without an appointment to share an idea—to the contrary, he seemed to welcome it. He really is an extraordinary leader. I hope our next department head will have the same kind of openness, positivity, and caring that Dale has in spades."

Van Harlingen has led the department through tumultuous times for the State of Illinois and for the University of Illinois System. Leadership changes at the top levels of the university's administration were the norm: he served with a total of five U of I presidents, five chancellors, seven provosts, and four College of Engineering deans.

Van Harlingen first came into the position during a time when the financial woes of the State of Illinois limited hiring of new faculty members at the U of I. At the same time, retirements were taking a toll on physics faculty numbers. Van Harlingen knew that to sustain the department's internationally recognized research programs and to be able to offer the highest quality education and research opportunities to graduate and undergraduate students, the department would need to make strategic hires, and he pushed hard to get tenure-track positions allocated and to open faculty searches, to return the department to its critical mass of about 67 core faculty members.

Over the course of his tenure as head, Van Harlingen made 28 faculty hires—that represents more than a third of the current core faculty and about half of the women faculty in the department's history. He also oversaw 18 retentions, 36 promotions, and 12 appointments to chaired professorships. And though he didn't hire them, he is also very pleased to have played a big role just prior to becoming head in recruiting Nadya Mason, Smitha Vishveshwara, and Peter Abbamonte.

Van Harlingen also expanded the physics staff in strategic areas, including advancement, communications, course management, and outreach personnel.

One tradition for which Van Harlingen will surely be remembered among the Illinois Physics faculty is his use of popular music to nucleate the challenges and opportunities the department faced during his tenure as head. Fall and spring faculty meetings were an opportunity for Van Harlingen to deliver a state-of-the-department address, and Van Harlingen started each one by naming a theme song that captured the tone of that point in time.

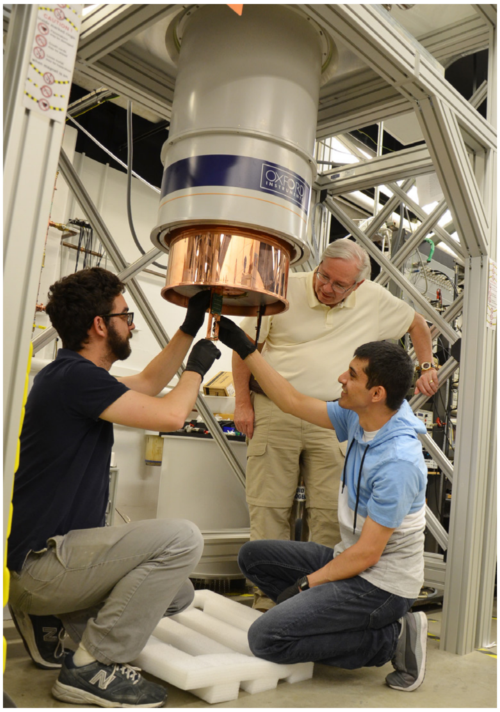
Songs he used include "Happy Days are Here Again," "Stormy Weather," "Everything is Awesome" (from the LEGO Movie), "If You Can't Be Good, Be Gone," "Don't Look Down," "If I Had a Million Dollars," "Climb Every Mountain," "We'll Get By with a Little Help from Our Friends," "Have I Stayed Too Long at the Fair?" "Aint Nobody Gonna Miss Me When I'm Gone," "Give Me the Highway," and "You Can't Always Get What You Want." The first theme Van Harlingen offered wasn't a song, but a quote from *A Tale of Two Cities*: "It was the best of times, it was the worst of times." And at one point, he used a paraphrased TV show title: "Orange and Blue is the New Black."

Asked what have been his most important contributions as head, the first answer that comes to Van Harlingen is his improving the quality of food and wine at departmental receptions and opening up the annual faculty reception to staff, to be more inclusive of the entire Illinois Physics family. This response won't surprise anyone who knows Van Harlingen. He has regularly invited faculty and staff to join together to celebrate the department and its milestones. And as he points out, the quality of the food and wine is not an insignificant thing, as it sets a tone at each gathering.

But in meeting with the candidates for the next head of department, what he shared wasn't about the wine or the food—it was about taking care of the faculty and staff and preserving and improving the department.

"I told each of them, I've always thought that taking care of the people was the most important part of the job. That, coupled with upholding and preserving the values and the reputation of the department. That was easy for me, because I have believed in it. It's important to recognize that the quality of the department is measured by its scholarship. And to maintain an environment that continues to produce world-class scholarship, the head of department has to support faculty in their research and teaching, treat the staff as a vital part of the team, and maintain the camaraderie that has been the hallmark of this department since long before I came here—this is what's most important. Beyond that, if there is time, then you can try to accomplish the things you want to do—and for me, that had to do with upgrading our infrastructure."

And in fact, Van Harlingen managed to complete an impressive list of infrastructure upgrades while head, improving communal spaces, teaching



Department Head and Professor Dale Van Harlingen works with graduate students Gilbert Arias (left) and David Hamilton in his lab in the Frederick Seitz Materials Research Laboratory. Photo by Siv Schwink for Illinois Physics

spaces, and public areas using funds from the college and campus, offset by departmental funds and generous financial contributions from alumni. These projects included reclaiming the closed physics library as a communal meeting space and naming it the Interaction Room, modernizing the graduate student lounge and study rooms, modernizing the classrooms in the Walnut Hallway including technology upgrades, adding a large modern classroom space on the second floor where the defunct publications room had been, updating the furniture in the first-floor lobby, adding an ADA-compliant ramp to the Green Street entrance, adding a patio with tables and chairs outside the Green Street entrance, renovating the first-floor bathrooms and adding a women's restroom on the fourth floor, installing a breakroom with a modern kitchen and furnishings for faculty and staff, and remodeling the main office.

An additional project is currently underway, a $5 million expansion of the upper-level instructional laboratory space slated to open in 2019. These labs will increase intro-lab teaching capacity by 50 percent. The new labs are located next to the existing labs on the fifth and sixth floors of the Engineering Sciences Building, in close proximity to the Institute for Condensed Matter Theory.

Another project now underway was inspired by undergraduate students. At a recent town hall meeting, students expressed how much they enjoyed the faculty-run drop-in "Help Room," held in the Interaction Room during the campus-wide graduate-student-employees strike earlier this semester. They asked the administration to make the drop-in-anytime office hours permanent after the strike ended. To satisfy this request, rooms on the second floor of Loomis Laboratory that currently house a classroom, an undergraduate physics major lounge, and a TA commons will be merged to form one large Help Room hosting all-day drop-in office hours.

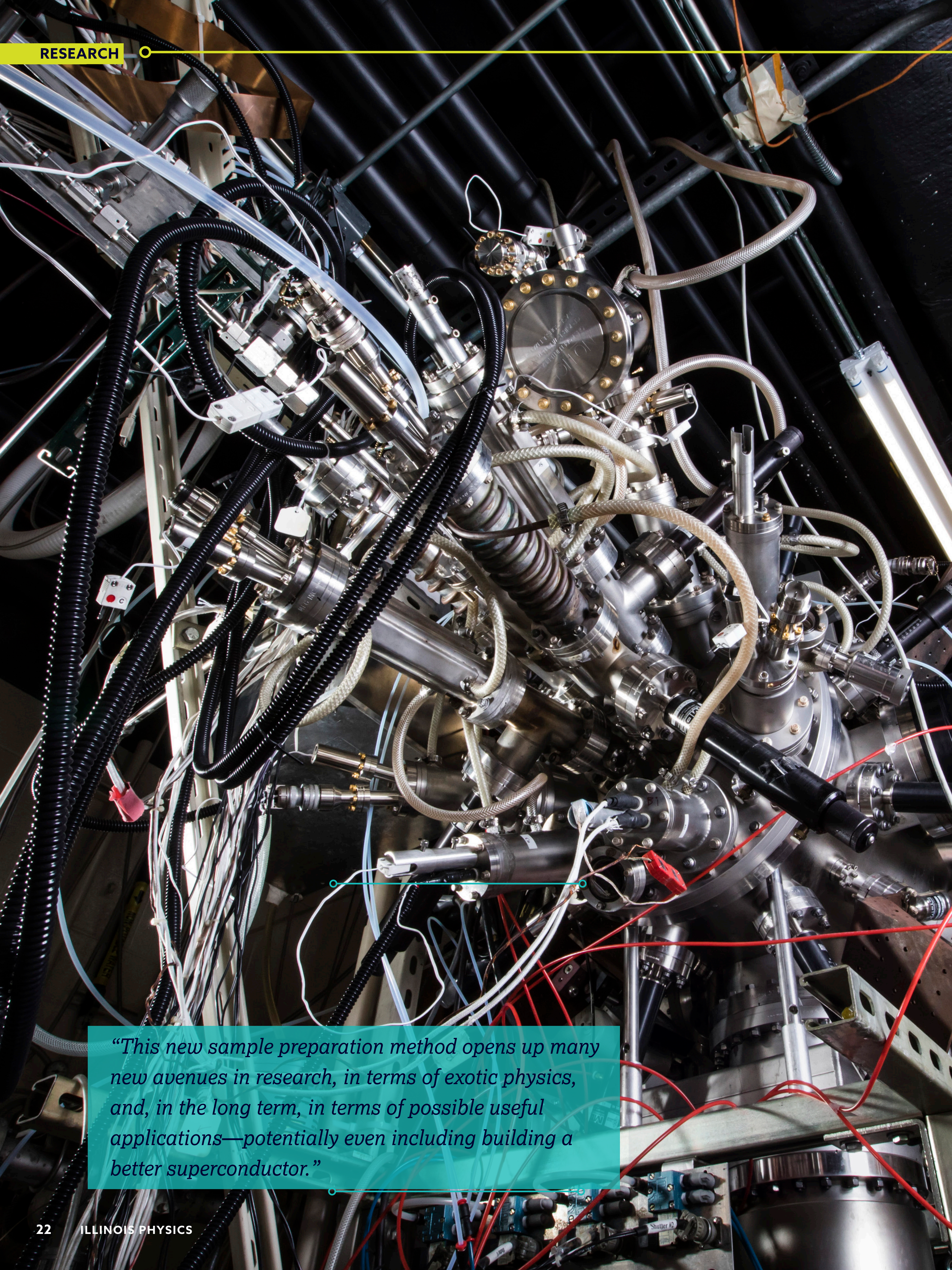
Van Harlingen's proposed infrastructure improvements actually went above and beyond this extensive list. In order to be shovel-ready should state funding for capital improvements be made available, he ordered architectural feasibility studies in 2013 for an advanced experimental research building (estimated at $20 million) and for a multi-story addition to Loomis Laboratory above the lecture halls (estimated at $40 million). And while these projects have not been funded, they do demonstrate Van Harlingen's confident vision for the future expansion of the department.

Underlying all of these efforts is Van Harlingen's can-do outlook and his steadfast dedication to the people in the physics department. He himself describes his leadership style as an inverted pyramid, with him at the bottom supporting everyone else in the department. His unique brand of servant-style leadership trusts and invests in the abilities of the people around him to do their best.

Director of the Illinois Materials Research Science and Engineering Center (I-MRSEC) and Professor Nadya Mason comments, "I think Dale's time as head can be summed up by one word: Vision. That's with a big V. Because Dale has Vision for us as the best physics department in the world, now and always. And he's been extremely thoughtful and effective in implementing plans that align with this vision, pushing forward with big grants, stellar new hires, classy building renovations, and more.

"I think his successful tenure boils down to the fact that Dale really loves this department. All of his actions show this. He loves the Urbana style of collaborations and friendships and the occasional martini lunch, and he's worked to keep this spirit alive. He cares about people, faculty and students, fostering an inclusive climate, and is always open to good ideas that make this place better for everyone."

Professor Brian DeMarco agrees, "Dale has led the physics department for the last 12 years with incredible ambition and vision. His impressive legacy includes 28 faculty hires, the new patio and interaction room in Loomis, upgraded classrooms in the Walnut Hallway, and the creation of a women's restroom on the fourth floor of Loomis. The tireless effort that Dale invested into these initiatives and our faculty, staff, and students is an expression of his great love for the Department of Physics."



"This new sample preparation method opens up many new avenues in research, in terms of exotic physics, and, in the long term, in terms of possible useful applications—potentially even including building a better superconductor."

TOPOLOGICAL INSULATOR 'FLIPS' FOR SUPERCONDUCTIVITY

Topology meets superconductivity through innovative reverse-order sample preparation

Left: The atomic layer by layer molecular beam epitaxy system used to grow the topological insulator thin-film samples for this study, located in the Eckstein laboratory at the University of Illinois. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

SIV SCHWINK
for Illinois Physics Condensate

A groundbreaking sample preparation technique has enabled researchers at the University of Illinois at Urbana-Champaign and the University of Tokyo to perform the most controlled and sensitive study to date of a topological insulator (TI) closely coupled to a superconductor (SC). The scientists observed the superconducting proximity effect—induced superconductivity in the TI caused by its proximity to the SC—and measured its relationship to temperature and the thickness of the TI.

TIs having induced superconductivity are of paramount interest to physicists because they have the potential to host exotic physical phenomena, including the elusive Majorana fermion—an elementary particle theorized to be its own antiparticle—and to exhibit supersymmetry—a phenomenon reaching beyond the standard model that would shed light on many outstanding problems in physics. Superconducting TIs also hold tremendous promise for technological applications, including topological quantum computation and spintronics.

Naturally occurring topological superconductors are rare, and those that have been investigated have exhibited extremely small superconducting gaps and very low transition temperatures, limiting their usefulness for uncovering the interesting physical properties and behaviors that have been theorized.

TIs have been used to engineer superconducting topological superconductors (TI/SC), by growing TIs on a superconducting substrate. Since their experimental discovery in 2007, TIs have intrigued condensed matter physicists, and a flurry of theoretical and experimental research taking place around the globe has explored the quantum-mechanical properties of this extraordinary class of materials. These 2D and 3D materials are insulating in their bulk, but conduct electricity on their edges or outer surfaces via special surface electronic states that are topologically protected, meaning they can't be easily destroyed by impurities or imperfections in the material.

But engineering such TI/SC systems via growing TI thin films on superconducting substrates has also proven challenging, given several obstacles, including lattice structure mismatch, chemical reactions and structural defects at the interface, and other as-yet poorly understood factors.

Now, a novel sample-growing technique developed at the U of I has overcome these obstacles. Developed by Physics Professor James Eckstein in collaboration with Physics Professor Tai-Chang Chiang, the new "flip-chip" TI/SC sample-growing technique allowed the scientists to produce layered thin-films of the well-studied TI bismuth selenide on top of the prototypical SC niobium—despite their incompatible crystalline lattice structures and the highly reactive nature of niobium.

These two materials taken together are ideal for probing fundamental aspects of the TI/SC physics, according to Chiang: "This is arguably the simplest example of a TI/SC in terms of the electronic and chemical structures. And the SC we used has the highest transition temperature among all elements in the periodic table, which makes the physics more accessible. This is really ideal; it provides a simpler, more accessible basis for exploring the basics of topological superconductivity," Chiang comments.

The method allows for very precise control over sample thickness, and the scientists looked at a range of 3 to 10 TI layers, with 5 atomic layers per TI layer. The team's measurements showed that the proximity effect induces superconductivity into both the bulk states and the topological surface states of the TI films. Chiang stresses that what they saw gives new insights into superconducting pairing of the spin-polarized topological surface states.

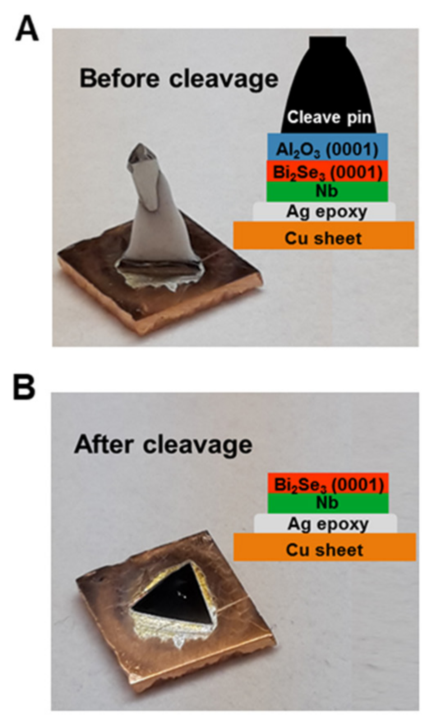
"The results of this research are unambiguous. We see the signal clearly," Chiang sums up. "We investigated the superconducting gap as a function of TI film thickness and also as a function of temperature. The results are pretty simple: the gap disappears as you go above niobium's transition temperature. That's good—it's simple. It shows the physics works. More interesting is the dependence on the thickness of the film. Not surprisingly, we see the superconducting gap is reduced for increasing TI film thickness, but the reduction is surprisingly slow. This observation raises an intriguing question regarding how the pairing at the film surface is induced by coupling at the interface."

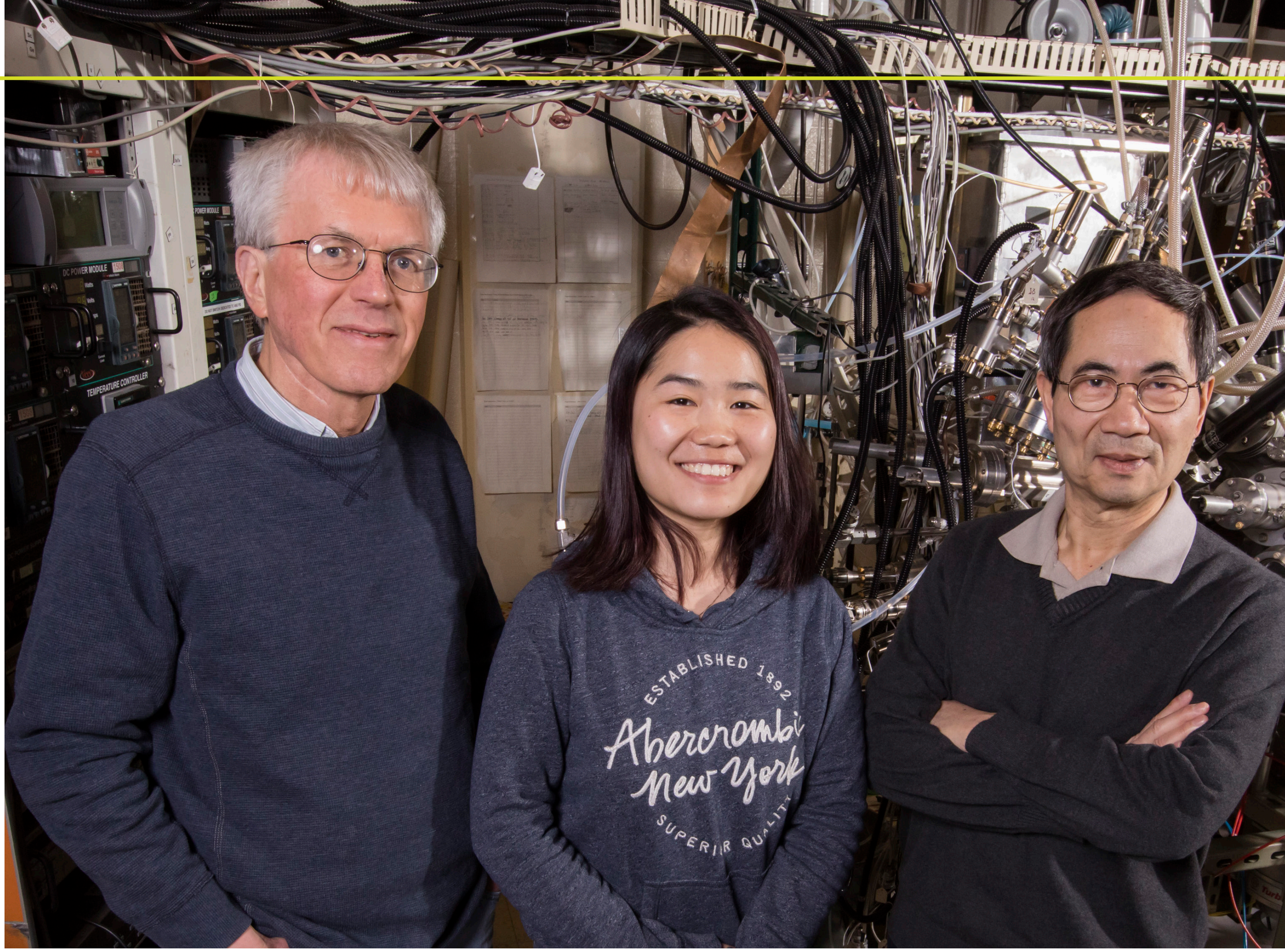
Chiang credits Eckstein with developing the ingenious sample preparation method. It involves assembling the sample in reverse order, on top of a sacrificial substrate of aluminum oxide, commonly known as the mineral sapphire. The scientists are able to control the specific number of layers of TI crystals grown, each of quintuple atomic thickness. Then a polycrystalline superconducting layer of niobium is sputter-deposited on top of the TI film. The sample is then flipped over and the sacrificial layer that had served as the substrate is dislodged by striking a "cleavage pin." The layers are cleaved precisely at the interface of the TI and aluminum oxide.

Eckstein explains, "The 'flip-chip' technique works because the layers aren't strongly bonded—they are like a stack of paper, where there is strength in the stack, but you can pull apart the layers easily. Here, we have a triangular lattice of atoms, which comes in packages of five—these layers are strongly bonded. The next five layers sit on top, but are weakly bonded to the first five. It turns out, the weakest link is right at the substrate-TI interface. When cleaved, this method gives a pure surface, with no contamination from air exposure."

The cleavage was performed in ultrahigh vacuum, within a highly sensitive instrument at the Institute for Solid State Physics at the University of Tokyo capable of angle-resolved photoemission spectroscopy (ARPES) at a range of temperatures.

Chiang acknowledges, "The superconducting features occur at very small energy scales—it requires a very high energy resolution and very low temperatures. This portion of the experiment was completed by our





Above: (L-R) Professor of Physics James Eckstein, his graduate student Yang Bai, and Professor of Physics Tai-Chang Chiang pose in front of the atomic layer-by-layer molecular beam epitaxy system used to grow the topological insulator thin-film samples for this study, in the Eckstein laboratory at the University of Illinois. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Left: The 'flip-chip' cleavage-based sample preparation: (A) A photo and a schematic diagram of assembled Bi_2Se_3(0001)/Nb sample structure before cleavage. (B) Same sample structure after cleavage exposing a 'fresh' surface of the Bi_2Se_3 film having a predetermined thickness. Image courtesy of James Eckstein and Tai-Chang Chiang, U of I Department of Physics and Frederick Seitz Materials Research Laboratory

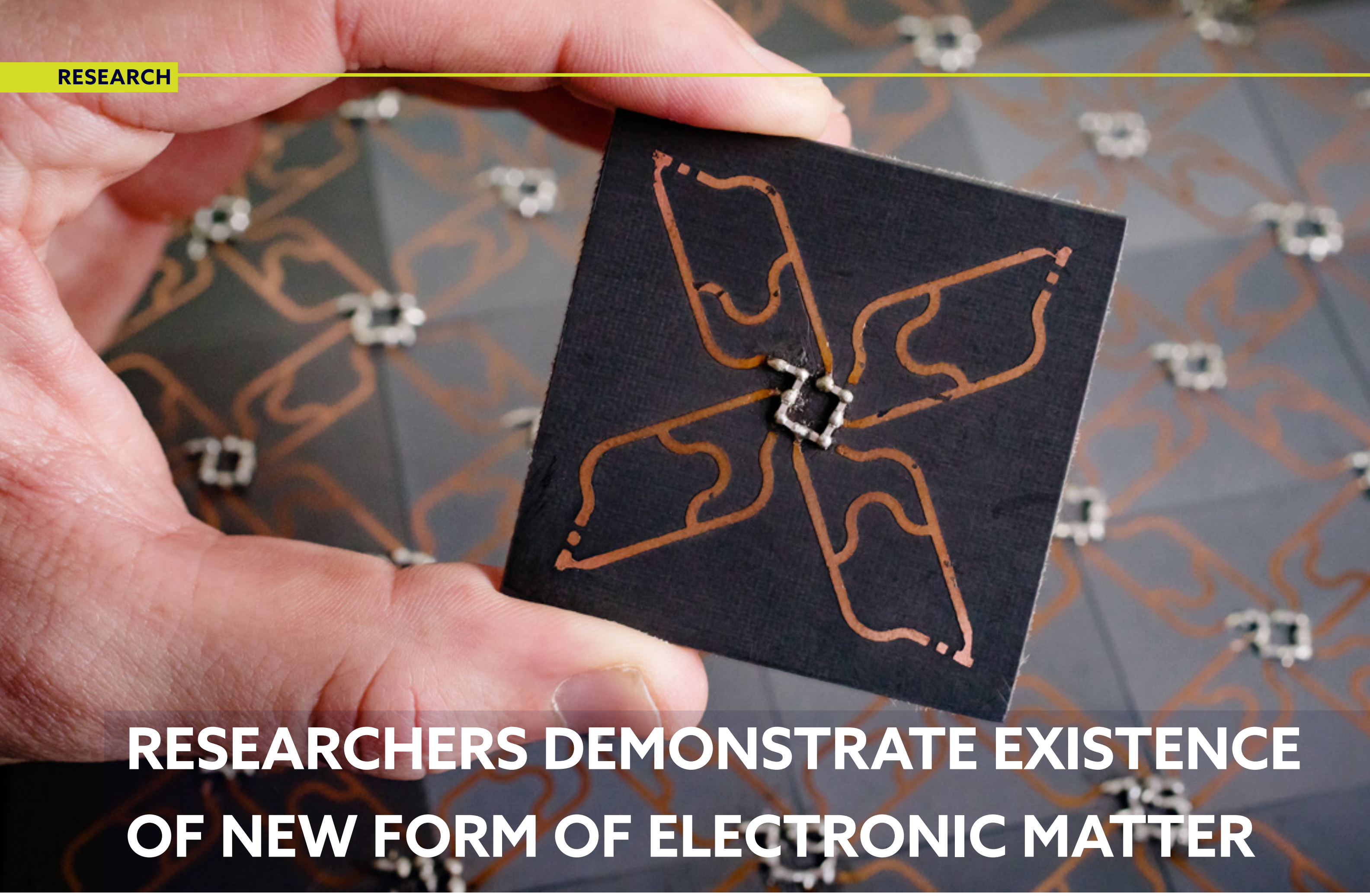
colleagues in the University of Tokyo, where they have the instruments with the sensitivity to get the resolution we need for this kind of study. We couldn't have done this without this international collaboration."

"This new sample preparation method opens up many new avenues in research in terms of exotic physics and ultimately in terms of possible useful applications—potentially even including building a better superconductor. It will allow preparation of samples using a wide range of other TIs and SCs. It could also be useful in miniaturization of electronic devices and in spintronic computing, which would require less energy in terms of heat dissipation," Chiang concludes.

Eckstein adds, "There is a lot of excitement about this. If we can make a superconducting TI, theoretical predictions tell us that we could find a new elementary excitation that would make an ideal topological quantum bit, or qubit. We're not there yet, and there are still many things to worry about. But it would be a qubit whose quantum mechanical wave function would be less susceptible to local perturbations that might cause dephasing, messing up calculations."

These findings were published online on 27 April 2018 in the journal *Science Advances*.

This research was funded by the U.S. Department of Energy, the National Science Foundation, the Deutsche Forschungsgemeinschaft, and by Japan's Ministry of Education, Culture, Sports, Science and Technology. The conclusions presented are those of the researchers and not necessarily those of the funding agencies.



RESEARCHERS DEMONSTRATE EXISTENCE OF NEW FORM OF ELECTRONIC MATTER

LOIS YOKSOULIAN
for the Illinois News Bureau

Researchers have produced a "human scale" demonstration of a new phase of matter called quadrupole topological insulators (QTIs) that was recently predicted using theoretical physics. These are the first experimental findings to validate this theory.

The researchers report their findings in the March 15, 2018, issue of the journal *Nature*.

The team's work with QTIs was born out of the decade-old understanding of the properties of a class of materials called topological insulators. "TIs are electrical insulators on the inside and conductors along their boundaries, and may hold great potential for helping build low-power, robust computers and devices, all defined at the atomic scale," said mechanical science and engineering professor and senior investigator Gaurav Bahl.

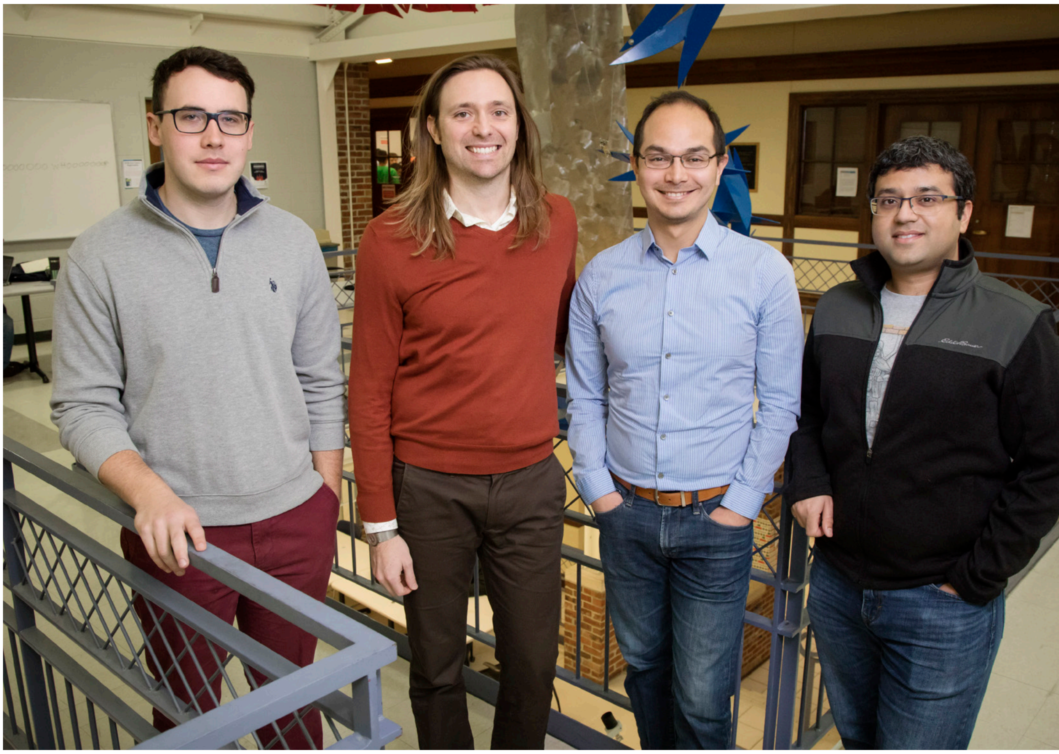
The uncommon properties of TIs make them a special form of electronic matter. "Collections of electrons can form their own phases within materials. These can be familiar solid, liquid and gas phases like water, but they can also sometimes form more unusual phases like a TI," said co-author and physics professor Taylor Hughes.

TIs typically exist in crystalline materials, and other studies confirm TI phases present in naturally occurring crystals, but there are still many theoretical predictions that must be confirmed, Hughes said.

One such prediction was the existence of a new type of TI having an electrical property known as a quadrupole moment. "Electrons are single particles that carry charge in a material," said physics graduate student Wladimir Benalcazar. "We found that electrons in crystals can collectively arrange to give rise not only to charge dipole units—that is, pairings of positive and negative charges—but also high-order multipoles in which four or eight charges are brought together into a unit. The simplest member of these higher-order classes are quadrupoles in which two positive and two negative charges are coupled."

It is not currently feasible to engineer a material atom by atom, let alone control the quadrupolar behavior of electrons. Instead, the team built a workable-scale analogue of a QTI using a material created from printed

Pictured left to right, grad student Kitt Peterson, Physics Professor Taylor Hughes, grad student Wladimir Benalcazar and Mechanical Science and Engineering Professor Gaurav Bahl are the first to demonstrate a new phase of matter called quadrupole topological insulators that was recently predicted theoretically. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign



circuit boards. Each circuit board holds a square of four identical resonators—devices that absorb electromagnetic radiation at a specific frequency. The boards are arranged in a grid pattern to create the full crystal analogue.

"Each resonator behaves as an atom, and the connections between them behave as bonds between atoms," said Kitt Peterson, the lead author and an electrical engineering graduate student. "We apply microwave radiation to the system and measure how much is absorbed by each resonator, which tells us about how electrons would behave in an analogous crystal. The more microwave radiation is absorbed by a resonator, the more likely it is to find an electron on the corresponding atom."

The detail that makes this a QTI and not a TI is a result of the specifics of the connections between resonators, the researchers said.

"The edges of a QTI are not conductive like you would see in a typical TI," Bahl said, "Instead only the corners are active, that is, the edges of the edges, and are analogous to the four localized point charges that would form what is known as a quadrupole moment. Exactly as Taylor and Wladimir predicted."

"We measured how much microwave radiation each resonator within our QTI absorbed, confirming the resonant states in a precise frequency range and located precisely in the corners," Peterson said. "This pointed to the existence of predicted protected states that would be filled by electrons to form four corner charges."

Those corner charges of this new phase of electronic matter may be capable of storing data for communications and computing. "That may not seem realistic using our 'human scale' model," Hughes said. "However, when we think of QTIs on the atomic scale, tremendous possibilities become apparent for devices that perform computation and information processing, possibly even at scales below that we can achieve today."

The researchers said the agreement between experiment and prediction offered promise that scientists are beginning to understand the physics of QTIs well enough for practical use.

"As theoretical physicists, Wladimir and I could predict the existence of this new form of matter, but no material has been found to have these properties so far," Hughes said. "Collaborating with engineers helped turn our prediction into reality." ■

This work is funded by the National Science Foundation and U.S. Office of Naval Research. The conclusions presented are those of the researchers and not necessarily those of the funding agencies.

THE 2018

A.C. Anderson Undergraduate Research Scholar: *Kyle Nelli*
This award supports summer research positions for outstanding physics majors. It is named for Ansel Anderson (1933–2015), an alumnus (PhD, 1961), faculty member (1962–1992), and department head (1986–1992). A condensed matter experimentalist, Anderson made seminal contributions to low-temperature physics, particularly in characterizing the thermal properties of metals and glasses.

Commonwealth Edison/Beryl Bristow Endowed Award: *Ritika Anandwade and Spencer Hulsey*
This award recognizes outstanding women physics majors. It was established by Commonwealth Edison in memory of alumna Beryl Love Bristow, the first woman to earn a both bachelor's and master's degrees in physics at the U of I. Bristow was inspired by her mother, who graduated Illinois in 1883 with a degree in mathematics, the first woman ever allowed to take a math course at the U of I. After graduation, Bristow worked at Commonwealth Edison Company.

Ernest M. Lyman Prize: *Rachel Smith*
This award recognizes the outstanding graduating senior physics major. It is named for Professor Ernest M. Lyman, a distinguished physicist who served on our faculty for 36 years. In addition to making seminal contributions to experimental nuclear physics, he was a world expert on electron scattering. An early proponent of computer-assisted physics education, he had a passion for teaching.

Jeremiah D. Sullivan Undergraduate Research Scholar: *Hannah Manetsch*
This award supports deserving undergraduates in their first experience in hands-on physics research. It was established by family, friends, and colleagues of Jeremiah Sullivan (1938–2016), a professor of physics (1967–2006) and department head (2000–2006). Sullivan's scientific career superbly integrated pioneering research in theoretical high-energy physics and in arms control and international security.

John A. Gardner Undergraduate Summer Research Award: *Zhiru Liu*
This award supports summer research positions for outstanding physics undergraduate students. The award is named for alumnus John Gardner (MS, 1963; PhD, 1966) who has made important contributions to materials physics. In 1996, he founded ViewPlus Technologies, a world leader in the development and manufacturing of assistive technologies for people with sensory learning disabilities.

Laura B. Eisenstein Award: *Camille Farruggio and Samantha Lapp*
This award recognizes outstanding woman physics majors. Established by the department in cooperation with the American Physical Society and its Committee on the Status of Women in Physics, the award is named for Professor Eisenstein (1942–1985), a distinguished biological physicist who served the department with distinction from 1969 to 1985. Eisenstein made important discoveries of the mechanism of light energy transduction by biomolecules.

Pictured left to right:

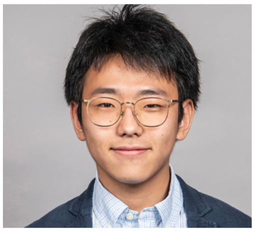
Vasundhra Agarwal
Itamar Allali
Ritika Anandwade

Dillon Brown
Barry Tzu-jui Chiang
Yufeng Du

Camille Farruggio
Gregory Fields
Sarah Habib

William Helgren
Spencer Hulsey
Thomas Kennedy

Samantha Lapp
Aike Liu
Guangkuo Liu



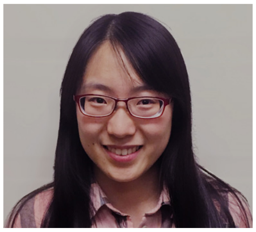
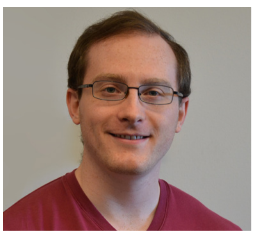
Zhiru Liu
Hannah Manetsch
Kyle Nelli

Minh N. T. Nguyen
Sam Qunell
Jake Rangel

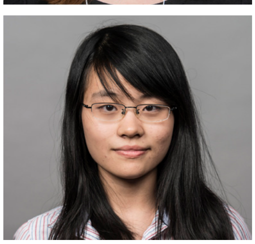
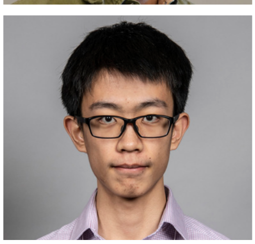
Rachel Smith
Carla Nicole Stelsel

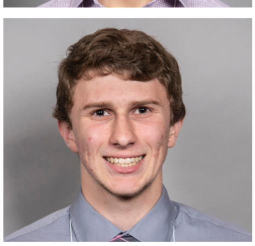
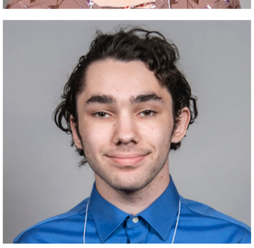
Not picutred: *Giovanni Diaz, Paul Graham*





UNDERGRADUATE STUDENT AWARDS

Lewis C. Hack Scholarship: *Jake Rangel*
This award provides support toward fall tuition for an outstanding physics major. It was established by a gift from Lois E. Hack in memory of her husband, Lewis C. Hack. Both the Hacks devoted their lives to teaching math and science in the public schools.

Lorella M. Jones Summer Research Award: Y*ufeng Du, Sarah Habib, and Carla Nicole Stelsel*
This fellowship supports summer research positions for outstanding physics undergraduate students. It is named for Professor Jones (1943–1995), a theoretical high energy physicist who served the department with distinction from 1968 to 1995. Jones was the first woman to attain tenure and full professorship in the department. A dedicated and innovative researcher and teacher, she pioneered the use of computerized quizzes in large elementary physics courses.

Philip J. and Betty M. Anthony Undergraduate Research Award: *Dillon Brown, Barry Tzu-jui Chiang, Gregory Fields, anonymous recipient, Thomas Kennedy, Guangkuo Liu, and Minh N. T. Nguyen*
This award supports summer research positions for outstanding physics majors. Alumnus Philip J. Anthony (MS, 1975; PhD 1978), a brilliant engineer and visionary inventor, has made pioneering contributions to photonic technologies and optical communications.

Richard K. Cook Scholarship: *Vasundhra Agarwal*
This scholarship recognizes an outstanding engineering physics student at the end of sophomore year. It is named for alumnus Richard Cook (1910–2016). Cook received his doctoral degree from the department in 1935. A specialist in ultrasonics and acoustics, he spent his entire career at the National Bureau of Standards.

Robert A. Stein Award: *Giovanni Diaz and Sam Qunell*
This award was established in memory of alumnus Robert A. Stein (BS, 1955) by his family and friends to provide opportunities to physics students at the U of I who come from the Chicago area.

Robert E. Hetrick Outstanding Undergraduate Research Award: *Itamar Allali*
This award recognizes outstanding independent research by an undergraduate physics major. It was established by alumnus W. Dale Compton (Ph.D, 1955) in honor of his first U of I graduate student, Robert E. Hetrick (BS, 1963; MS, 1964; PhD, 1969).

Undergraduate Outreach Achievement Award: *William Helgren and Spencer Hulsey*
This award recognizes outstanding undergraduate students involved in the Society of Physics Students and/or the Physics Van.

Yee Seung Ng Award: *Aike Liu*
This award recognizes an outstanding junior or senior international engineering physics student. It was established in memory of alumnus Yee Ng (BS, 1974) by his family and friends.

THE 2018

Drickamer Research Fellowship: *Eric Meier*
This fellowship recognizes outstanding research by a physics graduate student. It is named for Harry G. Drickamer (1918–2002), professor of physics, chemistry, and chemical engineering at Illinois, who contributed extensively to the understanding of physics and chemistry of matter at high pressure. Drickamer's work led to advances in the understanding of the molecular, atomic, andelectronic properties of matter and provided the tools to study these properties with greater detail and precision. Drickamer's students established the fellowship in his memory.

Felix T. Adler Award: *Thomas Rao*
This award recognizes outstanding work by a physics graduate student in the area of nuclear physics or nuclear engineering. Felix T. Adler (1911–79), professor of physics and nuclear engineering, served the university with distinction from 1958 to 1979. A theoretical nuclear physicist, his work spanned the development of nuclear energy—control theory, reactor kinetics and stability, neutron transport theory, chemical physics, operational calculus in electrodynamics, accelerator physics, and theoretical plasma physics. He was an exceptional teacher, noted for his infectious enthusiasm for physics and his painstaking patience with students.

Giulio Ascoli Award: *Cristina Schlesier*
This award recognizes outstanding work by a graduate student in experimental high energy physics. Giulio Ascoli (1922–1992) served the department with distinction from 1950 until his retirement in 1986. A high-energy physicist, Ascoli participated in the design and fabrication of experiments at CERN, Argonne National Laboratory, and Fermi National Accelerator Laboratory. He was versatile and painstaking in his development of algorithms for data analysis. His peers described his contributions as "innovative, elegant, and thorough."

John Bardeen Award: *Wladimir Benalcazar*
This fund supports outstanding work by a graduate student in condensed matter physics or the physics of electronic devices. John Bardeen (1908–1991) served as faculty in Physics and Electrical and Computer Engineering from 1951 to 1975. Bardeen was the first person to receive two Nobel Prizes in the same field.

Jordan S. Asketh Fellowship: *Benjamin Villalonga Correa*
This award recognizes an outstanding European graduate student. Upon his death, the late Jordan Asketh graciously bequeathed a generous portion of the proceeds from his estate to the University of Illinois to fund "graduate study grants" for students in the fields of physics, chemistry and medicine.

Virginia Bailey


Roshni Bano


John Bowers


Matthew Coon


Suraj Hegde


Eric Meier


Michael Highman

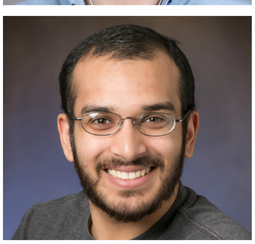

Elle Shaw


Progna Banerjee

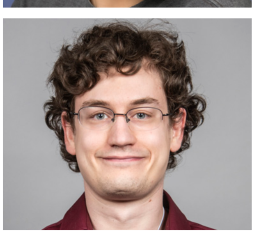
Wladimir Benalcazar

Yueqing Chang

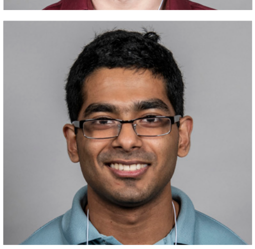
Alex Finnegan



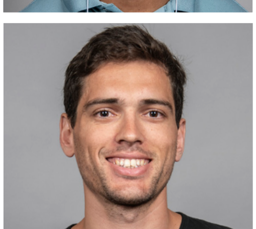
Ali Husain



Thomas Rao



Saavanth Velury



Benjamin Villalonga Correa

Not pictured: Cristina Schlesier

GRADUATE STUDENT AWARDS

L.S. Edelheit Family Biological Physics Fellowship: *Alex Finnegan*
This fellowship recognizes an exceptional student in experimental or theoretical biological physics. It was established through a generous gift from Illinois alumni Lonnie and Susan Edelheit.

Maurice Goldhaber Research Scholar Award in Nuclear Physics: *Virginia Bailey and Matthew Coon*
This award recognizes an outstanding graduate student who consistently demonstrates the highest level of performance in a nuclear physics research program. Professor Goldhaber (1911–2011) served the department with distinction from 1938 to 1950. His remarkable achievements in research, teaching and science administration made him one of the most distinguished nuclear and particle physicists of his time. The award was instituted on April 18, 2011, in honor of Dr. Goldhaber's centennial birthday.

Renato Bobone Award: *Roshni Bano*
This award recognizes a physics graduate student who has demonstrated academic excellence. The award was was endowed in 1985 by alumnus Renato Bobone (PhD, 1960), a student of Hans Frauenfelder who spent his entire career (1960–1987) at the General Electric Knolls Atomic Power Laboratory in Schenectady, New York.

Scott Anderson Award: *Progna Banerjee, John Bowers, Yueqing Chang, Suraj Hegde, Ali Husain, and Elle Shaw*
This award recognizes the year's outstanding physics teaching or research assistants. It is named for alumnus Dr. Scott Anderson (1913–2006), who founded Anderson Physics Laboratories in Urbana in 1944. It was through his initiative as president of our Physics Alumni Association and his generous philanthropy that the Anderson Award was endowed.

Vijay R. Pandharipande Prize in Nuclear Physics: *Akshat Puri*
This prize recognizes the year's outstanding nuclear physics graduate student. It is named for Professor Vijay Pandharipande (1940–2006), who served with great distinction on our faculty for 34 years. Pandharipande was an internationally recognized theoretical nuclear physicist who played a leading role in the development of the nuclear many-body problem. He pioneered variational Monte Carlo calculations that became the standard methods in his field. He also made notable conttributions to condensed matter theory.

National Science Foundation Graduate Research Fellowship: *Rachel Smith (graduating senior), Saavanth Velury, and Michael Highman. Alumni recipients include Clair Baum (U. Chicago) and Zack Cohen (U. Washington)*
NSF-awarded fellowships recognize and support outstanding graduate students in NSF-supported science, technology, engineering, and mathematics disciplines.

IOLab gets intro-physics students thinking more like physicists

SIV SCHWINK
for Illinois Physics Condensate

A new hands-on investigative learning approach has students designing their own experiments in introductory physics labs at the University of Illinois at Urbana-Champaign. And surveys show, they like it. Students are more invested in the lab exercises and are taking away greater satisfaction and confidence in their new 'expert-like' scientific research skills.

Having students design their own sound, replicable scientific experiments that uniquely deliver a sought-after answer is not generally done in traditional introductory physics labs. But this semester, about 350 students enrolled in 11 lab sections of Physics 101 were asked to do exactly that, using a remarkable new hand-held device called IOLab.

IOLab is a small but powerful data-acquisition tool that supports hands-on design-based learning. The device was invented by Associate Head for Undergraduate Programs and Professor Mats Selen and is manufactured and distributed by MacMillan Learning.

At a price point of about $100, students gain access to a magnetometer, microphone, buzzer, light intensity meter, accelerometer, gyroscope, temperature gauge, atmospheric pressure gauge, force probe, and expansion headers, plus a wheel encoder that measures position, velocity, and acceleration—all in a single device. The IOLab can measure rotation rates, forces, temperature, pressure, and voltages. It is also capable of wireless data sharing, so students can monitor the results of their experiments in real time.

Selen, a particle physicist who is also a noted expert in physics education research (PER) explains, "This

"It turns out for practical reasons, to implement an investigative-learning pedagogy with open-ended exercises in our labs, we needed this tool. I invented IOLab because it was fun. It's luck that it's turned out to be useful—the right tool for the job."

Left: Associate Head for Undergraduate Programs and Professor Mats Selen facilitates a Physics 101 lab during spring semester 2018. The IOLab device he invented, being manufactured and distributed by MacMillan Learning, enables design-based investigative learning in introductory physics labs.

Right: Students in Physics 101 collaborate to design their own experiments.

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

new approach is allowing us to shift the focus of our introductory labs toward creativity, design, sense-making, and communication. Students are learning to tackle a question without fear. They're collaborating, coming up with an idea, and designing a test to see if the idea might be right; then revising the idea and trying again when the results lead someplace unexpected.

"Not incidentally, these same behaviors are precisely what makes good physicists," Selen points out, "yet for a variety of reasons, some practical and some historical, these are often not the behaviors that we encourage in our introductory physics labs."

To accommodate the introduction of IOLab experiments, the room that hosts the Physics 101 labs was stripped of its traditional student-lab benches and stools and set up with group tables, chairs, and a cabinet full of supplies that students use for their experiments. Selen also put in a beverage station with coffee, tea, and hot cocoa, to warm up the comparatively empty space and promote the social interactions that good collaborative work requires.

Students complete a pre-lab homework assignment before each lab, involving data collection of real-world physics using their IOLabs in their dormitory rooms. A cloud-shaped button in the app allows students to share their pre-lab data with lab partners and instructors via an integrated cloud-based repository. That way, students arrive at the lab knowing how to work the particular IOLab sensors they'll need and what the software-generated graphs look like.

Selen stresses that, he invented the IOLab device, but not the pedagogy it's supporting.

"You still need a good curriculum," he asserts. "There is an important study done by Carl Wieman of Stanford's

A 1917 photo of the Electricity & Magnetism (E&M) Laboratory at the University of Illinois at Urbana-Champaign. Illinois was among the first universities in the country to teach laboratory classes in physics, starting in 1875. Stevens Institute of Technology introduced physics laboratory classes in 1871, and Massachusetts Institute of Technology, in 1873.

Associate Head for Undergraduate Programs and Professor Mats Selen is a particle physicist who has demonstrated tremendous dedication to evidence-based physics education research (PER) and to the development of innovative technologies to support modern pedagogies. He and his Illinois Physics PER colleagues have fundamentally changed the way physics is being taught at the U of I and beyond. Among the students at Illinois Physics, Selen is best known for making physics a lot of fun. He is the founder and faculty mentor of the Physics Van undergraduate outreach program, makes regular appearances on local station WCIA's Morning Show as the Why's Guy, and is co-inventor of the i>Clicker and the FlipItPhysics (smartPhysics) curriculum. He is the recipient of the 2016 Professor of the Year Award of the Carnegie Foundation and the Council for Advancement and Support of Education.

Graduate School of Education and Natasha Holmes of Cornell's Department of Physics. They measured the impact of traditional instructional labs on the learning of introductory physics and found it didn't contribute to students' mastery of the course curriculum or performance on exams.

"Our own physics education research was pointing to the same truth—and student surveys showed labs were not only not contributing to mastery, they were the least valued part of our introductory curriculum.

"Eugenia Etkina of Rutgers Graduate School of Education works on physics education research—she gave a colloquium here [at Illinois Physics] several years ago and talked about what she called an investigative science learning environment, or ISLE. The pedagogy we implemented is based on her work."

Students' lab work is graded on a scientific-abilities rubric, based on Etkina's pedagogy. Students were assessed on (1) the ability to design a reliable experiment that tests the hypothesis; (2) the ability to make a reasonable prediction based on a hypothesis; and (3) the ability to make a reasonable judgment about the hypothesis.

The curriculum now used across all Physics 101 labs has been through multiple iterations since 2011, when the very first small-scale feasibility studies were run using IOLab prototypes in Physics 212. What started back then with the idea that IOLab could support the learning of physics concepts, evolved into a discussion of how it could support the development of creativity, communication, and analytical and decision-making skills.

Early on, Selen enlisted the help of Illinois Physics PER graduate student Katie Ansell to run pilot programs, develop an investigative-learning lab curriculum for Physics 211, and assess the new IOLab curriculum's impact. Ansell, a natural teacher in her own right, is writing her doctoral thesis on this work.

Ansell recalls, "By the spring of 2014, we had shifted away from conceptual learning and focused more on the skills of decision making. From this point forward, prompts are devised to make students engage in meta-analyses: What is the problem? How am I thinking about this? What are my underlying assumptions? What equipment should I use to test my idea? What data are relevant and trustworthy? And how do I interpret the data?

"And whereas the old lab format had 16- to 20-page handouts with detailed instructions, our lab handouts contain only the overall experimental prompt and a few

Top: Illinois Physics students participate in a pilot study of the IOLab device during fall semester 2015.

Bottom: An Illinois Physics student takes a measurement using the IOLab, during a pilot study in the Fall 2015. Photos by L. Brian Stauffer, University of Illinois at Urbana-Champaign

brief questions to help students organize the informal reports they write for us in class. The rest is up to them to figure out and communicate to us.

"As we went forward—introducing the first classroom IOLab components in the fall of 2015 and then doing three sections in the spring of 2016 and five sections in the fall of 2016—we learned where the gaps were in the students' decision-making skills—things like how to read the data or how to know which part of a graph is relevant to a particular question. So we began to design tasks that made them confront those specific gaps, at the appropriate level of difficulty."

Two more PER graduate students, Bill Evans and Gabe Ehrlich, were enlisted last academic year to modify the Physics 211 lab curriculum for use in Physics 101. To measure the effect of the new laboratory pedagogy on learning and the student experience, in Fall 2017 two sections of the traditional Physics 101 lab ran in parallel with three IOLab sections, each having about 30 students. Both the traditional and IOLab sections were video recorded and continue to be analyzed. The PER team also measured the IOLab curriculum's impact through student surveys and by student performance on a practical exam that tested experimental skills.

Evans remarks, "The great thing about these new lab reforms using the IOLab is that we are really engaging the student. I really enjoyed teaching the traditional labs, but looking back, I can see how for the students, it was little more than jumping through hoops and filling out a worksheet. They would often go through the motions of doing science, without ever really doing science."

Ehrlich shares, "What has been most striking to me is the extent to which students in the new labs take collective responsibility for doing science. It's hard to say for sure at this early stage in video analysis, but it looks like a major and unexpected focus of students' energy is problematization, a part of the scientific process in which collaborators frame a previously unquestioned observation as interesting, problematic, or worthy of further study. I rarely see students take ownership of their inquiry that way in more traditional learning environments."

Ansell adds, "Comparing students in our new labs to those who took the old lab format, we have seen that our IOLab students are much more likely to choose to use their new skills, and that those skills have helped them become more discerning about experimental procedures and results, as well as more sophisticated in their conception of what physics experiments can be used for."

"At this point, we're working toward a sustainable teaching model and a stable course curriculum. We've put together a TA-training program, and we've started using learning assistants, students who previously took an IOLab section who come back and facilitate."

IOLab is already in use at many other institutions, where educators are developing their own PER studies and their own IOLab curricula. Given the open-source software package, free software upgrades, and the low cost of the device itself, there are few limits on the ways IOLab can be incorporated into laboratory classes or even into pre-lecture activities.

Remarkably, it was only after Selen invented the IOLab in his garage and, as he puts it, had fun tinkering with it that he recognized its potential to help students develop their intuition for physics research. In fact, the original idea behind IOLab's invention was to develop a wireless, portable electrocardiogram transmission device—for the fun of it.

That goal was achieved. The IOLab was successfully tested by U of I College of Medicine cardiologist Abrahim Kocheril in studies screening young athletes for prevention of sudden cardiac arrest—with members of the Fighting Illini football team as the studies' cohorts.

Once Selen knew he wanted to use the device as an educational laboratory tool, he reached out to MacMillan Learning and the company was willing to invest in Selen's further developing the IOLab device.

"It turns out for practical reasons, to implement an investigative-learning pedagogy with open-ended exercises in our labs, we needed this tool. I invented IOLab because it was fun. It's luck that it's turned out to be useful—the right tool for the job."

Funding for curriculum development and assessment studies came from the National Science Foundation.

Selen sums up, "What happens when you present students with a problem and give them the tools to design their own experiments, they all come up with different ways to get at the answer. Each group approaches experimentation differently, and sometimes their ingenuity, for example, in using more than one sensor at the same time, has surprised us.

"Students also learn that experimentation is messy. Data aren't always easy to interpret, and there is a method to refining results. They develop critical thinking, creativity, problem-solving, and sense-making skills—which really are very useful! What we are seeing being developed in our intro students using this new approach are really expert-like behaviors."

For more information, visit the IOLab Science website at www.iolab.science and the MacMillan Learning website at www.macmillanlearning.com/iolab.

This research was conducted with support from the National Science Foundation. The conclusions presented are those of the researchers and not necessarily those of the funding agency.

Introductory Course Manager and Lecturer Dr. Elaine Schulte has been awarded the Doug and Judy Davis Award for Excellence in Teaching Undergraduate Physics. The citation reads, "To Elaine Schulte, for improvements to the training of physics teaching assistants and for enhancements to the curricula for physics majors."

Schulte joined the Illinois Physics staff during the summer of 2013, having an insider's view of the department's collaborative culture, teaching strengths, and the teaching assistant (TA) experience. An alumna of the department, she received her bachelor's (1997), master's (2001), and doctoral (2002) degrees from Illinois Physics.

Schulte says her biggest accomplishment since taking on the post of introductory course manager has been streamlining the organization and management of the introductory physics courses. She coordinated with the undergraduate office staff, Kate Shunk and DaShawnique Long, to develop and refine a system that efficiently and effectively manages a staff of more than 100 instructors and cares for approximately 4,500 students each semester "consistently, confidently and professionally."

Schulte has also updated the curriculum of the heavily enrolled introductory physics courses.

Schulte outlines, "PHYS 101 and PHYS 102 are introductory physics courses for non-engineering/non-physics majors. Most of the students who take these courses are scientists-in-training in various fields—including the life sciences, chemistry, and the College of Agricultural, Consumer and Environmental Sciences. We also serve students studying architecture and

ELAINE SCHULTE SELECTED FOR DAVIS AWARD

various other disciplines. To further develop expert analytical skills in our students, we have been re-tooling our discussion materials. We are practicing a problem-solving method called conceptual analysis. We have introduced this into straightforward physics problems. We have also deployed readily available simulations to encourage inquiry-based applications of conceptual analysis."

Since 2015, Schulte has additionally worked to revise the introductory-courses electronic testing program.

"We have leveraged resources within the department to deliver one-hour exams to students in PHYS 101 and PHYS 102 electronically," Schulte continues. "This method allows our students to select times to take their exams, within bounds, as their schedules permit. Our students use an interface that is familiar to them when they execute the exams. Using electronic testing reduces grade turn-around time and staffing cost."

Schulte has also worked to improve the training and mentoring offered to the department's more than 100 TAs, and this has been her favorite job responsibility.

"It's rewarding to work with our graduate students and to guide them through the early stages of their professional development," she shares.

Schulte has also participated each year in the annual campus-level Graduate Academy Teaching Assistant Training, mandatory for all incoming U of I grad students holding TA appointments. She and a physics faculty member or TA partner teach a physics TA break-out session, providing an overview of best teaching practices and classroom management strategies.

Among her first accomplishments, Schulte instituted a TA training program for the department in the fall of 2013. In addition to participation in the all-campus Graduate Academy each fall, seminars for TAs are incorporated into the academic semesters. Topics include teaching students with disabilities and accessing disability resources on campus, academic integrity issues in the classroom, Counseling Center resources, among other topics. In addition at the beginning of each fall semester, experienced TAs lead our incoming graduate TAs through exercises designed to help them [the incoming TAs] understand the techniques they will be expected to use during their TA experience in the department.

At the college level, Schulte participated in the AE3 TA-training group from 2013 through 2015. This was a forum for lecturers who manage TA programs to discuss innovative teaching practices that could be brought into the college units.

Starting this academic year, she is serving as the department's learning outcomes assessment coordinator, working within the requirements of the Higher Learning Commission to maintain regional accreditation. This work involves developing the metrics, rubrics, and reports that identify the learning outcomes that students completing our degrees should have, as well as assessing how well we meet these outcomes.

More recently, working closely with Professor Brian DeMarco, Schulte has been instrumental in the development of a new applied physics undergraduate major, to be introduced in the near future.

"My responsibilities have been to research the administrative procedures for proposing and guiding a new degree program through the university–Illinois State Board of Education process. I've also worked on the curriculum maps," she shares.

Additionally, through the LAS SUCCESS Workshops program, Schulte gives a couple of workshops each semester on how students can best prepare for, take, and evaluate their performance on exams.

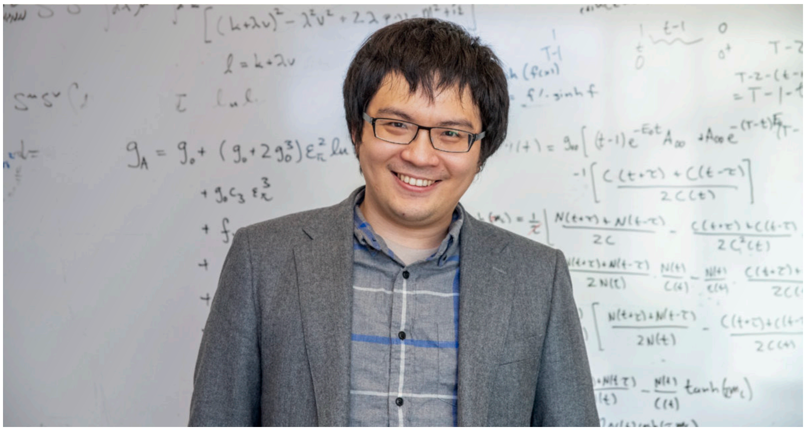
"These workshops are open to all," explains Schulte, "but are intended to help students who are struggling with managing aspects of their courses or to provide support for useful study habits for physics courses."

Schulte says she feels honored to be singled out for this award: "It's a privilege to have the ordinary work one does recognized by the community."

The Davis Award was endowed by Doug and Judy Davis to recognize members of our faculty or staff for their excellent teaching in undergraduate physics.

SUPERCOMPUTERS PROVIDE NEW WINDOW INTO THE LIFE AND DEATH OF A NEUTRON

Illinois Physics alumnus part of Berkeley Lab research team that simulated a sliver of the universe to tackle a subatomic-scale physics problem



Chia Cheng "Jason" Chang, Illinois Physics alumnus, is the lead author in a study describing the supercomputer-intensive calculation of a property known as nucleon axial coupling. He completed the work as a Berkeley Lab postdoctoral researcher. He currently holds an appointment as a research scientist at RIKEN. Photo by Marilyn Chung, courtesy of Berkeley Lab

GLEN ROBERS JR.
for Berkeley Lab

Experiments that measure the lifetime of neutrons reveal a perplexing and unresolved discrepancy. While this lifetime has been measured to a precision within 1 percent using different techniques, apparent conflicts in the measurements offer the exciting possibility of uncovering as-yet undiscovered physics.

Now, a team led by scientists in the Nuclear Science Division at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) has enlisted powerful supercomputers to calculate a quantity known as the "nucleon axial coupling," or g_A—which is central to our understanding of a neutron's lifetime—with unprecedented precision. Their method offers a clear path to further improvements that may help to resolve the experimental discrepancy.

Illinois Physics alumnus Chia Cheng "Jason" Chang is lead author on the paper. These study results were achieved while Chang was a postdoctoral researcher in Berkeley Lab's Nuclear Science Division. Chang currently holds an appointment as a research scientist at the Interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS) of the Institute of Physical and Chemical Research (RIKEN), Japan. Chang received his bachelor's degree in 2008 and his doctoral degree in 2015, both from the Department of Physics at the University of Illinois at Urbana-Champaign. Chang's doctoral adviser at Illinois was Professor Aida El-Khadra.

In this study, the researchers created a microscopic slice of a simulated universe to provide a window into the subatomic world. Their findings were published online May 30, 2018, in the journal *Nature*.

The nucleon axial coupling is more exactly defined as the strength at which one component (known as the axial component) of the "weak current" of the standard model of particle physics couples to the neutron. The weak current is given by one of the four known fundamental forces of the universe and is responsible for radioactive beta decay—the process by which a neutron decays to a proton, an electron, and a neutrino.

In addition to measurements of the neutron lifetime, precise measurements of neutron beta decay are also used to probe new physics beyond the standard model. Nuclear physicists seek to resolve the lifetime discrepancy and augment it with experimental results by determining g_A more precisely.

The researchers turned to quantum chromodynamics (QCD), a cornerstone of the standard model that describes how quarks and gluons interact with each other. Quarks and gluons are the fundamental building blocks for composite particles including neutrons and protons. The dynamics of these interactions determine the mass of the neutron and proton, and also the value of g_A.

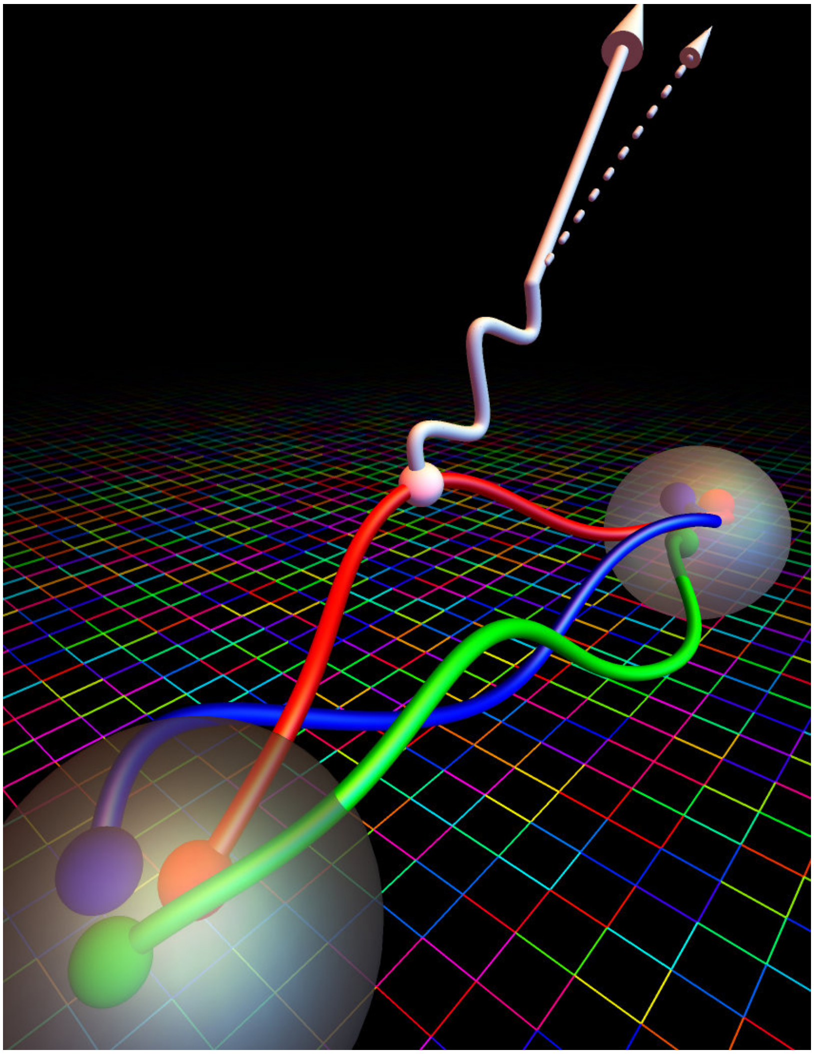
But sorting through QCD's inherent complexity to produce these quantities requires the aid of massive supercomputers. In the latest study, researchers applied a numeric simulation known as lattice QCD, which represents QCD on a finite grid.

While a type of mirror-flip symmetry in particle interactions called parity (like swapping your right and left hands) is respected by the interactions of QCD, and the axial component of the weak current flips parity—parity is not respected by nature (most of us are right-handed, for example). Because nature breaks this symmetry, the value of g_A can be determined only through experimental measurements or theoretical predictions with lattice QCD.

The team's new theoretical determination of g_A is based on a simulation of a tiny piece of the universe—the size of a few neutrons in each direction. They simulated a neutron transitioning to a proton inside this tiny section of the universe to predict what happens in nature.

The model universe contains one neutron amid a sea of quark-antiquark pairs that are bustling under the surface of the apparent emptiness of free space.

"Calculating g_A was supposed to be one of the simple benchmark calculations that could be used to demonstrate that lattice QCD can be utilized for basic nuclear physics research, and for precision tests that look for new physics in nuclear physics backgrounds," said André Walker-Loud, a staff scientist in Berkeley Lab's Nuclear Science Division who led the new study. "It turned out to be an exceptionally difficult quantity to determine."



In this illustration, the grid in the background represents the computational lattice that theoretical physicists used to calculate a particle property known as nucleon axial coupling. This property determines how a W boson (white wavy line) interacts with one of the quarks in a neutron (large transparent sphere in foreground), emitting an electron (large arrow) and antineutrino (dotted arrow) in a process called beta decay. This process transforms the neutron into a proton (distant transparent sphere). Image courtesy of Evan Berkowitz/Jülich Research Center, Lawrence Livermore National Laboratory

This is because lattice QCD calculations are complicated by exceptionally noisy statistical results that had thwarted major progress in reducing uncertainties in previous g_A calculations. Some researchers had previously estimated that it would require the next generation of the nation's most advanced supercomputers to achieve a 2 percent precision for g_A by around 2020.

The team participating in the latest study developed a way to improve their calculations of g_A using an unconventional approach and supercomputers at Oak Ridge National Laboratory (Oak Ridge Lab) and Lawrence Livermore National Laboratory (Livermore Lab). The study involved scientists from more than a dozen institutions, including researchers from UC Berkeley and several other Department of Energy national labs.

Chang comments, "Past calculations were all performed amidst this more noisy environment," which clouded the results they were seeking."

Walker-Loud adds, "We found a way to extract g_A earlier in time, before the noise 'explodes' in your face."

"We now have a purely theoretical prediction of the lifetime of the neutron, and it is the first time we can predict the lifetime of the neutron to be consistent with experiments," asserts Chang.

"This was an intense 2 1/2-year project that came together only because of the great team of people working on it," remarks Walker-Loud.

This latest calculation also places tighter constraints on a branch of physics theories that stretch beyond the standard model—constraints that exceed those set by powerful particle collider experiments at CERN's Large Hadron Collider. But the calculations aren't yet precise enough to determine if new physics has been hiding in the g_A and neutron lifetime measurements.

Chang and Walker-Loud noted that the main limitation to improving upon the precision of their calculations is in supplying more computing power.

"We don't have to change the technique we're using to get the precision necessary," Walker-Loud states.

The latest work builds upon decades of research and computational resources by the lattice QCD community. In particular, the research team relied upon QCD data generated by the MILC Collaboration, an open source software library for lattice QCD called Chroma, developed by the USQCD collaboration, and QUDA, a highly optimized open-source software library for lattice QCD calculations.

The team drew heavily upon the power of Titan, a supercomputer at Oak Ridge Lab equipped with graphics processing units, or GPUs, in addition to more conventional central processing units, or CPUs. GPUs have evolved from their early use in accelerating video game graphics to current applications in evaluating large arrays for tackling complicated algorithms pertinent to many fields of science. The axial coupling calculations used about 184 million "Titan hours" of computing power—it would take a single CPU about 75,000 years to work through the same set of calculations.

As the researchers worked through their analysis of this massive set of numerical data, they realized that more refinements were needed to reduce the uncertainty in their calculations.

The team was assisted by the Oak Ridge Leadership Computing Facility staff to efficiently utilize their 64-million Titan-hour allocation, and they also turned to the Multiprogrammatic and Institutional Computing program at Livermore Lab, which gave them more computing time to resolve their calculations and reduce their uncertainty margin to just under 1 percent.

"Establishing a new way to calculate g_A has been a huge rollercoaster," Walker-Loud comments.

With more statistics from more powerful supercomputers, the research team hopes to drive the uncertainty margin down to about 0.3 percent. "That's where we can actually begin to discriminate between the results from the two different experimental methods of measuring the neutron lifetime," Chang explains. "That's always the most exciting part: When the theory has something to say about the experiment."

He adds, "With improvements, we hope that we can calculate things that are difficult or even impossible to measure in experiments."

Already, the team has applied for time on a next-generation supercomputer at Oak Ridge Lab called Summit, which would greatly speed up the calculations.

In addition to researchers at Berkeley Lab and UC Berkeley, the science team also included researchers from University of North Carolina, RIKEN BNL Research Center at Brookhaven National Laboratory, Livermore, the Jülich Research Center in Germany, the University of Liverpool in the U.K., the College of William & Mary, Rutgers University, the University of Washington, the University of Glasgow in the U.K., NVIDIA Corp., and Thomas Jefferson National Accelerator Facility.

One of the study participants is a scientist at the National Energy Research Scientific Computing Center (NERSC). The Titan supercomputer is a part of the Oak Ridge Leadership Computing Facility (OLCF). NERSC and OLCF are DOE Office of Science User Facilities.

The work was supported by Laboratory Directed Research and Development programs at Berkeley Lab, the U.S. Department of Energy's Office of Science, the Nuclear Physics Double Beta Decay Topical Collaboration, the DOE Early Career Award Program, the NVIDIA Corporation, the Joint Sino-German Research Projects of the German Research Foundation and National Natural Science Foundation of China, RIKEN in Japan, the Leverhulme Trust, the National Science Foundation's Kavli Institute for Theoretical Physics, DOE's Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program, and the Lawrence Livermore National Laboratory Multiprogrammatic and Institutional Computing program through a Tier 1 Grand Challenge award.

Vishveshwara receives Nordsieck

SIV SCHWINK
for Illinois Physics Condensate

Professor Smitha Vishveshwara has been awarded the 2018 Nordsieck Award from the Department of Physics at the University of Illinois at Urbana-Champaign. This award recognizes faculty members for excellence in teaching. The citation reads, "To Smitha Vishveshwara, for the development of the course 'Where Art Meets Physics' that communicates the principles and elegance of physics through artistic expression."

Vishveshwara first introduced PHYS 498: Where the Arts Meet Physics in the spring 2016 semester and has offered it each spring since. Students in the course are a blend of physics majors and students from a broad spectrum of other majors, including the arts. The curriculum covers a range of frontier physics topics from the quantum world to the universe in addition to exploring the depiction of scientific concepts in the visual arts, theater, music, and literature. To complement her own lectures, Vishveshwara invites guest presenters—physicists and her arts collaborators from across campus—to speak about their creative processes, whether in research or art. Some guests have shared their expertise with students through performances and by engaging in creative collaborations with them, including U of I performance arts faculty Kirstie Simson in dance and Latrelle Bright in theater.

Vishveshwara has structured the course to encourage students to learn from one another and to share the development of their creative ideas, while they work together inside and outside of the classroom. Assignments include scientific write-ups, "creative fragments" that explore artistic expressions of scientific concepts, and team work, all culminating in a collaborative final project.

For the final project, students work in groups, each comprising physics and non-physics majors, to create their own science-inspired artwork in any artistic medium they choose. This artwork is exhibited in an art show at the end of the term.

Vishveshwara says, "Because we have a good mix of physics majors and students from other majors across campus, the discussion is truly interdisciplinary—there are enough physics students contributing, so that very rich science comes through."

In its inaugural year, the course covered concepts related to light and sound, quantum theories, chaos and flow, the universe, and mechanics. The final exhibit was held in the Interaction Room at Loomis Laboratory, with projects ranging from building a theremin instrument to producing video shorts that explored light.

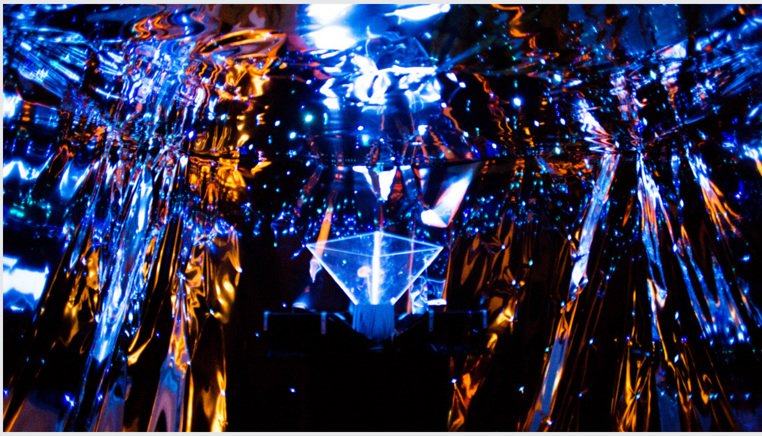
In its second year, Vishveshwara shifted the course theme: students focused on "the universe, fluids and flows, and the quantum world." The final art show, entitled "Flowing from the Quantum to the Cosmic," was held at the Krannert Art Museum; the exhibits can be viewed online at https://publish.illinois.edu/flowing-from-quantum-to-cosmic/.

This semester, the course focus was the quantum world and the universe. A culminating event at the Independent Media Center showcased student performance and visual art pieces on the subject of the cosmos. Students also contributed extensively to an additional major culminating event, the production of *Quantum Voyages*, a performance piece co-created by Vishveshwara and her theater collaborator Latrelle Bright. Student involvement included performing and creating original quantum-themed music, costumes, and paintings. Vishveshwara's graduate student Karmela Padavic, who studies Bose-Einstein condensates and topological materials, served as exhibit coordinator while taking the course last year; this year, as the teaching assistant, she also served as the Production Manager for Quantum Voyages. The performance, which also featured guest appearances by physicists, premiered at the 80th birthday celebration of Sir Anthony J. Leggett, Nobel laureate and the John D. and Catherine T. MacArthur Professor and Center for Advanced Study Professor of Physics. The piece was also performed at the Beckman Institute for Advanced Science and Technology, where Vishveshwara, a member of the Social and Emotional Dimension of Well-Being research group, is continuing to explore the convergence of art and science.

Vishveshwara is a condensed matter theorist who has spent a lifetime exploring the literary, visual, and performing arts alongside her beloved science—for her, it's a very natural pairing. Atomic landscapes, quantum conundrums, and exotic states of matter in the coldest spaces of the universe beg artistic expression. The same qualities required to do physics are likewise needed to practice art—creativity, analytic work, innovation, and intuition. In her own work, Vishveshwara has found that where the arts and physics converge, the effect can be riveting and inspirational.

Vishveshwara's parents are both scientists, and the family found joy in drawing, writing, theater, music, and other forms of expression. Her grandfather was a noted playwright, and her uncle, a violinist, lived with her immediate family. As a child growing up in India, Vishveshwara and her sister attended The Valley School, founded by the educator and philosopher J. Krishnamurti, which allowed them to flourish in both the arts and sciences. As a young adult, Vishveshwara chose to study in the U.S., where she could continue this dual focus.

"The Pop in Quantum, by student Napat Saengthongsrikamol, depicts the debate that took place between key legendary physicists involved in the birth of the quantum revolution in a style that pays tribute to Andy Warhol and the Pop Art movement, part of the 2017 Flowing from the Quantum to the Cosmic *exhibit at the Krannert Art Museum at the the University of Illinois at Urbana-Champaign.*



The Cosmic Canopy, created by students Andrew Pappert, Carolyn, Kan, Claire Baum, Kann Yumlu, Kaliroe Pappas, Lark Moreno, and Xiuting Wu, was a seven foot cube enclosure pierced by two hundred optical fibres providing an immersive cosmic experience. Within, a hoverogram showed suspended animations of galaxy and black hole mergers set to ambient music. , part of the 2017 Flowing from the Quantum to the Cosmic *exhibit at the Krannert Art Museum at the the University of Illinois at Urbana-Champaign.*

"I went to Cornell as an undergraduate," she shares. "If I had studied in India, in my circumstances back then, my choices would have been rather narrow— for instance, I would have had to solely focus on physics or engineering or medicine. Cornell gave me a wonderful liberal arts education. I took courses in creative writing, visual arts, African dance, and more. I did physics during the day, and explored art in the evenings."

Vishveshwara's late father, C.V. "Vishu" Vishveshwara, a renowned physicist, founder and director of the Jawahardal Nehru Planetarium, and a black hole expert whose work came to the limelight during the recent discovery of gravitational waves, had a profound influence on her work and creative pursuits.

"My connection to my father is both spiritual and intellectual. In addition to being an accomplished and unassuming scientist, he would be scripting planetarium shows and working with visual artists to bring them alive, or writing popular essays and books, such as his *Black Holes in my Bubble Bath*. In 2012, while I was on sabbatical, we began writing a book together on the two physics revolutions of the past century, Einstein's relativity and quantum physics, the bread and butter of each of our fields. The format is personal letters between father and daughter. Despite his passing last year, through his talks

Top Left: "Perspicacity," by student Grace Sun, represents a fusion of the quantum world with the universe, with imagery and equations converging, part of the Krannert student exhibit in Spring 2017.

Top right: Physics 498: Where the Arts Meet Physics *student Angelo Niqula plays the electric guitar he built as his final project, during the class exhibit in the Loomis Lab Interaction Room, Spring 2016.*

Bottom: U of I harp duo Ginger & Spice perform their unconventional fusion of drama, harp music, and video for Where the Arts Meet Physics *students and members of the department, in the Loomis 141 lecture hall, Spring 2016.*

and so many other legacies, we are continuing, and the book is nearing completion. Starting this project with my father awakened something deep and inspirational within me and has fueled my science-art explorations.

"Returning to what we are doing here with *Where the Arts Meets Physics* and related ventures, it is the beginning of a euphoric journey! The students are so motivated and talented and boldly tap into their passions along uncharted paths to come up with beautiful, educational, tantalizing work. As if it weren't enough to be part of the best physics milieu I could hope for, these endeavors build connections among campus units and beyond—Theater, Dance, Astronomy, Art and Design, Krannert, Beckman, the Amasong choral group, and more. And the collaborative creations that emerge transcend traditional boundaries, in harmony!" ■

Below: Dance performance at the Champaign Public Library by dancer Kirstie Simson's CoLab class, costumed in renowned knitter Stephen West's creations and accompanied by the music group of Erik Lund. It concluded with a piece on the Universe based on a script and narration by Physics Professor Smitha Vishveshwara.

Illinois Physics Academic Adviser Merissa Jones was selected for the Engineering Council Outstanding Advising Award. This award is conferred annually to the top 10 percent of advisers in the College of Engineering; recipients are nominated and selected by engineering undergraduate students.

Over the last six years in this role, Jones has worked to make sure all undergraduate physics students are on track not only to graduate, but to meet their career goals. She advises more than 650 physics majors in two colleges and believes it's important to help every student to examine his or her unique aspirations, strengths, and areas needing improvement—her approach is not one-size-fits-all.

"Students' intended career paths evolve over the four years they are here," Jones points out, "through their interactions with faculty, friends, and through their experiences. It's important to gear their individual programs toward those evolving goals, whether that's a professional career or an advanced degree. In advising our first- and second-year physics students, it's important to get a sense of what a student's skills are, how they are performing in their classes, and generally how they are coping with the stresses of university life and a rigorous major. Some students seem to breeze through, but many of our students require additional resources and support, whether academic or emotional. I'm there as an advocate—my role is to let them voice how they are doing and point them to resources that can benefit them."

Jones meets with each freshman and sophomore physics major at least once each fall and spring semester to review progress toward degree and planned courses; she always encourages students to come back to see her if they have any concerns or questions. In this way, Jones not only provides timely information about college policies, registration, course enrollment, academic status, and degree requirements, she also connects students to important resources within the University's network of enrichment opportunities for high-achieving students and for international students.

"I really feel for our international students who are so far away from their families," comments Jones. "As a mother myself, I know it's important for them to receive encouragement and reassurance. I'm always happy when they stop in to see me."

Jones also connects at-risk students with academic-support and campus counseling resources, supporting and guiding the necessary return to good academic standing with some motherly "tough love." She does her best always to make time for students who may need her attention.

Merissa Jones receives Engineering Council Outstanding Advising Award

"Mandatory advising takes about seven to eight weeks each semester to get through all of the students," she says. "Even then, I see walk-ins. I never turn students away—they may have an emergency or even just have something that's stressing them out, and getting the answer to a question could ease their minds."

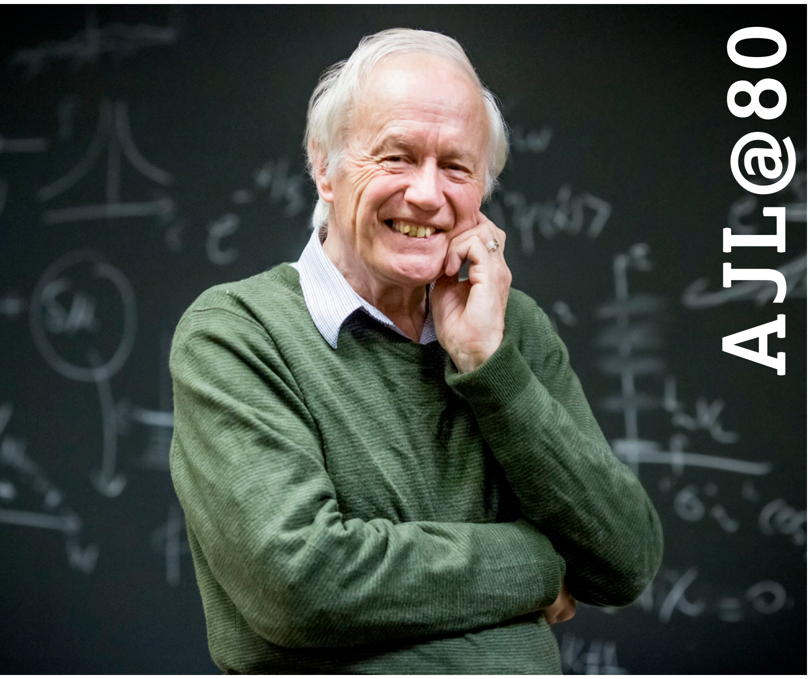
Jones also meets with prospective and admitted students and their families, organizes the PHYS 110 Physics Orientation course and the PHYS 199 Physics Careers and Research course, and coordinates a peer- and faculty-mentor program. And she works closely with Engineering Career Services to provide students with professional development opportunities at each stage of their four years at the university.

"Working with Career Services, we are able to help students figure out what is best for them individually—even if that doesn't keep them in physics. Career Services also helps students learn how to prepare resumes and applications. For those going on to jobs in industry, we always tell our physics graduates going out and interviewing for jobs to lead with what skills they have. Not everyone knows the amazing skillset that a physics graduate brings."

"What I find most rewarding is watching the students become successful, especially their reaching the completion of their degrees. When you have seen their hard times, their rises and falls, and then you get to watch them find their way through and meet their own goals—I'm just very happy to see them thrive."

Jones received her bachelor's degree in sociology in 2008 and her master's degree in educational policy with a concentration in diversity and equity issues in education in 2011, both from the University of Illinois. She has worked at the university for a total of 18 years, 10 of those as an academic adviser. She is a member of the University of Illinois at Urbana-Champaign Academic Advising Committee.

Jones was presented with the award at the annual College of Engineering Faculty Awards Ceremony in April. The Engineering Council is a collective of student organizations and societies within the College of Engineering that provides leadership training and opportunities, hosts career and science fairs, and encourages collaboration among its constituents. ■



Department celebrates Tony Leggett's 80th Birthday

Sir Anthony J. Leggett, winner of the 2003 Nobel Prize in Physics and the John D. and Catherine T. MacArthur Professor of Physics at the University of Illinois at Urbana Champaign, turned 80 years old on March 26, 2018. To celebrate, the Department of Physics hosted a symposium in his honor, with participants and invited speakers coming from around the world. The symposium, "AJL@80: Challenges in Quantum Foundations, Condensed Matter Physics and Beyond," ran Thursday evening, March 29, through Saturday evening, March 31.

After dinner on Friday, March 30, the public was invited to join in the celebration and attend a theater presentation and lecture at the I Hotel and Conference Center's Illinois Ballroom in Champaign.

First up was the premier performance of "Quantum Voyages." This work, the collaborative effort of U of I Physics Professor Smitha Vishveshwara and Theatre Studies Professor Latrelle Bright, tells the story of the quantum realm. The presentation included cameo appearances by several renowned physicists, including Leggett himself.

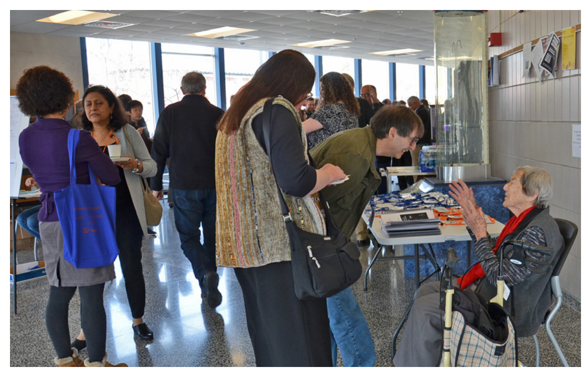
Next up was a popular talk by U of I alumnus and University of California, Santa Barbara Professor of Physics Matthew Fisher, entitled, "Are We Quantum Computers, or Merely Clever Robots?"

In honoring Leggett, the event also celebrated his legacy. Three generations of physicists were represented in the program: Fisher is a former doctoral student of Leggett; and Vishveshwara is a former doctoral student of Fisher.

Left page, from top: (1) Nobel laureate and Professor Anthony Leggett poses in the Institute for Condensed Matter common area. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign. (2) An invited speaker addresses participants. (3) Symposium secretary Becky McDuffee is in a quantum superposition of here, there, and everywhere. (4) Nobel laureate Michael Kosterlitz and Warren Picket visit with a symposium participant over lunch.

This page, clockwise from top right: (1) Nobel laureates David Lee and Michael Kosterlitz visit with symposium goers. (2) Professors Nigel Goldenfeld and Susan Lamb greet Lizie Goldwasser. (3) Symposium participants visit over lunch. (4) Professor Philip Phillips visits with David Campbell and Jan Engelbrecht (5) Professor Paul Kwiat makes the rounds during a break. (6) Nobel Laureate and Professor Anthony Leggett visits with a participant.

Photos taken during the AJL@80 symposium by Siv Schwink for Illinois Physics.

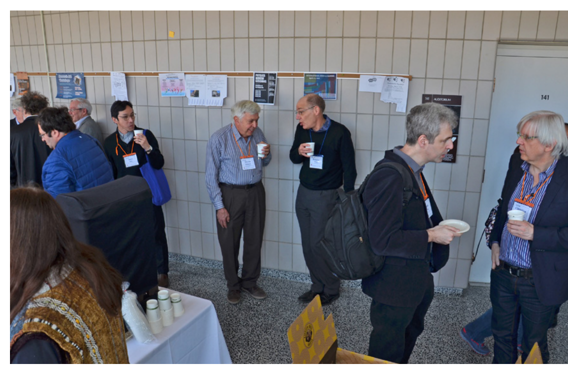


Sir Anthony J. Leggett, the John D. and Catherine T. MacArthur Professor and Center for Advanced Study Professor of Physics, has been a faculty member at Illinois since 1983. He is widely recognized as a world leader in the theory of low-temperature physics, and his pioneering work on superfluidity was recognized by the 2003 Nobel Prize in Physics.

Leggett has shaped the theoretical understanding of normal and superfluid helium liquids and other strongly coupled superfluids. He sets directions for research in the quantum physics of macroscopic dissipative systems and use of condensed systems to test the foundations of quantum mechanics. His research interests lie mainly within the fields of theoretical condensed matter physics and the foundations of quantum mechanics. He has been particularly interested in the possibility of using special condensed-matter systems, such as Josephson devices, to test the validity of the extrapolation of the quantum formalism to the macroscopic level; this interest has led to a considerable amount of technical work on the application of quantum mechanics to collective variables and in particular on ways of incorporating dissipation into the calculations. He is also interested in the theory of superfluid liquid ^{3}He, especially under extreme nonequilibrium conditions, in high-temperature superconductivity, in the low-temperature properties of glasses and in topological quantum computing,particularly in so-called "*p+ip*" Fermi superfluids.

He is a member of the National Academy of Sciences, the American Philosophical Society, the American Academy of Arts and Sciences, the Russian Academy of Sciences (foreign member), and is a Fellow of the Royal Society (U.K.), the American Physical Society, and the American Institute of Physics. He is an Honorary Fellow of the Institute of Physics (U.K.). He was knighted (KBE) by Queen Elizabeth II in 2004 "for services to physics."

From the top: (1) (left to right) Viktor Vikaryuk, Nadya Mason, Mike Norman, and Eduardo Fradkin enjoy lunch. (2) Professor Doug Beck and Professor Emeritus Myron Salamon visit over coffee. (3) Monique Combescot visits with Dervis Vural during a break. (4) Vice Chancellor for Academic Affairs and Provost Dean Cangellaris, Professor Eduardo Fradkin, and Professor and Head Dale Van Harlingen visit with participants over dinner.



This page: Quantum Voyages is a theatrical production by U of I Professors Smitha Vishveshwara and Latrelle Bright in collaboration with a quantum-theater crew: Guided by Sapienza, the spirit of knowledge, two voyagers enter the microscopic realm of atomic landscapes and quantum conundrums to discover a magnificent and baffling world.

Top right: Nobel laureate and Professor Anthony Leggett delivers an introduction to quantum physics during Quantum Voyages.

Middle right: Professor Smitha Vishveshwara (far right) thanks the cast and crew and her creative collaborator Theater Professor Latrelle Bright (far left). Cameo appearances by Illinois physicists (pictured front row, left to right) Virgina Lorenz, Anthony Leggett, Nadya Mason, Dale Van Harlingen, and Brian DeMarco were well received.

Lower images, clockwise from top left:
(1) Professor Brian DeMarco travels to the quantum realm in Quantum Voyages.
(2) Professor Philip Phillips visits with Professor Tony Leggett during intermission.
(3) Smitha Vishveshvara and two of the Quantum-Theater crew introduce Professor Matthew Fisher of UC Santa Barbara.
(4) Professor and Head Dale Van Harlingen dons a 'SQUID' hat during his cameo appearance in Quantum Voyages.

Photos by Siv Schwink for Illinois Physics

CHARLES P. SLICHTER

1924–2018

Charles P. Slichter, University of Illinois professor emeritus of physics and of chemistry, was a pioneer in the development and application of nuclear magnetic resonance (NMR) spectroscopy to elucidate the structure and behavior of matter at the atomic scale, and a renowned expert on superconductivity. Slichter's seminal contributions to condensed matter physics and chemistry have been recognized with numerous awards, including the 2007 National Medal of Science.

Slichter is revered at the University of Illinois, where he served on the faculty for 57 years, for his fostering of the "Urbana style"—a way of tackling longstanding scientific problems by a combination of theory and experiment that emphasizes close interdisciplinary collaboration and mutual respect. Known by everyone for his brilliant smiles, infectious enthusiasm, and trademark bow ties, Slichter exemplified science at its finest—creative, rigorous, curious, and scrupulously honest. His inspired teaching trained generations of American physicists and chemists and, through them, enabled a host of modern technologies.

NMR studies atomic nuclei by probing them with radio waves and measuring their response. The nuclei respond only when the radio waves are tuned to specific resonance frequencies, which depend on both the properties of the nuclei and their local magnetic field. The measured spectrum of resonance frequencies, as well as the time dynamics of the resonance response, gives information about the local environment of the nuclei. Magnetic resonance imaging (MRI), widely used in medicine, is an extension of NMR that enables 2D and 3D images to be reconstructed from NMR spectra.

Slichter pioneered many fundamental techniques in NMR. He was a co-discoverer (with H.S. Gutowsky and D.W. McCall) of indirect spin-spin coupling, known as J-coupling, in molecules. This phenomenon enables structural information about molecules to be deduced from their NMR spectrum, and is a key analytical tool in modern chemistry. With T.R. Carver, Slichter performed the first dynamic polarization of nuclei using electron spins. Dynamic nuclear polarization can be used to increase the sensitivity of NMR dramatically, enabling the study of more complex molecules and smaller samples. Extensions of the technique are used to determine aspects of molecular structure, or to provide a method of operation for the three-level maser, a microwave-frequency precursor to the laser.

Slichter and his student L.C. Hebel performed the first NMR studies on superconductors, materials in which electric current can flow without resistance. This was a major feat in itself, because superconductors exclude the magnetic fields and radio waves used to perform NMR spectroscopy. The results of their experiments are recognized as the first proof of the electron-pairing concept central to the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity, which was developed concurrently, also at the University of Illinois, and was honored with the 1972 Nobel Prize in Physics. Slichter conceived of the experiment while listening to a presentation from Bardeen, and the analysis was carried out with substantial collaboration from the BCS authors, even while they raced to prepare their own theoretical work. This strong collaborative interaction between theory and experiment typified the "Urbana style" of research, and Slichter played an important role in setting this tone for colleagues. Another research "first" of Slichter's, the measurement of the Pauli spin susceptibility, came after a chance hallway meeting with colleague David Pines, who had just derived a more precise theoretical model for the effect, but lamented to Slichter that "no one can measure it." Slichter, who had worked on some related problems as a graduate student, replied "David, I know how to measure it", and the experimental results were published shortly thereafter.

At the University of Illinois, Slichter directed the research of 63 doctoral students and more than 15 postdoctoral researchers, including Nobel laureate Sir Peter Mansfield, co-inventor with Paul Lauterbur of MRI. Slichter's textbook, Principles of Magnetic Resonance, now in its third edition, has trained students around the world for nearly 60 years. Slichter said in 2004, "I really love doing physics; the personal connection is the way I love to do it. If I were not in a university setting, I would have to find students to work with."

Slichter's contributions to science were not limited to the laboratory and the classroom. He served the nation with distinction as a member of the President's Science Advisory Committee (1965–1969), the President's Committee on the National Medal of Science (1969–74), the President's Committee on Science and Technology Policy (1976), and the National Science Board

(1975–1984). In 1975, Slichter chaired a delegation of U.S. solid-state physicists selected by the National Academy of Sciences in an initiative to open scientific exchanges with the People's Republic of China. On this trip he met his future wife Anne FitzGerald, who worked for the National Academy of Sciences and acted as translator for the U.S. delegation.

President George W. Bush awards the 2007 National Medal of Science to Dr. Charles Slichter during an East Room ceremony at The White House in Washington, DC on Monday, September 29, 2008. Photos by Ryan K. Morris

In academia, Slichter served for 25 years (1970–1995) as a Fellow of the seven-member Harvard Corporation, Harvard University's highest governing body, including 10 years as Senior Fellow. He chaired the selection committee that chose Neil Rudenstine as the president of Harvard in 1991. Slichter was the president of the International Society of Magnetic Resonance from 1986 to 1989. His service to US industry included membership on the board of directors of Polaroid (1975–1995) and on science advisory committees to IBM (1978–1993) and United Technologies (1972–1982).

Among his many honors and awards are the National Medal of Science (2007), the Comstock Prize (shared with E.L. Hahn) of the National Academy of Sciences (1993), the Irving Langmuir Prize in Chemical Physics (1969) and the Oliver E. Buckley Prize in Condensed Matter Physics (1996) from the American Physical Society, the Citation for Chemical Breakthrough Award (shared with H.S. Gutowsky and D.W. McCall) from the American Chemical Society (2016), and the Triennial Prize of the International Society of Magnetic Resonance (1986). He received honorary doctor of science degrees from the University of Waterloo (1993) and the University of Leipzig (2010) and an honorary doctor of laws degree from Harvard University (1996). He was elected a member of the National Academy of Sciences in 1967, the American Academy of Arts and Sciences in 1969, and the American Philosophical Society in 1971.

Sir Anthony J. Leggett, Nobel laureate and the John D. and Catherine T. MacArthur Professor and Center for Advanced Study Professor of Physics at the University of Illinois, described Slichter as "a towering figure in condensed matter physics, on both the national and international stage. He was a warm and supportive figure in the Urbana physics department right up to his last years."

University of Illinois emeritus professor Gordon Baym said, "Charlie was a remarkable colleague, one of the last of the great physicists of the postwar generation. He was always intellectually curious and remarkably wise. At the same time he was a great human being, amazingly encouraging and supportive of his colleagues, students, and friends, whether young or old. Just seeing his warm smile would brighten everyone's day."

Head of the University of Illinois Department of Physics and professor Dale Van Harlingen said, "Charlie Slichter was a legend, a role model, and a friend to everyone who ever had the opportunity to meet him. His passion for good science, his contagious kindness, and his remarkable energy has inspired me throughout my career, and I think everyone else at the University of Illinois and beyond. In many ways, Charlie has best defined the Urbana style that characterizes the culture and spirit of the Department of Physics at Illinois through his stellar contributions in NMR that have significantly impacted our understanding of condensed matter physics, especially superconductivity, and the chemistry of materials, his excellence in teaching and mentoring of students, and his unparalleled warmth and friendliness. He is truly one the great scholars and gentlemen of our generation. Charlie has made a lasting impression on all of us—he will be missed but never forgotten."

Slichter was born on January 21, 1924, in Ithaca, New York, to Sumner Huber Slichter, a labor economist who became the first Lamont University Professor at Harvard University, and Ada (née Pence) Slichter. Slichter was named after his paternal grandfather, Charles Sumner Slichter, a noted professor of applied mathematics and dean of the graduate school at the University of Wisconsin. His maternal grandfather, William David Pence, was a professor of railway engineering at the Wisconsin. From a young age, Slichter was interested in science and mathematics. It was his senior-year physics course at the Browne & Nichols School in Cambridge, Massachusetts that made it clear, without a doubt, that he wanted to be a physicist.

Slichter studied physics at Harvard University, receiving his A.B. (1946), M.A. (1947), and Ph.D. (1949) degrees there. During World War II, while an undergraduate at Harvard, he worked as a research assistant at the Underwater Explosives Research Laboratory at Woods Hole, Massachusetts, where he constructed oscilloscopes—experience that prepared him for his doctoral research with Edward Purcell, who led the group at Harvard that co-discovered nuclear magnetic resonance. Slichter was his third graduate student, beginning research with Purcell shortly after that discovery.

Slichter came to the University of Illinois in 1949 as an instructor, recruited by then-department head F. Wheeler Loomis as an integral part of an effort to build a world-class faculty in the emerging field of solid-state physics. Slichter was appointed assistant professor two years later and quickly rose through the ranks to full professor in 1955. At Illinois, he held additional professorial appointments at the Center for Advanced Study (1968–1997) and the Department of Chemistry (1986–1997).

After his retirement in 1996, Slichter maintained an active research program at Illinois, holding an appointment as research professor of physics and continuing to advise graduate students (1997–2006).

Slichter is survived by his wife, Anne FitzGerald Slichter of Champaign, Illinois; by his children William Almy Slichter of Minneapolis, Minnesota; Jacob Huber Slichter of Brooklyn, New York; Ann Thayer Slichter of Los Angeles, California; Daniel Huber Slichter of Boulder, Colorado; and David Pence Slichter of Binghamton, New York; and by his grandchildren, Sarah Thayer Slichter of Kingston, New York; Thayer Slichter and Lila Slichter of Minneapolis, Minnesota; and Trevor Hagar Slichter and Isabela Hagar Slichter of Boulder, Colorado. He was preceded in death by his son Sumner Pence Slichter. He is also survived by his first wife, Gertrude Thayer Almy of Mitchellville, Maryland, who is the mother of Sumner, William, Jacob, and Ann. ■

ALFRED W. HUBLER

1957–2018

Professor of Physics Alfred Wilhelm Hubler died on Saturday, January 27, 2018, at Carle Foundation Hospital in Urbana, following a four-year battle with lymphoma. He was 60 years old.

Hubler worked on a broad range of theoretical problems in nonlinear dynamics and occassionally guided experimental and computational work investigating nonlinear phenomena. He made important contributions to the study of the chaotic dynamics in classical systems, both in idealized physical models and in engineering systems.

Hubler is best known for his research into the control of chaos, the resonant coupling of nonlinear oscillators, and resonant stimulation and novel spectroscopies in nonlinear systems. He was among the first to recognize that seemingly erratic, random motions associated with deterministic chaos could, in fact, be controlled, and that “chaotic” systems could be more “flexible” than systems undergoing more regular motion.

Over the course of his career, Hubler maintained a growing list of unique research ideas, including designing wireless power for cars and developing an ultra-powerful battery. He held four patents.

In 1990, Hubler was named the associate director of the Center for Complex Systems Research at Illinois, eventually becoming its director. On a yearlong sabbatical in Japan in 1993/94, he served as a Toshiba Chair Professor at Keio University, Tokyo. Hubler also spent several summers as a visiting scholar at the Santa Fe Institute in New Mexico.

Hubler was a skillful and committed teacher, and his name regularly appeared on the U or I List of Teachers Ranked Excellent by Their Students. Hubler developed an interactive web-based software package for teaching science; CyberProf software analyzes student homework problems in real time and provides individualized feedback to each student.

Hubler received his diplom in 1983 and Ph.D. in 1987, summa cum laude, from the Department of Physics, Technical University of Munich, Germany. After a postdoctoral fellowship at the University of Stuttgart, Germany, he came to the University of Illinois as a visiting professor in 1989 and joined the faculty at Illinois Physics in 1990.

Hubler was born on May 16, 1957, in Munich, Germany, to Wilhelm and Therese (née Kammerloher) Hubler. He met Marietta (née Deutscher) Hubler when he was 16, and they were married seven years later. The couple had six daughters, three born in Germany, three in Illinois.

Hubler is survived by his wife, Marietta (Deutscher) Hubler; his six daughters, Ines (Hubler) Mitra, Mija Hubler, Merla Hubler, Thera Hubler, Zita Hubler and Amrei Hubler; his sons-in-law, Sumit Mitra, Keven Wyld and Anthony Messina; his two grandchildren, Clara Wyld and Leo Mitra; and his brother and sister-in-law, Walter and Gabi Hubler, and their children, Florian Hubler, Jakob Hubler and Caroline Hubler. ■

DAVID PINES

1924–2018

Center for Advanced Study Professor Emeritus of Physics and of Electrical and Computer Engineering David Pines, one of the foremost condensed matter theorists, died on May 3, 2018, in Urbana, Illinois. He was 93 years old. Pines is survived by his children Catherine Pines and Jonathan Pines, by his three grandchildren Josie, Tillie, and Maisie Pines, and by his sister Judith Fried. He was preceded in death by his wife Aronelle "Suzy" Pines (1925–2015).

Pines made lasting contributions to condensed matter physics, establishing, with Bohm, the collective nature of electron-electron interactions in solids, which underlies the BCS theory of superconductivity; and to nuclear physics, contributing to our understanding of the collective motion in nuclei; and to theoretical astrophysics, providing early input on the structure and development of neutron stars. Pines ported new approaches across disciplines to elucidate complex systems and emergent behavior, helping to chart the earliest course of inquiry in many-body physics.

He was internationally recognized not only for his significant research contributions, but also for the key role he played in bringing scientists together to explore the most pressing scientific questions of his time. He was the founding director of the Center for Advanced Study (1967–1970) at the University of Illinois at Urbana-Champaign. He served as vice president of the Aspen Center for Physics from 1968 to 1972. He was one of the key organizers and founding members of the Santa

Fe Institute (SFI) in 1984; he later played a variety of organizational roles for the institute, most recently holding the title of co-founder in residence. And in 1999, he co-founded the Institute for Complex Adaptive Matter, a virtual campus collective of scientists, and served as its first director and on its board of trustees and science steering committee; in 2004, he cofounded its international component I2CAM. And from 2005, Pines held an appointment as distinguished professor of physics at the University of California, Davis.

Pines was a dedicated teacher and his work as an author and editor likewise facilitated scientific advances in several branches of physics. In addition to producing hundreds of peer-reviewed scientific articles, Pines was the founding editor (1961–1981) of Frontiers in Physics, a lecture-note and reprint series that delivered leading-edge science to a broad audience; 53 volumes were published. He served as editor of the American Physical Society's Reviews of Modern Physics (1973–1996), reinvigorating the publication and making it one of today's leading physics journals. And he served many years on the editorial boards of the Journal of Physics and Chemistry of Solids and of the SFI's Studies in the Sciences of Complexity. Pines's physics textbooks have been widely used in the US and abroad. Because of his focus on communicating complex science through basic concepts, these volumes are still relevant to the teaching of physics today: The Many-Body Problem (1961; in Russian, 1963); Elementary Excitations in Solids, (1963; in Russian 1965; in Japanese, 1974); and Theory of Quantum Liquids first published in (1967; in Russian, 1968). With economics Nobel laureate Kenneth Arrow and Philip W. Anderson, Pines edited the volume The Economy as a Complex Evolving System, summarizing a series of SFI workshops on complexity economics.

Pines was born on June 8, 1924, in Kansas City Missouri to Sidney and Edith (née Adelman) Pines. He attended Highland Park High School in Dallas, graduating in 1940 just before his sixteenth birthday. He enrolled in a small experimental liberal arts college, Black Mountain College, in Asheville, NC, for one year, before transferring to University of California, Berkeley.

At Black Mountain, Pines studied calculus with Dr. Nathan Rosen, a former postdoc of Albert Einstein. Pines wrote about Rosen in an autobiographical article in the American Association of Physics Teacher (AAPT) journal The Physics Teacher (Dec 2015, vol. 53, pp. 526–531): "Toward the end of the year, Nathan, the first scientist I had ever met and an exceptionally good teacher, told me I should consider becoming a theoretical physicist. I remember being quite skeptical, telling Nathan that physics had been my least favorite subject in high school (my physics teacher was the baseball coach and knew little about physics and less about teaching it)."

As a result of that interaction, Pines signed up for physics courses at Berkeley. However, he wasn't truly inspired by the subject until he took quantum mechanics with Dr. Joseph Weinberg, who had been a doctoral student of Robert Oppenheimer. Oppenheimer was serving in a leadership role in the Manhattan Project at Los Alamos at the time, but Pines was inspired by him through the stories Weinberg told.

Pines received his bachelor's degree in physics from UC Berkeley in 1944 and enrolled in the graduate program at Berkeley, hoping to work with Oppenheimer himself. After his first semester of coursework, Pines was drafted into the Navy and served two years. He returned to Berkeley in 1946. Oppenheimer had at that time also returned, and Pines found in him a great mentor.

In 1947, Pines followed Oppenheimer to Princeton University, where Oppenheimer had accepted a position as director of the Institute for Advanced Study. In the end, Oppenheimer's obligations as a leading scientific adviser on U.S. policy turned his attention away from research, so Pines asked one of Oppenheimer's former students, David Bohm, to be his thesis adviser. A noted theoretical physicist in his own right, Bohm happened to be Pines's roommate at the time.

In the AAPT article, Pines remembered Bohm as a born teacher, like Oppenheimer: "What I learned from them both was the importance of focusing on physical concepts rather than equations, the primacy of experiment in telling us what theories will be correct, and the essential role in physics that is played by what we would now call the social network: trying out ideas on colleagues, following carefully the latest experimental discoveries; going to conferences; and attending journal clubs in which the latest 'hot' results are reported and discussed." (pp. 527–528)

With Bohm, Pines undertook his first work on many-body systems, focused on electron interactions in a dense gas. Pines received his master's (1948) and doctoral (1950) degrees in physics from Princeton. He then planned a series of three scientific papers with Bohm, based on his doctoral thesis. But in December of the same year, Bohm's U.S. scientific career came to an abrupt conclusion; under the toxic climate of McCarthyism, Bohm was investigated by the House Un-American

Activities Committee. Suspected of Communist Party ties, he was indicted in a federal court. Though he would later be acquitted, Bohm lost his position at Princeton and could obtain no other academic posts in the U.S. Bohm joined the faculty at University of São Paulo in Brazil in 1952. In the meantime, Pines worked as an instructor for 18 months at the University of Pennsylvania, prior to coming to the U of I as John Bardeen's first postdoc, with the academic title research assistant professor.

In the AAPT article, Pines wrote of Bardeen: "John quickly became my third major mentor in physics. My desk was in a corner of his office and we discussed physics over lunch almost every day. At his suggestion I started work on a problem he thought might be relevant to developing a microscopic theory of superconductivity, understanding polarons, single electrons strongly coupled to lattice vibrations in polar crystals."

This work prepared the way for Pines and Bardeen's work on electron-lattice coupling in metals, and then on electron-phonon coupling in metals. Pines's work under Bardeen between 1952 and 1955 would form the underpinnings of the Nobel prize-winning work a later graduate student, Bob Schrieffer, did under Bardeen. Schrieffer's invention of the wave function for the superconducting ground state in 1957 was directly inspired by Pines's wave function.

The third paper coauthored with Bohm was written in 1953, via an exchange of letters between Urbana and São Paulo. In it, they introduced the random phase approximation (RPA), now widely used in many-body physics.

From 1955 to 1958, Pines joined the faculty at Princeton as an assistant professor. In 1957, he embarked on a 15-month combined Guggenheim and National Science Foundation fellowship in Europe, spending the summer at the Bohr Institute and the academic year at the École Normale Supérieure. At the Bohr Institute, he collaborated with Aage Niels Bohr and Ben Roy Mottelson, introducing them to the theory of superconductivity by showing the relevance of these concepts to pairing in nuclear physics. The paper by Bohr, Mottelson, and Pines on a possible analogy between the excitation spectra of nuclei and those of the superconducting metallic state represents the first-ever application of BCS concepts to nuclear physics. This work laid the foundation for the 1975 Nobel Prize-winning work by Bohr, Mottelson, and Leo James Rainwater on the connection between collective motion and particle motion in atomic nuclei, and the theory based on this connection.

At the invitation of Oppenheimer, Pines spent 1958/59 as a visiting member of the Institute for Advanced Study, where he collaborated on developing a microscopic understanding of superfluid helium-4. In 1959, Pines joined the faculty at the U of I as a professor of physics and electrical engineering; here he would spend most of his academic career. His office was next door to that of John Bardeen.

Pines served his scientific community as a member of advisory boards, boards of trustees, and organizing committees, in too many roles to list here. A partial list includes his work with the Association of Universities for Research in Astronomy, The Institute for Theoretical Physics in Santa Barbara, the Joint US–USSR Commission on Scientific and Technological Cooperation, Los Alamos Scientific Laboratory, the National Academy of Science's National Research Council.

Pines often took the lead in organizing scientific symposia, workshops, and exchanges of scientists. He was a great proponent of building a US–USSR scientific cooperation, starting in the post-war era, when Jewish scientists were heavily discriminated against. Pines chaired the Board on International Scientific Exchange (1973–1977) and co-chaired the US–USSR Commission on Cooperation in Physics (1975–1980) of the National Research Council. He was also instrumental in securing several faculty exchanges for Russian scientists at the U of I at the end of the Cold War.

Pines was the recipient of numerous honors over the course of his long and productive career. He was elected a member of the National Academy of Sciences and of the American Philosophical Society; he was elected a Fellow of the American Academy of Arts and Sciences, of the American Association for the Advancement of Science, of the American Astronomical Society, and of the American Physical Society. He was an honorary member of the Hungarian Academy of Sciences and a foreign member of the Russian Academy of Sciences and of the Science Academy Society of Turkey. He was selected a Fellow of the J.S. Guggenheim Memorial Foundation (1962 and 1969); won the 1983 Friemann Prize in Condensed Matter Physics; was awarded the 1984 Dirac Silver Medal for the Advancement of Theoretical Physics and the 1993 Tau Beta Pi Daniel C. Drucker Eminent Faculty Award of the U of I College of Engineering; was conferred an honorary degree from the University of St. Andrews in Scotland (2009); received the 2009 John Bardeen Prize of the International Conference on the Materials and Mechanisms of Superconductivity; and received the 2013 John David Jackson Excellence in Graduate Physics Education Award of the American Association of Physics Teachers. ■

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