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PHYSICS ILLINOIS

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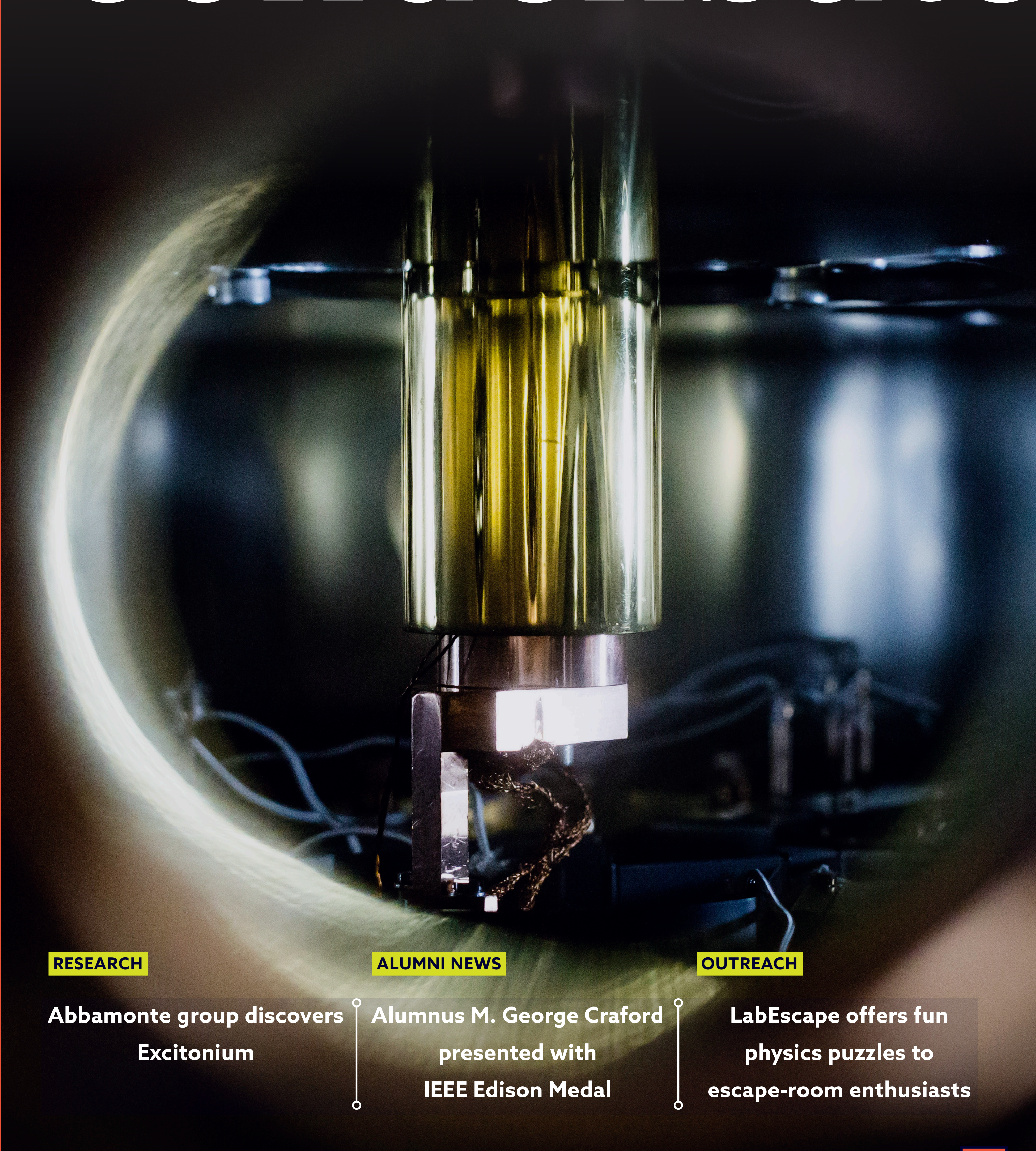

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Abbamonte group discovers Excitonium

ALUMNI NEWS

Alumnus M. George Craford presented with IEEE Edison Medal

OUTREACH

LabEscape offers fun physics puzzles to escape-room enthusiasts

THE NEWS MAGAZINE *of the* DEPARTMENT OF PHYSICS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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PHYSICS ILLINOIS
CONDENSATE

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Please send us your comments or ideas for future stories:

Siv Schwink
sschwink@illinois.edu
or (217) 300-2201

Department of Physics
1110 West Green Street
Urbana, IL 61801-3080

DALE VAN HARLINGEN
Professor and Head

CELIA ELLIOTT
Director, External Affairs and Special Projects

AMBER LANNERT
Director of Advancement

ROSS WILLIAMS
Assistant Director of Advancement

SIV SCHWINK
Communications Coordinator
Editor, Physics Illinois Condensate

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Cover image: The low-temperature sample stage on which samples are mounted in the new M-EELS instrument, developed in the laboratory of U. of I. Professor of Physics Peter Abbamonte, in the Frederick Seitz Materials Research Laboratory. The Abbamonte group successfully used this instrument to discover a new form of matter, excitonium, first predicted about 50 years ago. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Back cover image: Loomis Laboratory of Physics, exit to Green Street. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

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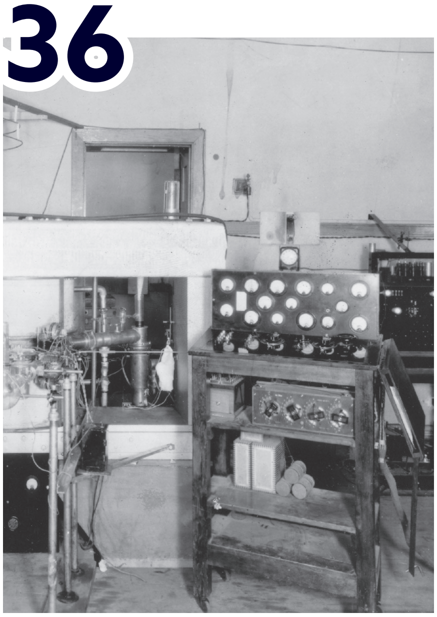

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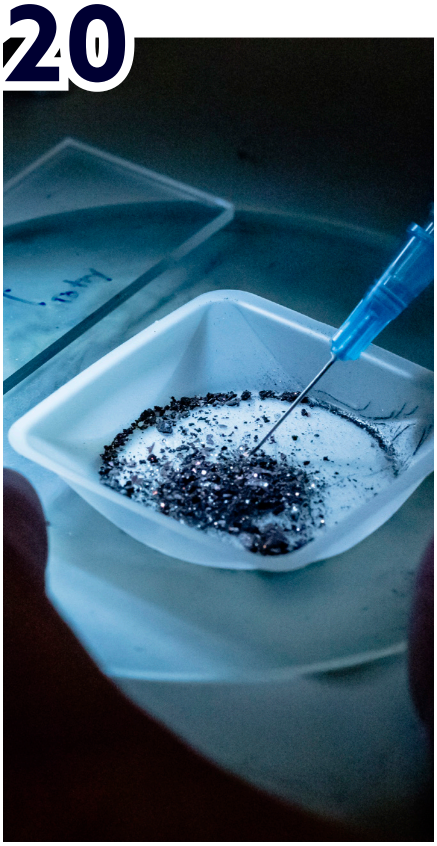


IN MEMORIAM

FROM OUR Department Head

DALE VAN HARLINGEN

A new look, a new name, an unwavering commitment to excellence and impact

This is a time of big changes and big challenges at the University of Illinois and in the Department of Physics. As you read our newsletter about some of the exciting and transformative activities and people in Physics Illinois, what you will notice first is the new look and the new name.

The new look is part of a major effort over the last year to create a fresh, vibrant, and modern style for the Physics Illinois website and communications, a look better aligned with the energy and vision of the department and the faculty, staff, and students who shape our program.

The new name—condensate—was selected to describe our legacy and our style that is unique to our program. More than a scientific term, condensate is a concept, a way of thinking and interacting that promotes the emergence of ideas and discoveries. First used to describe states of matter, it was redefined in the BCS Theory of Superconductivity to characterize the Cooper pairs in the ground state. It is now widely used to characterize a wide variety of emergent coherent states in Physics and has leaked into almost every area of Physics. It is a manifestation of the "Urbana style" of research that provides a framework for addressing key problems in Physics and in many ways defines our program.

The recent changes in the department go far beyond the new name and new look of our newsletter. This year will be particularly active as we move forward on many fronts:

Hiring. For the first year in quite a while, we do not have any new Physics faculty starting this year—the one hire we made last year, Barry Bradlyn, a condensed matter theorist from Princeton, will arrive in fall 2018. We have had several departures in the last year—Shinsei Ryu (Condensed Matter theory) to the University of Chicago, Verena Martinez Outschoorn (High Energy experiment) to UMass-Amherst, and Peter Schiffer (Condensed Matter experiment and Vice Chancellor for Research) to Yale University. All told, our faculty size has dropped from ~65 faculty, our optimum size, to only 57, creating pressure on covering teaching assignments and maintaining research productivity in some areas. To restore our size, we are carrying out faculty searches in High Energy and Nuclear theory, Biological Physics experiment, and Condensed Matter experiment this year. We are also looking to grow our program in Physics Education Research.

Infrastructure. We are completing an extensive project to provide energy-efficient heating and cooling to our buildings, remodeling research space for our faculty, opening a new outdoor patio on the south corner of Loomis Laboratory, and launching a massive remodeling project in ESB to expand our upper-level labs and provide additional space for the Institute for Condensed Matter Theory.

Diversity and Inclusiveness. The Department of Physics is passionately committed to providing opportunities for people of all genders, race, beliefs, and backgrounds. We have made great progress in gender diversity, with 10 women currently holding tenure or tenure-track positions, and 25% of our graduate student population being women. Our current efforts are focused on increasing the diversity of our Physics majors and increasing participation at all levels by underrepresented minorities. We are also committed to providing a friendly, welcoming, and productive environment for all of our faculty, staff, and students. We firmly reject those at all levels who seek to stand in the way of such progress.

Student activities. We welcomed 53 new graduate research students and 168 new undergraduate Physics majors to our department this year. The talent of these students is remarkable, and we expect great things from them in the next few years. They are also very engaged and active—this year we will see the launch of two new undergraduate student organizations, *Society for International Physics Students* and *Society for Underrepresented Physics Students*, joining the long-standing *Society of Physics Students*, *Society for Women in Physics*, and *Physics Van*. These groups are strong allies in helping to shape our curricula and in our quest to build a vibrant, productive, safe, friendly, and inclusive environment within Physics Illinois.

Curriculum upgrades. We are continuing with our strategic plan to move the majority of our Physics majors into the College of Engineering so that we can provide better educational and research opportunities for them and sustain the vitality of our department. Part of that will be the creation of a new Applied Physics degree and the development of a suite of new technical courses for the growing segment of our student population interested in industrial or entrepreneurial careers.

New Initiatives. In research, we continue to work toward the formation of a center in Quantum Information Science and Technology to leverage our interests and expertise in Condensed Matter, Quantum Physics, and Atomic Molecular Optical Physics. We are also exploring the development of online courses to propagate our experience and success in physics education to students and teachers beyond the U. of I.—to different age groups, including high school, and to locations across the state, the nation, and the world.

New budget models. In the midst of uncertainties and reduced funding in the state budget, the campus is undergoing an extensive change in the way resources are allocated to the departments. This change was achieved through an interactive effort involving all department and research units; the colleges and departments on campus were not just asked to deal with the pressures of declining budgets, but to offer solutions for focusing the goals and operations of the campus and reinventing the financial model. The Department of Physics has taken this opportunity very seriously, approaching this problem with creative thinking and collaboration, in the same way we have approached much harder problems in our research programs. What emerged is a commitment to the very values and principles that build our record of achievement and reputation—an unwavering commitment to excellence in everything we do and to advancing science and science education.

New leadership. As seems to be the case each year, we will see changes in the campus leadership. We will soon have a new provost when Andreas Cangellaris, currently dean of the College of Engineering, assumes that role; a new vice-chancellor for research, and a new dean of the College of Engineering. There will also be a new leader of the Department of Physics. This will be my last year as head of the department—my plan is to step down on June 30, 2018, at the end of my 12th year as head and 37th year on the faculty at Illinois. I am not going anywhere except to my lab to focus on some unfinished research projects, to my home to spend more time with my family and my wine cellar, and to places around the world that I have always wanted to see. This is not an easy decision for me—I have thoroughly enjoyed the challenges of this position and especially the opportunity to work with the faculty and staff in Physics to advance our shared vision of excellence in research and education. However, I think it is the right decision for me, for my family, for my research program, and for the department. It has truly been a great honor and privilege to serve in this role, which I believe to be the best position in the university because of the unique combination of scholarship, interactivity, and camaraderie, which characterize our program. I look forward to enjoying the year ahead and to working to accomplish a number of important things on my agenda before turning over the leadership to a new head, whom the dean will select later this year.

Yes, there are many challenges ahead. There are real challenges to our environment, culture, and society arising from population growth, healthcare needs, climate change, and external threats to our security. There is a toxic political and social climate in our country: There are unnecessary challenges being created by our highest leaders because of their self-serving greed, lack of understanding of science, disregard for the truth, and disrespect for the cultural diversity of our world community. And there are financial issues facing the State of Illinois and the nation. However, physicists—especially the faculty, students, and alumni of Physics Illinois—are good at solving all kinds of problems, and we will meet all of these challenges with energy, creativity, and teamwork.

The popularity of Physics is at an all-time high, as demonstrated by recent discoveries about our universe, rising student enrollments, and the demand for trained STEM researchers, which continues to grow. The Department of Physics will continue to be a leader in the education of Physics and STEM students, a major player in the quest for discovery and creativity in scientific research, and a beacon for truth and the inclusion and respect of all people. There is a right side of history, and we will be on it.

Dale J Van Harlingen

PHYSICS ILLINOIS Spectrum

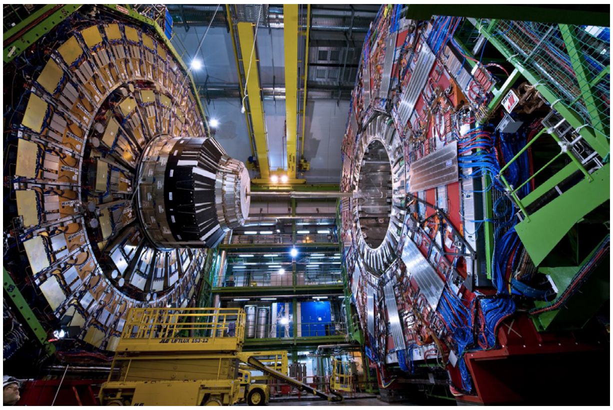
The Department of Physics at the University of Illinois at Urbana-Champaign is known for its collegial style of research—the "Urbana style"—that often involves collaborations across research areas and among theoretical and experimental physicists. Here is an inside glimpse of what some of our leading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

BEN HOOBERMAN

HIGH ENERGY PHYSICS

My research is in the field of particle physics, which focuses on understanding the composition and fundamental laws and symmetries of the universe. In 2012, the Higgs boson was discovered at the world's most powerful particle accelerator, the Large Hadron Collider (LHC) at CERN in Switzerland. This discovery marked the completion of the standard model of particle physics, which summarizes our understanding of the building blocks of matter and the fundamental forces. While the standard model has been extremely successful, several key open questions indicate that it cannot be the final theory of nature. In particular, the standard model predicts that the Higgs boson mass is 16 orders of magnitude larger than the observed value (the "hierarchy problem"). Additionally, the standard model cannot explain the origin of dark matter, a mysterious, as-yet undiscovered substance believed to permeate the universe. Understanding the nature of physics beyond the standard model is now the centerpiece of the LHC physics program and the focus of my research.

Supersymmetry is an extension to the standard model that may resolve the hierarchy problem, explain the origin of dark matter, and pave the wave to a grand unified theory of nature. Supersymmetry theorizes exotic new particles that may be produced in particle collisions. My research focuses on searching for them in data collected by the ATLAS detector at the LHC. My group is leading searches for supersymmetric particles in collisions containing leptons (electrons or their heavier cousins, the muons) and large missing transverse energy from escaping dark matter particles. We are also adapting machine-learning techniques used in computer vision fields to identify particles produced in LHC collisions and upgrading the ATLAS trigger system to perform fast hardware-based charged particle tracking, which will enhance the sensitivity of these searches. A discovery in these searches would transform our understanding of the composition and fundamental laws of the universe, leading to a paradigm shift in physics comparable in historical scale to Einstein's relativity superseding classical Newtonian physics in the early 20th century.

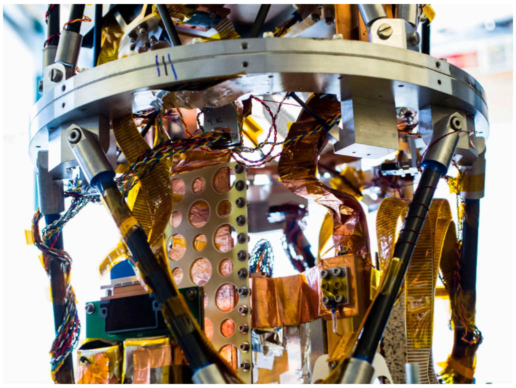


The ATLAS detector at the Large Hadron Collider (LHC) at CERN in Switzerland. Photo courtesy of CERN.

JEFF FILIPPINI

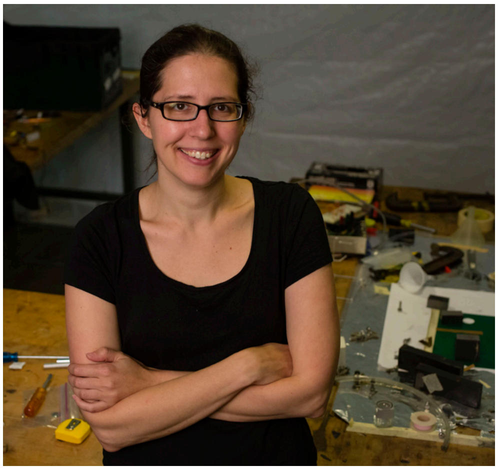
ASTROPHYSICS

My work focuses on astrophysical probes of fundamental physics: the ways in which the deepest workings of the universe are imprinted onto the grandest structures we see through our telescopes. I love the idea that there are deep connections between the largest and smallest scales of our cosmos, and the tantalizing possibility of unlocking new physics inaccessible in terrestrial laboratories. This work has led me to hunt for dark matter deep underground and to take baby pictures of the universe from the Antarctic ice. I look forward to seeing where it takes me next. These kinds of measurements are enabled by the superconducting technologies developed in our condensed matter groups here at Illinois, and I expect fruitful collaborations for the next generation of measurements.



The original SPIDER telescope made its way to Urbana for repairs in the Filippini lab, after its Antarctica flight. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Right now I'm excited about the search for primordial gravitational waves: quantum "noise" imprinted on spacetime by the universe's earliest moments. LIGO has shown that modern cataclysms leave ripples in spacetime; the theory of inflation suggests that the early Universe did the same, but at vastly longer wavelengths. These waves should have left a unique imprint on the polarization of the cosmic microwave background (CMB): the glow of the hot plasma of the early universe, detectable in the sky today at ~100 GHz. Our "readout system" for this cosmic photograph is a powerful balloon-borne telescope called SPIDER. In January 2015 (just before I joined the Illinois faculty!) we lofted SPIDER for a 16-day flight at 118,000 feet over Antarctica. Our team at Illinois and collaborators worldwide are hard at work on the analysis of this exquisite data set, and new telescopes for SPIDER's second flight are taking shape on the 4th floor of Loomis. Future efforts include next-generation CMB instrumentation from the ground, balloons, and space, as well as novel instruments (cryogenic and otherwise) for future measurements.



Anne Sickles poses in the Nuclear Physics Laboratory on Stadium Drive in Champaign. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign.

ANNE SICKLES

NUCLEAR PHYSICS

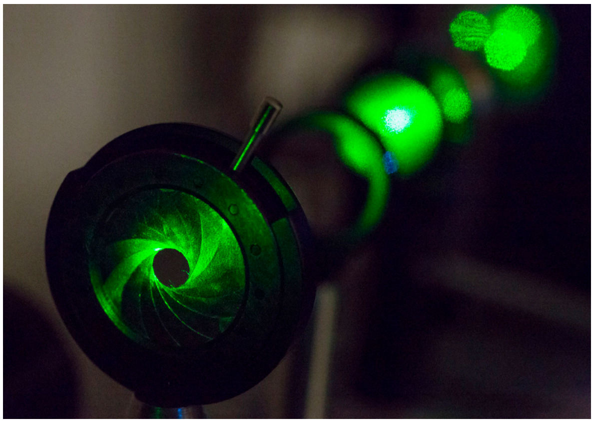
My group studies the trillion-degree matter , the quark-gluon plasma, made in the collisions of two large nuclei. Just as with more conventional substances, we want to study how it's properties change when we change its temperature. Since the collisions happen in particle accelerators, this process is more challenging than simply adjusting a thermostat. We make the highest temperature matter at the LHC in Geneva and are in the process of building a new detector, sPHENIX, for the Relativistic Heavy Ion Collider in New York, where the lower collision energy translates into a cooler, but still very hot, quark-gluon plasma. Under the leadership of Illinois Distinguished Postdoctoral Fellow Vera Loggins, at the Nuclear Physics lab we've constructed prototype calorimeters for sPHENIX. The calorimeters are of a novel design and are bricks of powdered tungsten with clear fibers running lengthwise. This design allows us to see the light generated when electrons interact with the tungsten. It's all held together with epoxy. With our collaborators from other institutions, we've tested the detectors in particle beams at Fermilab. This testing is designed to tell us whether the detectors are performing as well as we need them to in sPHENIX. The analysis is ongoing, but it is looking very promising!

YANN CHEMLA

BIOLOGICAL PHYSICS

My lab works at the interface between physics and biology. Generally speaking, we are interested in mechanical processes in biology. What do I mean by this? The living cell is much more complex than a bag of well-mixed molecules that encounter one another by diffusion and undergo chemical reactions. The cell is more like a highly organized factory of molecular machines, proteins that carry out specific mechanical tasks such as moving cargo around the cell, manipulating the cell's genome, or even propelling the entire cell.

How do we study these processes? We use laser-based techniques—optical tweezers, which utilize focused light to exert forces, and fluorescence microscopy, which detects light emitted from a dye molecule—because they are sensitive enough to measure forces and motions at the level of the individual biomolecule. A recent example is our work applying both techniques to understand helicases—proteins which separate the two strands of DNA (Comstock et al. Science, 2015). We discovered that a class of helicases possess a "switch" that determines the direction in which they move along DNA—akin to the gearbox on a car. We suspect that this switch is used to control what the protein does inside the living cell, but further experiments will be necessary.



ALUMNI RECEPTION

Mark your calendar for the annual gala Physics alumni reunion! Tuesday, March 6, 6:00–8:00 P.M. at the JW Marriott Hotel in downtown Los Angeles.

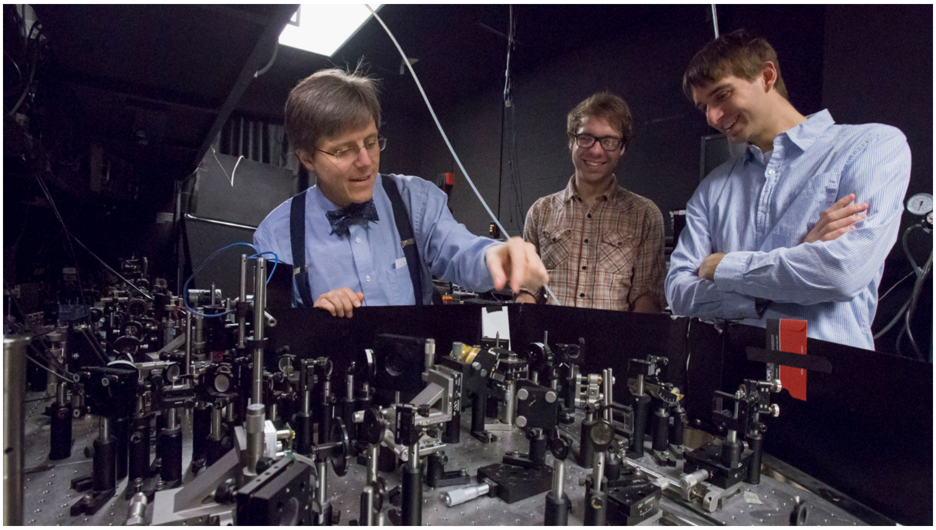
The gala Physics alumni reunion is held annually in conjunction with the American Physical Society's March meeting. Sponsored by the Department of Physics and the Physics Alumni Association, the Illinois reunion has long been known as the best party at the March Meeting. Please join us and help us maintain that reputation of warmth and collegiality. It's a great chance to renew old acquaintances and learn about the exciting new initiatives for Physics Illinois!

You need not be an APS member or registered for the meeting to attend—we are also extending an invitation to all our alumni living in the greater Los Angeles area. Great refreshments and door prizes!

PAUL KWIAT

AMO/QUANTUM INFORMATION SCIENCE

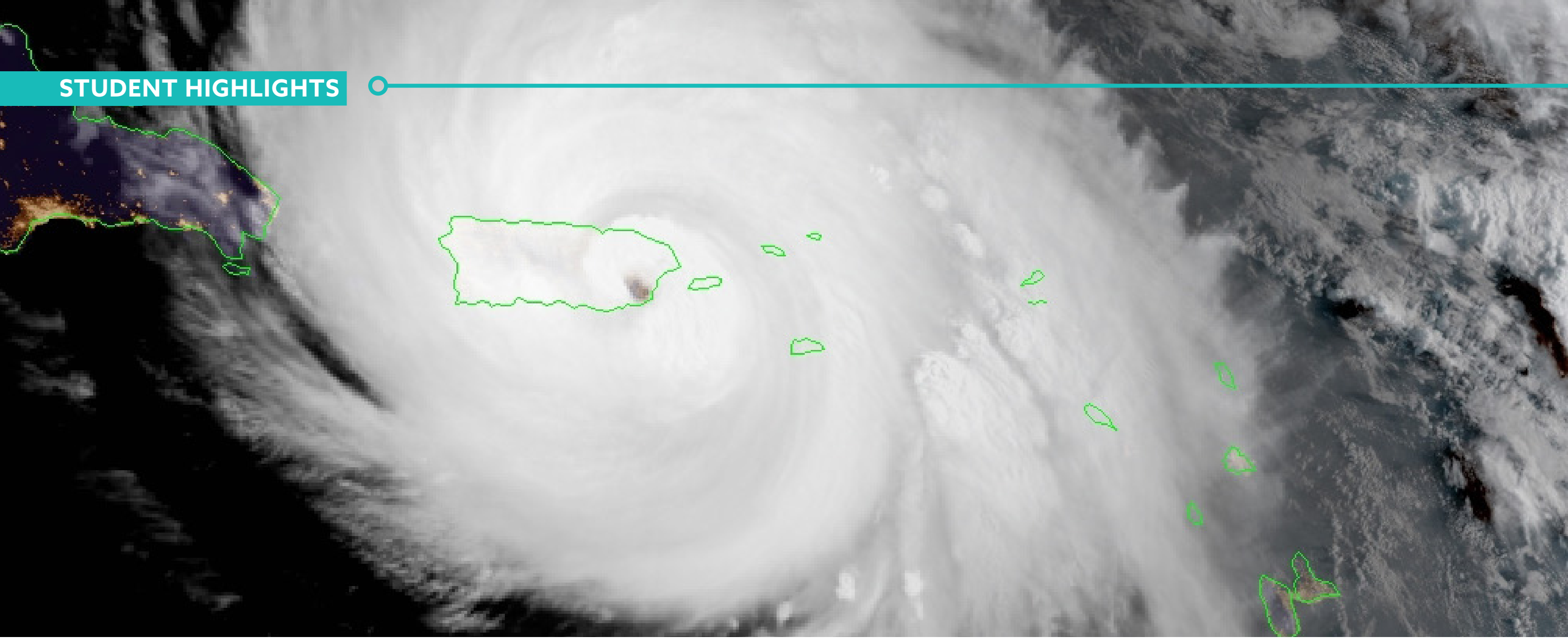
Entanglement, the bizarre non-local correlations that can exist between two quantum systems, is the quintessential quantum mechanical phenomenon, distinguishing it from classical lines of thought. In our group we employ the non-local features of entanglement to explore fundamental science, e.g., showing that no local realistic model can explain quantum correlations, and practical applications. For example, we are currently working on projects to implement quantum communication channels (which could allow provably secure ship-to ship communication) for the Navy; one particularly appealing approach is the use of quad-copter drones, which might eventually allow quantum cryptography to be applied to communications to the home. We are also working on a NASA-funded project with the goal of realizing quantum communication from the International Space Station to a receiver on Earth. Such an experiment would be a critical milestone on the path toward an eventual quantum network, whose applications could include secure communication, coherent quantum sensors (imagine the optical equivalent of a radio telescope array, with the collection optics separated by more than the diameter of the planet!), and eventually even distributed quantum computing.



Above: Paul Kwiat works with graduate students in one of his laboratories in Loomis. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Opposite page: A special lens focuses a green laser beam, mounted on research apparatus in one of Yann Chemla's laboratories at Loomis. Image by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Another area of research focuses on human vision. Although 70+ years have passed since the first low-light vision experiments, it remains an open question whether humans can see single particles of light—"photons." In our lab we are developing unique hardware and methodology to definitively answer this question, by reliably preparing pulses of light containing exactly one photon. The photon is directed at random to one of two sets of rods in the observer's retina; by forcing the observer to choose where they believed they saw the photon (including cases where it was lost before detection), single-photon sensitivity can be determined, simply by looking for correct answers better than random guessing would allow. Recent psychology experiments suggest that awareness of visual events may depend on the phase of an observer's alpha brain waves; therefore, to improve sensitivity we can incorporate signals from an EEG, and send the photons only when the subject is most likely to 'see' them. We are also exploring the use of 'adaptive optic' techniques to enable us to hit a single rod at will. The payoff would be an extremely powerful measurement system, enabling entirely new types of experiments on the human visual system at the single-quantum level. For example, we can then contemplate tests of nonlocality in which one of the 'detectors' is a human observer. Or we can direct the photon in a quantum superposition, simultaneously hitting two separate locations on the retina; the result would be a human-scale version of Schroedinger's famous cat! ■



Illinois students collect aid for Puerto Rico in aftermath of Hurricane Maria

SIV SCHWINK
for Physics Illinois Condensate

When Hurricane Maria struck Puerto Rico on September 20, it was the strongest storm to hit the U.S. territory in over 80 years. It ravaged the island's infrastructure—tearing up roadways, destroying power lines, razing homes, and contaminating fresh water sources.

Three months later, there was still no power, and without it, many don't have access to clean water. Transportation and communication are limited across the island. More than 73,000 of the island's 3.4 million U.S. citizens have evacuated to Florida. Most schools remain closed. And the official death toll has risen to 64, though some sources say it may be as high as 1,000.

Luis Miguel de Jesús Astacio closely followed the catastrophic storm and its aftermath in the news. Born and raised in Puerto Rico, he had moved to Urbana on August 14 to attend the prestigious doctoral program in physics at the University of Illinois at Urbana-Champaign.

After the storm pummeled the island, about a week and half would pass before De Jesús Astacio was able to reach members of his family and learn that they were all safe and whole.

"They are doing okay. No one was injured or died among my family and friends. We were very lucky," he shares.

De Jesús Astacio recounts how his immediate family worked to save their home in Trujillo Alto, one of the municipalities adjacent to the capital, San Juan:

"My two brothers went out into the storm and cut down a metal fence that was piled up with leaves and debris, blocking the water from draining and causing our home to flood. They also unclogged a storm drain of debris—right in the middle of the hurricane. They are very strong and a little bit crazy. My family spent about 10 hours during the storm just bailing water out from the house as it was seeping in."

The water has since receded from the part of the island where De Jesús Astacio's immediate family lives. But today, much of his extended family is still without power or clean water. One uncle lost a portion of his house to the storm.

De Jesús Astacio says he was disappointed in the U.S. emergency response to the devastation of his home island. That's why he spent a good part of the fall semester doing what he could from Urbana to make sure Puerto Ricans received much-needed assistance.

"I wanted to take matters into my own hands—to help. I started contacting people, seeing what I could do, and then I was contacted by a group on campus called Puerto Rico Rises that was trying to do the same thing. I joined forces with them."

Puerto Rico Rises is a non-profit organization initiated in Florida in the wake of Hurricane Maria, and chapters have popped up across the states.

“Puerto Rico Rises was started in Florida because Puerto Ricans there realized most of the aid being sent wasn’t getting to the people who needed it,” De Jesús Astacio elaborates. “It was mostly going to San Juan ports and being held there, not getting to the central island, where most help is needed.”

Luis Miguel de Jesús Astacio and friends from the Illinois chapter of Puerto Rico Rises deliver physical donations to a warehouse in Aurora, IL, on October 22, 2017. The donations were transported from there to Florida and then on to Puerto Rico. Photo courtesy of Luis Miguel De Jesús Astacio

“The mission of Puerto Rico Rises is to collect donations—in particular physical goods—and deliver this aid to the places where it’s most needed. The group on campus was just getting going at the same time I was trying to get started. A graduate student in civil engineering, Jose Rivera-Perez, started the campus group. It was Rebeca Agosto, a political science student, who reached out to me—I have known her since elementary school, and she knew I would be interested. Soon, there were a lot of students who got involved in helping—probably about 20, all from different disciplines, like political science, engineering, and entomology,” he continues.

“Our chapter has two missions, and the first is directly related to the mission of Puerto Rico Rises in Florida: all chapters send the physical donations they collect to the Florida chapter, and that chapter will get it to Puerto Rico,” De Jesús Astacio explains.

That portion of the mission is now complete, and the group is no longer accepting material donations. Four students from the campus chapter, including De Jesús Astacio and Rivera-Perez, drove to Aurora, IL, on Sunday, October 22, to deliver the physical contributions they’d collected to the Aurora chapter, for transport to Florida, and then on to Puerto Rico.

The second mission of the campus chapter was to collect monetary donations through a crowdfunding website, YouCaring.com. This part of the effort concluded on November 7. Funds raised were shared with another relief effort. One half went to Puerto Rican emergency response efforts that have demonstrated effectiveness:

The students appointed a committee to assemble a list of known initiatives in Puerto Rico with demonstrated impact. After a couple weeks of review, the students settled on Organización Boricuá de Agricultura Ecológica and Red de Albergues para menores, and each group received about $2,500, according to De Jesús Astacio.

The second half of the funds went to Mexico for earth quake relief. That portion was distributed to Mexican relief agencies by another campus registered student organization called M.CE.Ch.A. (Movimiento Estudiantil Chicanx de Aztlan).

De Jesús Astacio did his best to keep up on his studies this fall—though it wasn’t easy to focus on his challenging physics graduate program at Illinois. He completed the first of three rotations in faculty research labs, required before joining a faculty member’s research team. He is leaning toward biological physics as his subdiscipline of choice—in part because of his affinity for biology and in part because he enjoys working on interdisciplinary research.

“In biophysics, you can use the formalism of physics to see the same biological problem from a different perspective,” De Jesús Astacio shares. “I’m also very interested in applying physics to the neurosciences, but it seems natural to focus on biophysics before specializing in neurophysics.”

Over winter break, De Jesus Astacio will be in Puerto Rico. He plans to meet up with another member of Puerto Rico Rises to help in the delivery of goods to places that are difficult to reach: “We want to make sure that all of the physical donations that we received were delivered in Puerto Rico,” he says. ■

An interview with Kevin Pitts, vice provost for undergraduate education and physicist

Our alumni who knew Vice Provost for Undergraduate Education and Professor Kevin Pitts when he served as our associate head for undergraduate programs (August 2010–January 2014) will remember the unflagging passion and energy he invested into improving the undergraduate experience here in the Department of Physics. He supported and enabled student initiatives, blogged extensively about professional development opportunities and physics-degree careers, and generously shared his vision and experience with our undergraduates. He built up the most diverse REU physics program in the nation and acted as a strong proponent of diversity, equity, and inclusion, not just in our department, but in physics and in the sciences in general.

A gifted teacher whose commitment to proven pedagogies has been recognized with numerous honors, Pitts also developed several courses over the years, for majors and non-majors alike.

As the College of Engineering associate dean for undergraduate programs (January 2014–August 2017), Pitts brought that same passion and leadership to improving the student experience on a wider scale and worked tirelessly toward the goal of equality of access to higher education. His broad-sightedness and effectiveness in this position led to his being tapped for his current post in the Provost's Office, where his ability to work for positive change will strengthen undergraduate education across campus.

> *"Access and affordability are a priority. Beyond that, I'm excited to facilitate cross-campus cross-disciplinary instructional efforts that are just now in early stages of development. Illinois is not a top-down organization, so we really want to support initiatives and bring people together."*

Opposite page: Kevin Pitts taking part in a Physics Van demo when he was associate head for undergraduate programs in physics.

Page 14: Kevin Pitts works with graduate student Adithya Kuchibhotla in his lab at Loomis. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Q: *How has your approach to improving undergraduate education changed over the course of the three administrative positions you've held, from department, to college, to campus?*

A: At each level, I've been entrusted with essentially the same job, only at a different scale. That job is to ensure that our undergraduate students are receiving the best education possible and have access to the preparation and resources they need to be successful while they are here and after they leave. But in terms of day-to-day responsibilities, these three positions are quite different. As associate head, I got to work very closely with undergraduates in the physics department. As I have gone forward, I've had the opportunity to think more broadly and to interact with people with a wide variety of viewpoints. Taking all of this in, my goal has been to see the undergraduate experience from different angles, to be able to make a meaningful impact at each level.

Across higher education, I can see that priorities are changing and thinking has broadened. New innovative methods for educating across disciplines are coming into play. It's an exciting time to be advising and supporting the efforts of folks across campus who are working toward bettering our undergraduate educational effort.

Q: *At the department and college levels, you've been a strong proponent of equality of access to STEM education. Will you continue to pursue initiatives along these lines as vice provost?*

A: That's a good question. My responsibilities in this position are quite a bit broader than STEM education. This remains an important issue to me, and I'm still tied to engineering and science education through some of the access programs we put in place when I was associate dean. For example, AT&T gave us funding to support a K-12 outreach effort—I was a part of the effort and planning leading up to that gift, so I'm still plugged in to that program. And I'm the principal investigator on an NSF grant that we received to support low-income students. I have a great deal vested in that program and continue to be involved there as well.

Kevin Pitts in his office at the Swanlund Administration Building. Photo by Siv Schwink for Physics Illinois Condensate

Q: *There has been a good deal of discussion at the national level about the rising costs of higher education and the crippling debt young people accumulate in order to get an undergraduate degree. What is your office doing to help make higher education affordable in Illinois?*

A: Undergrad admissions is now part of my portfolio, as is the Office of Student Financial Aid. At the campus level, we're doing everything we can to make the top-notch education we offer affordable and accessible to the brightest students. We're freezing tuition again for Illinois residents this year. Scholarships offered at campus, college, and unit levels total more than $100 million in aid to our Urbana-Champaign students—that is separate from Federal Pell Grants and guaranteed loans. But the kicker is, if you look at the financial need of our student body, there's still about $100 million in unmet need.

Scholarships are a big part of our current capital campaign. We are also looking at other ways we can bring in money for student support—and then of course, being thoughtful about spending the money wisely. We offer both need-based aid and merit-based aid, and we use it to attract the best students.

It's important to realize that unmet need equates to student debt at graduation. On average, a student with loans will have $26,000 in debt at graduation. That's a heavy burden that crosses over into the next stage of their careers.

The other question is, how many don't come here because of the cost? This is all-important to diversity—not only in terms of racial and gender equality, but also cutting across all walks of life. This issue is important not just to me, but to the Provost and to campus.

To make positive changes in terms of access, we really have to step beyond our comfort zone, influencing students before they get to campus. We have several initiatives that work with and supplement the K-12 education system. In this, we have an opportunity to have a large impact on the lives of youth who won't otherwise have access to educational opportunities.

Q: *What are some of your goals as a vice-provost?*

A: Access and affordability are a priority. Beyond that, I'm excited to facilitate cross-campus cross-disciplinary instructional efforts that are just now in early stages of development. Illinois is not a top-down organization, so we really want to support initiatives and bring people together.

Along these lines, campus is about to break ground on the new Siebel Center for Design that will provide new opportunities. While many schools have design or maker spaces, ours will be unique in being multidisciplinary and the nucleus of an innovative curriculum. No single discipline would own this initiative, which will encourage design-thinking, creativity with a goal, and multidisciplinary teamwork. Folks in fine and applied arts will play just as important a role in this as folks in the humanities or the sciences.

Q: *What are the accomplishments you are most proud of in your three administrative posts?*

A: In physics, it was helping students understand the breadth of opportunities available to them with a physics degree. I spent a lot of time and effort on that. Enrollment grew while I was there and part of the reason for that was that we retained students at a higher rate. Admissions rose only a modest amount over that period. Part of the greater retention was attributable to students' understanding how in a 21st century economy, physics is an ideal degree, not just for those who want to pursue a graduate degree or be a high school science teacher. Our students are always smart, always well prepared—but to see them grasp the possibilities, that was very gratifying.

On the downside, we did not make as much progress as I had hoped on diversity—it's still lagging in physics. One reason for this is again the misperception of career options, which we can overcome only through communication. And we have to acknowledge issues of climate in the physics field, which is male dominated. People from underrepresented groups do not always feel welcome.

We still have a challenge in getting people to recognize the intrinsic value of diversity. We all benefit when people with different backgrounds and perspectives come together to attack a problem, whether it's physics or another discipline. Our field needs to embrace the benefits of a diverse workforce and work toward making that a reality. And we need to think long term to effect a change. People sometimes push back on the issue of diversity. To be clear, my hope isn't to achieve a particular population profile, it's just opening the opportunity, giving equal access.

Q: *What about at the college level—what was your greatest achievement as associate dean?*

A: I was able to assemble a very strong and diverse team. Dean Cangellaris gave me a good deal of freedom. I'm proud that I empowered our team to do great things. For example, we instituted an academic-support program, a new degree program in innovation and entrepreneurship in technology, study abroad opportunities, and some amazing innovations in the classroom. I'm very proud of what our team did. The student experience and education is better than ever, and it was a joy to work with a very dedicated, very talented team in the Engineering College.

Also, with NSF and Grainger Foundation support, we developed a new program that brings in students from a low socio-economic background who are bright and interested in an engineering degree, but may not have been allotted the same foundational instruction in math and science that most of our students come in with. Our student body is so high achieving, most have many advanced placement (AP) credits coming in. What about students who didn't have access to accelerated courses or AP?

We've put these students on a five-year plan, where the first year is really the "bridge" to college and the advanced curriculum. We've also given them academic faculty mentors and are using a cohort model—the students live together in a dorm, taking as many classes together as scheduling allows.

We held a dedicated orientation for this group, covering life skills, study skills, and engineering project opportunities. I remember, I asked them, how many of you know what an internship is? Nobody raised a hand. Many are the first in their family to go to college. So we also do our best to teach the parents how to navigate the system. This is a new model—a new way to level the playing field. It's providing access. The program is in its first year. I'm excited to see how it does.

Q: *It's early days, but what about in your current role?*

A: We are starting a number of exciting initiatives focused around student success. One very interesting aspect of my portfolio is online education. Technology is really changing the way we view education in general and providing new opportunities to work with new learners. It provides access to students around the world and the quality of online courses is very good. I'm impressed with what we are doing now and see tremendous opportunities for the future.

Q: *How has your background in research and teaching influenced the kind of administrator you are today?*

A: I worked on the Collider Detector Experiment (CDF) at Fermilab from 1994 until it shut down in 2011, in fact we are still analyzing data from that experiment. It was an amazing experience because it was incredibly collaborative science. We needed to work together in order for the experiment to be a success. That collaborative approach is incredibly important in administration. I would also say that thinking systematically and understanding things from "the ground up," which is what we always want to do in science, is a very helpful approach to understanding organizations, budgets and how to make progress.

I wouldn't trade my research experiences for anything. Working on CDF as a postdoc and as a faculty member was one of the best experiences of my life.

Q: *You have made seminal contributions to experimental high energy physics, particularly to our understanding of charge-conjugation and parity-symmetry violation in bottom quark decays. You've also held several research-related leadership positions. Given your current administrative responsibilities, do you still find time for research?*

A: My research time is definitely reduced, but it's still really important to me to stay involved in physics research. I'm no less passionate about physics research now, and it provides relief from the many meetings I attend! To be able to do both, it's important to stay well organized and to prioritize—to distinguish between what needs to be done and what can wait.

I am still active on two experiments and still have a small research group here at Illinois: I'm working with two graduate students, a postdoc, and two undergraduates. My graduate students migrate between here and Fermilab, and I meet with them regularly by video conference or in person.

I am currently working on the Muon *g*–2 experiment, which began to take data in November 2017. It's exciting science—the previous version of the experiment had an unexpected result that didn't correlate with current theory. Now we've built a better experiment to further improve upon the precision of the measurement. Aida El-Khadra and other theorists have significantly improved the theoretical calculations. The next data-taking run will go for about two years. Our first peek at bits of data will take place this spring—we'll see then if we need to refine the experiment. But we are still some time away from any definitive results. It's exciting to be a part of it.

I have also had the good fortune to be able to participate in advisory and planning groups for our field. A couple of years ago, I served on the national decadal planning effort for high energy physics. And I currently serve on a committee that advises the Fermilab director and the U.S. Department of Energy on the U.S. efforts in neutrino physics. I enjoy helping to craft the vision for the future of our field, and it's also a nice way to stay plugged into the broader research community. ■

LabEscape

ESCAPE ROOM GOES QUANTUM PHYSICS IN URBANA

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. YOU MUST FIND OUT WHAT HAPPENED TO PROFESSOR SCHRÖDENBERG, A UNIVERSITY OF ILLINOIS PHYSICIST WHO DISAPPEARED WHILE DEVELOPING A TOP-SECRET QUANTUM COMPUTER THAT COULD CRACK ANY DIGITAL-SECURITY ENCRYPTION CODE IN THE WORLD. UNFORTUNATELY, THE PREVIOUS GROUPS OF SPECIAL AGENTS ASSIGNED TO THE CASE DISAPPEARED WHILE INVESTIGATING THE VERY ROOM IN WHICH YOU NOW FIND YOURSELF LOCKED UP, SCHRÖDENBERG'S SECRET LAB.

SIV SCHWINK
for Physics Illinois Condensate

LabEscape is a science-themed escape room at Lincoln Square Mall in Urbana, testing the puzzle-solving skills of groups of up to six participants at a time. Escape rooms, a relatively new form of entertainment cropping up in cities across the U.S. and around the globe, provide in-person mystery-adventure experiences that have been compared to living out a video-game or movie script. A team of participants is presented with a storyline and locked into a room with only one hour to find and decipher a sequence of interactive puzzles that will unlock the door and complete the mission.

U. of I. Professor of Physics Paul Kwiat initiated the LabEscape project as a community outreach effort, with the goal of showing that science is not only fun, it's useful, relevant, amazing, and accessible to all.

"So many people have a fear of science and technology, because they have this idea that it's too hard. So they don't even try," Kwiat comments. "But kids come into the world with the curiosity of scientists. Unfortunately, for many people, that gets lost. That's why our first goal in creating LabEscape was to make it a fun and memorable experience, and I think we've achieved that."

> *"Curiosity, communication, and collaboration—the three C's—are really all that's needed to solve the LabEscape puzzles. Incidentally, those same three attributes are integral to successful scientific research."*

LabEscape opened its doors in January 2017 and more than 1,700 people have gone through to date. The feedback from participants on social media has been extremely positive.

Two levels of play are available within the first storyline—the advanced mode adds several puzzles beyond those in the novice mode. A second storyline, a sequel that will play out in the same room with other puzzles, has been developed over the past six months and will launch in January 2018.

To make it all happen, Kwiat enlisted support from sponsors and the help of physics department colleagues, Professor Tim Stelzer and IT Director Rebecca Wiltfong, plus a group of 12 undergraduate physics students. Before the doors opened, Paul and his team had spent about a year developing the storyline, props, and video and then beta testing the adventure with volunteers. Together they've created a unique interactive adventure using puzzles largely based on physical phenomena.

Kwiat emphasizes, no one need fear the science: the scientific knowledge required to solve any given puzzle is provided among the clues in the escape room. So while the storyline is based on quantum physics, no understanding of quantum physics is needed to succeed in saving the free world at LabEscape.

"Everything is targeted to a junior-high or high-school level of understanding. We've had a number of junior-high students go through and they all had a blast—they had no more trouble with the science puzzles than the physics graduate students!" Kwiat assures.

LabEscape participants jump with enthusiasm. Photo courtesy of Paul Kwiat, University of Illinois at Urbana-Champaign

Kwiat adds, "Curiosity, communication, and collaboration—the three C's—are really all that's needed to solve the LabEscape puzzles. Incidentally, those same three attributes are integral to successful scientific research. The STEM fields—science, technology, engineering, and math—are vital to so many aspects of modern life, and we need more young people to select STEM career paths. So in addition to having fun, we hope young people who go through will achieve a sense that science is amazing, relevant, and useful in an accessible way. Of course we want *everyone* to appreciate that, not just students."

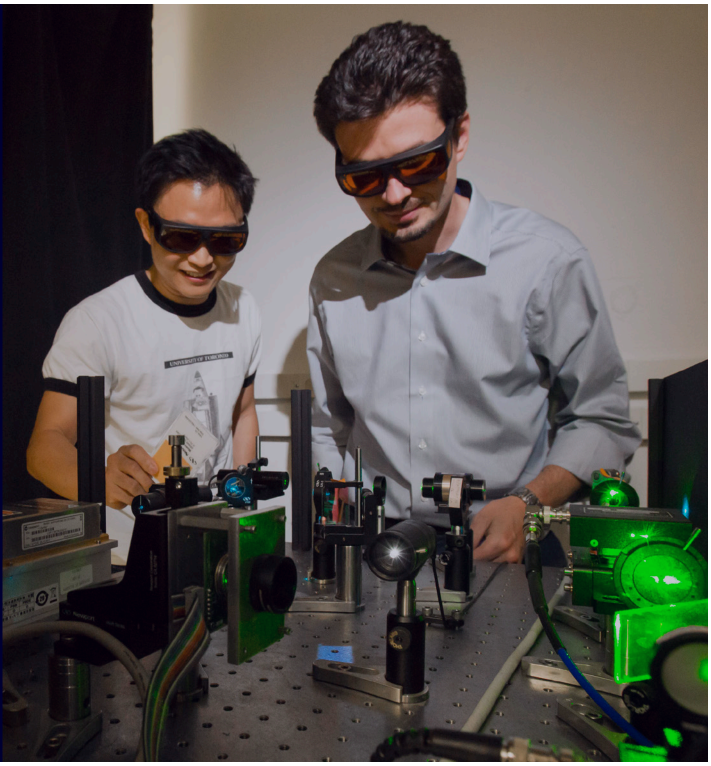
In his own cutting-edge research, Kwiat manipulates the quantum behaviors of entangled photons to develop techniques for secretive communications with unbreakable encryption, so he is uniquely qualified to write Dr. Schrödenberg's storyline.

"For me, a compelling escape room experience means the storyline needs to make perfect sense. Why there are puzzles and why there is a time limit—it all needs to fit the story. Physics-based puzzles work really well here because they are so interactive—we study and manipulate physical things and physical effects," he shares.


LabEscape staff on opening day, January 28, 2017. Photo courtesy of Paul Kwiat, University of Illinois at Urbana-Champaign

Day-to-day operations at LabEscape are handled by a team of U. of I. student employees who have completed several core physics courses. Tickets are only $20 per person, or $15 with a student ID. Reservations must be booked online at LabEscape.org.

Financial support for this nonprofit outreach project has been provided by the American Physical Society, the National Science Foundation, and 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. 🟦



Jun Song elected APS Fellow

Founder Professor of Physics and Bioengineering Jun Song has been elected a Fellow of the American Physical Society "for the development of advanced signal processing methods to reveal patterns in genomic data and study chromatin structures."

Song is an internationally renowned theoretical biological physicist and bioengineer. His research program in computational biology and biomedicine leverages the methodologies and tools of physics, mathematics, and statistics to discover how transcription factors, chromatin structure and non-coding RNAs regulate gene expression.

Song is particularly interested in the genomic study of cancer. His ongoing research has implications for prognosis and treatment of cancer, in particular of malignant melanoma, one of the deadliest cancers.

Song is a co-principal investigator on the Knowledge Engine for Genomics (KnowEnG) Center of Excellence in Big Data Computing at the University of Illinois at Urbana-Champaign, supported by the National Institutes of Health. He is co-investigator on the Center for the Physics of Living Cells, a National Science Foundation Physics Frontiers Center.

Song is the recipient of many honors, including a National Science Foundation CAREER Award (2011) and a Sontang Foundation Distinguished Scientist Award (2011).

Song received his bachelor's degree in physics from Harvard University in 1996, graduating summa cum laude, and went on to receive a master of advanced study degree in mathematics from the University of Cambridge in 1997, graduating with distinction. He received his doctoral degree in physics from the Massachusetts Institute of Technology in 2001 under thesis adviser Gang Tian of the Department of Mathematics.

Prior to joining the faculty at Illinois, Song held an appointment as associate professor in the Department of Epidemiology and Biostatistics and in the Department of Bioengineering and Therapeutic Sciences at the University of California at San Francisco, where he advised students within the biomedical sciences graduate group, the biological and medical informatics graduate group, and the developmental and stem cell biology graduate group.

Prior to his appointment at UCSF in 2009, Song held a position as a Charles B. Morrey, Jr. Assistant Professor of Mathematics at the University of California at Berkeley (2001–2003); held an appointment as instructor and research fellow in medical physics and as research fellow in biostatistics and computation biology at Harvard University (2003–2005); and was a member of the Institute for Advanced Study's Simons Center for Systems Biology (2007–2009).

Song joined the faculty at Illinois in 2014 as a full professor. His primary laboratory is at the Carl R. Woese Institute for Genomic Biology on the Urbana-Champaign campus. ■

PHYSICISTS EXCITED BY DISCOVERY OF NEW FORM OF MATTER, EXCITONIUM

Abbamonte group achieves first-ever measurement of excitonium collective modes and first observation of soft plasmon in any material

> *"This result is of cosmic significance. Ever since the term 'excitonium' was coined in the 1960s by Halperin and Rice, physicists have sought to demonstrate its existence."*

Left: The crystals used in this experiment were grown at the Frederick Seitz Materials Research Laboratory, part of the Physics Illinois complex.

SIV SCHWINK

for Physics Illinois Condensate

Excitonium has a team of researchers at the University of Illinois at Urbana-Champaign... well... excited! Professor of Physics Peter Abbamonte and graduate students Anshul Kogar (now graduated) and Mindy Rak, with input from colleagues at Illinois, University of California, Berkeley, and University of Amsterdam, have proven the existence of this enigmatic new form of matter, which has perplexed scientists since it was first theorized almost 50 years ago.

The team studied non-doped crystals of the oft-analyzed transition metal dichalcogenide titanium diselenide (1T-TiSe^2) and reproduced their surprising results five times on different cleaved crystals. University of Amsterdam Professor of Physics Jasper van Wezel provided crucial theoretical interpretation of the experimental results.

SO WHAT EXACTLY IS EXCITONIUM?

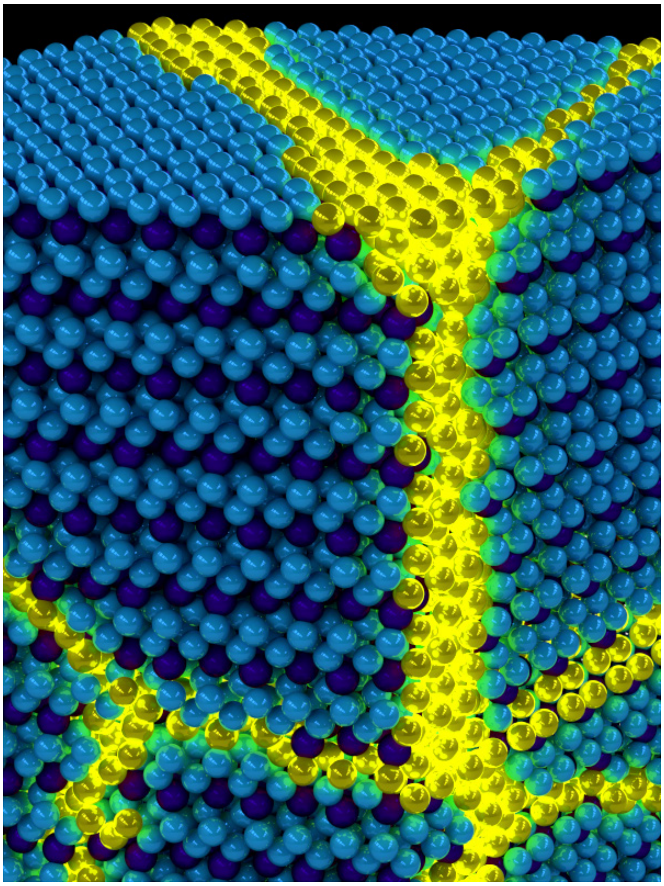
Excitonium is a condensate—it exhibits macroscopic quantum phenomena, like a superconductor, or superfluid, or insulating electronic crystal. It's made up of excitons, particles that are formed in a very strange quantum mechanical pairing, namely that of an escaped electron and the hole it left behind.

It defies reason, but when an electron, seated at the edge of a crowded-with-electrons valence band in a semiconductor, gets excited and jumps over the energy gap to the otherwise empty conduction band, it leaves behind a "hole" in the valence band. That hole behaves as though it were a particle with positive charge, and it attracts the escaped electron. When the escaped electron with its negative charge pairs up with the hole, the two remarkably form a composite particle, a boson—an exciton.

In point of fact, the hole's particle-like features are attributable to the collective behavior of the surrounding crowd of electrons. But that understanding makes the pairing no less strange and wonderful.

WHY HAS EXCITONIUM TAKEN 50 YEARS TO BE DISCOVERED IN REAL MATERIALS?

Until now, scientists have not had the experimental tools to positively distinguish whether what looked like excitonium wasn't in fact a Peierls phase. Though it's completely unrelated to exciton formation, Peierls phases and exciton condensation share the same symmetry and similar observables—a superlattice and the opening of a single-particle energy gap.



Left: Artist's depiction of the collective excitons of an excitonic solid. These excitations can be thought of as propagating domain walls (yellow) in an otherwise ordered solid exciton background (blue). Image courtesy of Peter Abbamonte, U. of I. Department of Physics and Frederick Seitz Materials Research Laboratory

Right: U. of I. Professor of Physics Peter Abbamonte (center) works with graduate students Anshul Kogar (right) and Mindy Rak (left) in his laboratory at the Frederick Seitz Materials Research Laboratory. Photo by L. Brian Stauffer, University of Illinois at Urbana-Champaign

Abbamonte and his team were able to overcome that challenge by using a novel technique they developed called momentum-resolved electron energy-loss spectroscopy (M-EELS). M-EELS is more sensitive to valence band excitations than inelastic x-ray or neutron scattering techniques. Kogar retrofit an EEL spectrometer, which on its own could measure only the trajectory of an electron, giving how much energy and momentum it lost, with a goniometer, which allows the team to measure very precisely an electron's momentum in real space.

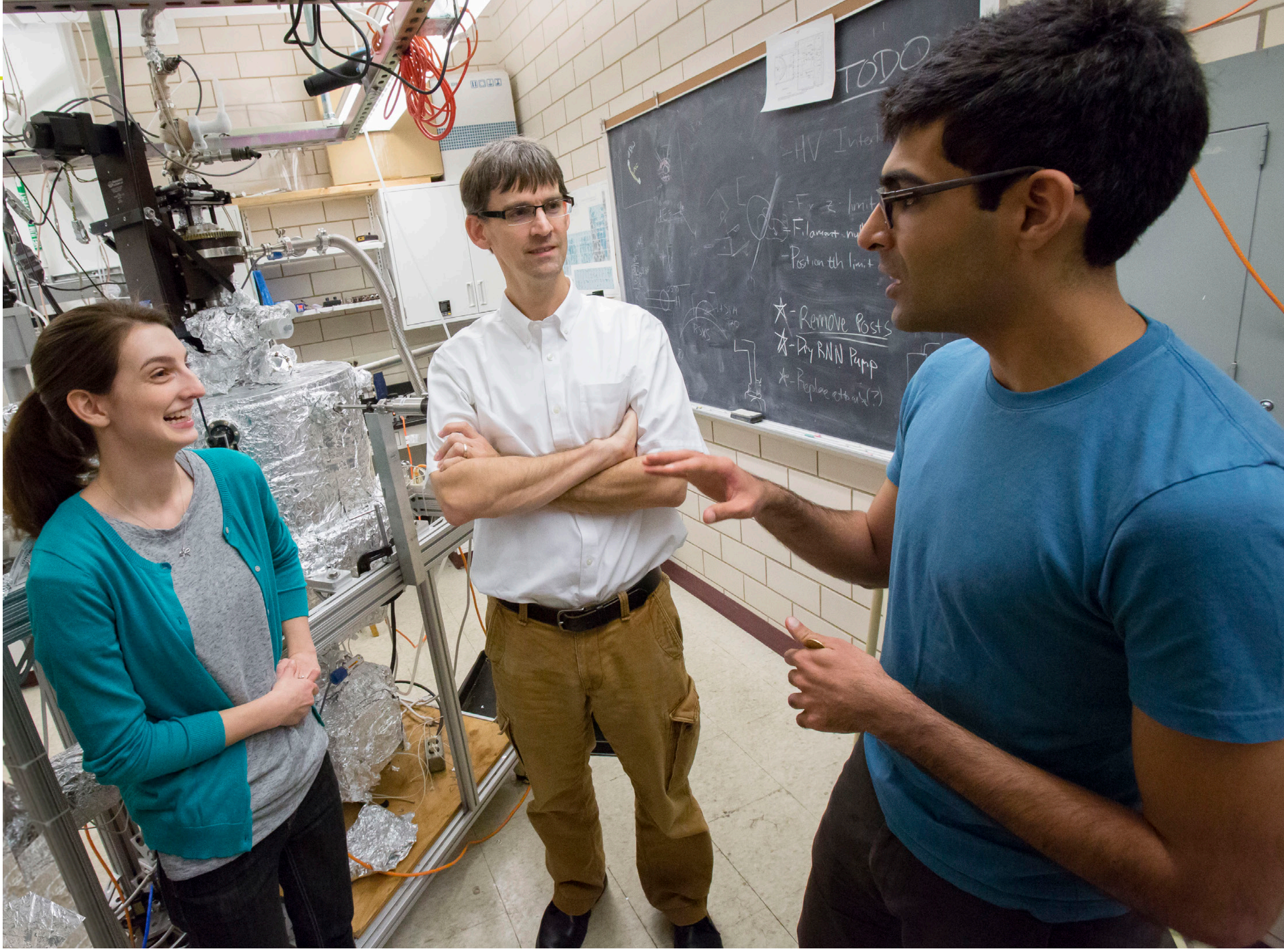
With their new technique, the group was able for the first time to measure collective excitations of the low-energy bosonic particles, the paired electrons and holes, regardless of their momentum. More specifically, the team achieved the first-ever observation in any material of the precursor to exciton condensation, a soft plasmon phase that emerged as the material approached its critical temperature of 190 K. This soft plasmon phase is "smoking gun" proof of exciton condensation in a three-dimensional solid and the first-ever definitive evidence for the discovery of excitonium.

"This result is of cosmic significance," affirms Abbamonte. "Ever since the term 'excitonium' was coined in the 1960s by Halperin and Rice, physicists have sought to demonstrate its existence. Theorists have debated whether it would be an insulator, a perfect conductor, or a superfluid—with some convincing arguments on all sides. Since the 1970s, many experimentalists have published evidence of the existence of excitonium, but their findings weren't definitive proof and could equally have been explained by a conventional structural phase transition."

Rak recalls the moment, working in the Abbamonte laboratory, when she first understood the magnitude of these findings: "I remember Anshul being very excited about the results of our first measurements on TiSe^2. We were standing at a whiteboard in the lab as he explained to me that we had just measured something that no one had seen before: a soft plasmon."

"The excitement generated by this discovery remained with us throughout the entire project," she continues. "The work we did on TiSe^2 allowed me to see the unique promise our M-EELS technique holds for advancing our knowledge of the physical properties of materials and has motivated my continued research on TiSe^2."

Kogar admits that discovering excitonium was not the original motivation for the research—the

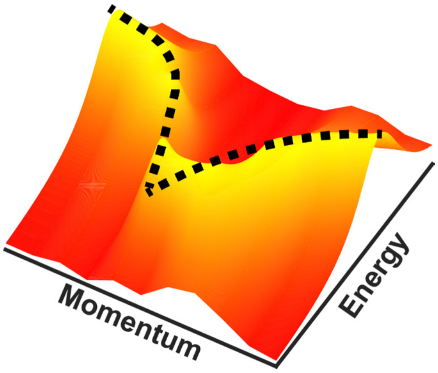


team had set out to test their new M-EELS method on a crystal that was readily available—grown at Illinois by former graduate student Young Il Joe, now of NIST. But he emphasizes, not coincidentally, excitonium was a major interest:

"This discovery was serendipitous. But Peter and I had had a conversation about 5 or 6 years ago addressing exactly this topic of the soft electronic mode, though in a different context, the Wigner crystal instability. So although we didn't immediately get at why it was occurring in TiSe2, we did know that it was an important result—and one that had been brewing in our minds for a few years."

The team's findings are published in the December 8, 2017 issue of the journal Science in the article, "Signatures of exciton condensation in a transition metal dichalcogenide."

This fundamental research holds great promise for unlocking further quantum mechanical mysteries: after all, the study of macroscopic quantum phenomena is what has shaped our understanding of quantum mechanics. It could also shed light on the metal-insulator transition in band solids, in which exciton condensation is believed to play a part. Beyond that, possible technological applications of excitonium are purely speculative. ■



Relationship between energy and momentum for the excitonic collective mode observed with M-EELS. Image courtesy of Peter Abbamonte, U. of I. Department of Physics and Frederick Seitz Materials Research Laboratory

This research was made possible by generous support from the Gordon and Betty Moore Foundation's EPiQS Initiative. Development of the new M-EELS instrument was supported by the U.S. Department of Energy Center for Emergent Superconductivity, an Energy Frontier Research Center. Please see the journal article for entire funding acknowledgment. The conclusions presented are those of the authors and do not necessarily represent those of the funding agencies.

Ask the Van

van.physics.illinois.edu/qa/

Ask the Van is turning 20! Since 1998, *Ask the Van* has served as the most reliable physics Q&A site on the internet. The site spun off of the Physics Van outreach program and over the years has fielded questions from people living in every country on our planet. The site's longevity is thanks to the unflagging efforts of Emeritus Professor Mike Weissman, who answers most of the questions. Here are excerpts from some of his favorites.

Q: My husband and I are having a converstion, and he disagrees with me about the way the earth spins on its axis. I say it spins clockwise and he says counter-clockwise. This may sound strange but he wants it in writing on the computer before we can settle this debate. I am a high school grad from 1973 and I am almost certain that if the earth spins like a top, it has to go clockwise. I personally have never seen a top spin any other way. Thank you.

Sue Martin (age 47)
Gaston, SC, USA

A: Dear Sue—University Counsel has warned us never to intervene in marital disputes, but we'll try to answer anyway.

You know that the Sun "rises" in the east. That means that the Earth is turning toward the east. Now try turning a globe like that.

If you were to look at the Earth from a point above the North Pole, then, it would look like it's turning counter-clockwise. But before your husband gloats too much, think what happens if you look from a point above the South Pole. It looks like it's turning clockwise! So the whole question, like many topics of marital disputes, is meaningless.

We assume that, if all goes normally, both of you will now be reconciled and mad at us.

Mike W.

Q: Dear expert, Is it possible to prove by a simple experiment or otherwise that there are ONLY two kinds of electric charges in existence?

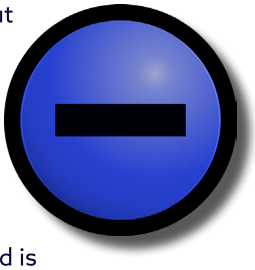
Thanks
Julian, Israel

A: Julian—That's a really wonderful question, my favorite ever from this site, but you'll have to settle for a mediocre answer. I think the important proofs are experimental, because the whole theoretical framework within which things like this can be 'proved' is based on experimental results, not written on the sky.

We couldn't truthfully say that there were only two types of electrical charge unless we had some way of distinguishing between electrical charges and the 'charges' involved in other forces (gravity and the nuclear forces). Let's say that by electrical charges, we mean the sort of charges that cause forces at appreciable distances (that excludes the nuclear forces) and which can be transferred by rubbing different objects together (that pretty much excludes gravity).

When we say 'there are only two types of charge' what we mean is that charge can be represented by an ordinary real number, corresponding to a point on the real number line. Real numbers can be either positive or negative. For any positive, you can find a negative just big enough to cancel it and give zero.

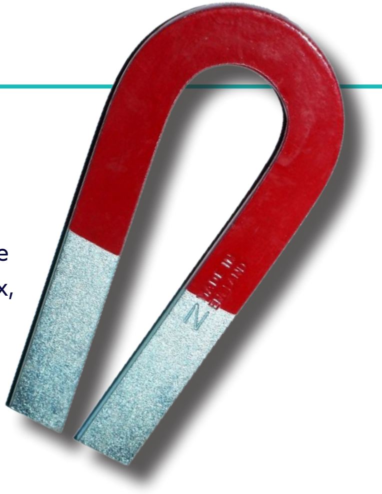
What's a simple experimental version of this? You may have seen the experiment with a couple of gold leaves connected to each other. Whenever an electrical charge is deposited on the leaves, they push apart, because they share the same type of charge. You can get electrical charges to put on them from all sorts of static electricity—rubbing a rock on a wool rug, and touching the rock to the gold, etc. Now for all the many ways you can dump charge onto the gold, you can divide the whole collection into two batches, which we'll call N and P. For any charge in batch "P", you can always get back to zero (where the leaves touch) by dribbling in bits of charge of type "N", and vice versa. So that's just like positive and negative numbers and is the basic justification for representing the charges with positive and negative numbers.



You might ask (since you sound like a pretty profound asker) whether any other situation is even imaginable. Try this. Say there were some sort of charge that were represented not by numbers but by position in a plane. Say you had some "north" charge, and some "east" charge. There's no way of combining them to get back to zero—so they can't be like numbers of opposite sign. And there's no other type of charge that could be used by itself to cancel both of them—so they aren't like numbers of the same sign. There's no way to divide these planar charges into two distinct batches, where you can cancel any charge in one batch with the right amount of any charge from the other batch. So you know these charges can't be represented by real numbers.

In case that sounds imaginative, I can't claim credit. Nature has a lot of imagination. The 'color charges' of the strong nuclear force are pretty much like that.

Mike W. (w. suggestions from Tom J.)



Q: Where does gravitational/magnetic force originate from and why does all matter get pulled by gravity (which is magnetic I believe) yet only certain metals (ferrous) appear to get attracted to magnets and other forms of matter like wood or plastic, etc. Don't seem to get pulled by magnets? —Chris (age 10) Halifax, Canada

…AND…

Q: I wanted to ask what the difference is between a magnetic force and a gravitational force? If there's no difference, I'd like to know, how come the Earth's gravitational pull is able to attract non-magnetic materials, e.g human beings, yet no matter how much powerfull a magnet is it can never attract non-magnetic (non-ferrous) material? —curious Starvos (age 12), Kenya

A: Chris & Starvos—

Since your questions are roughly the same, I'll answer them both at once. Gravity and magnetism are not the same thing. In fact, they are completely separate forces. Gravity is a force that acts between any two objects with mass. No matter what they are made of, both objects get pulled towards each other just because they have mass. The reason it seems like gravity only pulls you towards the earth is because the earth is so big that the pull from you on it isn't enough to do much to its motion.

Unlike gravity, which occurs between any objects, magnetism depends on specific properties of objects. Magnetism can either pull the two objects together or push them apart, depending on which way the magnets point. Most importantly, it depends on what is going on with the electrons in the material, since each electron is like a tiny magnet itself. Most materials feel very little magnetic force because their electrons act like magnets that are pointing every which way, more or less equal numbers pulling or pushing.

In some materials, the electrons can lower their energy by lining up magnetically into magnetic domains. In each domain, most of the electrons pull and push together, so you can get big forces. In some materials (permanent magnets) the domains can all be lined up so you get really big magnetic forces. If you measure very carefully, however, you find that there are small magnetic forces between magnets and 'non-magnetic' materials like pieces of copper or pieces of wood or people. Some of those 'non-magnetic' things are attracted to magnets and others are repelled.

By the way, only some ferrous materials are magnets, and only a few magnetic materials are ferrous.

Both magnetism and gravity can affect objects at a distance. Both get weaker as the objects get farther apart. This is why you are affected by the pull of gravity from the earth, but not from distance planets. It's also why two magnets may move together if you set them near each other, but if you set them far apart nothing will happen. However, as two objects get far apart, the gravity between them goes down by a factor of four when you double the distance, but the magnetic force goes down by (at least) a factor of sixteen. On the scale of the solar system, with planets far apart, gravity is much more important than magnetism.

For more information on these forces, you can search this site.

Tamara (and Mike)

Q: I put a bottle of water in the freezer every night before bed. In the morning, I take it out and drink it. Sometimes its frozen solid, sometimes it stays liquid, depending on when I put it in there. But here's the kicker, sometimes I will pull the bottle out, it will be liquid, but as soon as I open it, it starts to turn into ice, from the top down (it takes a few seconds for the entire bottle to freeze. Is there an explanation for this?

- Greg (age 26)
Army, Iraq

A: We suspect that what's happening here is that the water in the bottles which did not freeze overnight was "supercooled." Water normally freezes when it is cooled below 0 degrees Celsius, forming ice crystals. Ice crystals form more easily when they grow on existing ice crystals—the water molecules like to pack themselves in place on a crystal that's already gotten started. It doesn't take much to start the crystallization process going—a little piece of dust or other impurity in the water, or even a scratch on the bottle are sometimes all it takes to get ice crystals growing. The process of starting off a crystal is called "nucleation."

In the absence of impurities in the water and imperfections in the bottle, the water can get "stuck" in its liquid state as it cools off, even below its freezing point. We say this supercooled state is "metastable." The water will stay liquid until something comes along to nucleate crystal growth. A speck of dust, or a flake of frost from the screw-cap falling into the bottle are enough to get the freezing going, and the crystals will build on each other and spread through the water in the bottle.

Water releases 80 calories per gram when turning from a liquid to a solid. We suspect your freezer is only a few degrees Celsius below zero (perhaps ten or fifteen?), and the specific heat of water is one calorie per degree per gram. This means that your water, as it freezes, warms up the rest of the water until the process stops at 0 degrees Celsius, freezing perhaps ten or twenty percent of the water. This ice may be distributed throughout the bottle, though—the crystallization process happens very quickly and heat flows slowly.

We suspect you have slush in your bottle rather than hard ice when this is done. You can compare with another bottle which froze hard in your freezer overnight how hard it is to squeeze the bottle and how long it takes to melt. The ice will also take up more room than the water it used to be, and some water may spill out the top.

There can also be some small effects of pressure and of dissolved gases on the freezing temperature. Is your water under pressure?

Tom and Mike

EXPLORE MORE ANSWERS AT

van.physics.illinois.edu/qa/

A visit with alumna Claire Baum

Physics alumna Claire Baum (BS Physics, 2017) made the most of her time in the department—she took a leadership role in several student groups, surmounted her fear of public speaking, took advantage of undergraduate research opportunities, and formed lasting relationships with friends and mentors. Born and raised in Illinois, she is now a graduate student at the University of Chicago, working in the Simon Lab doing atomic molecular optical physics.

What are your favorite memories from your time at Physics Illinois?

Probably all of the crazy antics of SWIP (Society for Women in Physics) and SPS (Society of Physics Students), especially the donut eating contest, playing the Star Trek bridge simulator, Artemis, building a 33-foot straw and trying to drink from it. And interacting with the physics faculty, especially finding and hanging out with Dale Van Harlingen at a bar in New Orleans during the APS March Meeting—that was amazing!

What are the three most important things you learned here?

Ask questions! It doesn't have to be in front of the whole class, but asking questions has helped me see physics from different perspectives, or has made me think of things in ways I haven't before.

One of the things I learned as an undergrad is that you really can always be busier. Each year, I thought my schedule was so crammed full, and then the next year, it was more so. You end up just chipping away at your sleep to fit it all in.

I came in so shy. I was afraid of public speaking—I was that kid whose face turned red. Being actively involved and especially being president helped with that. Getting up in front of a group casually, on the fly, and speaking—it got much easier.

You were a member of PhySAB (Physics Student Advisory Board) all four years at Physics Illinois, and served as co-leader of the group your junior year. What was your greatest accomplishment in PhySAB?

Probably creating an actual schedule of events for the first time. When I was a younger member on PhySAB, we had difficulty just scheduling a Town Hall. But PhySAB really started getting out there around my junior and senior year with the start of the Coffee, Cookies, and ___ meeting series and better advertising!

In SWIP, you served as treasurer your sophomore year and as president your junior and senior years. What did you achieve in those roles?

People actually come to the meetings now! SWIP has been doing a lot of new meetings over the past couple

While at Physics Illinois, Baum was recognized with several honors, including the APS March Meeting Outstanding Undergraduate Presentation (2017), the Laura B. Eisenstein Award (2016), the AWIS Kirsten R. Lorentzen Award (2016), and the SPS Leadership Scholarship (2015). She was ranked an "Excellent TA" by her students in PHYS 123 in her junior year and an "Outstanding TA" by her students in PHYS 101 in her senior year.

Right: Claire Baum at Engineering Open House in her junior year, demonstrating SWIP's theremin.

of years, which I think has attracted people. We still need more women, though.

In SPS, you served as snack officer in your sophomore and junior years. Besides providing scrummy nosh, what was your greatest achievement with SPS?

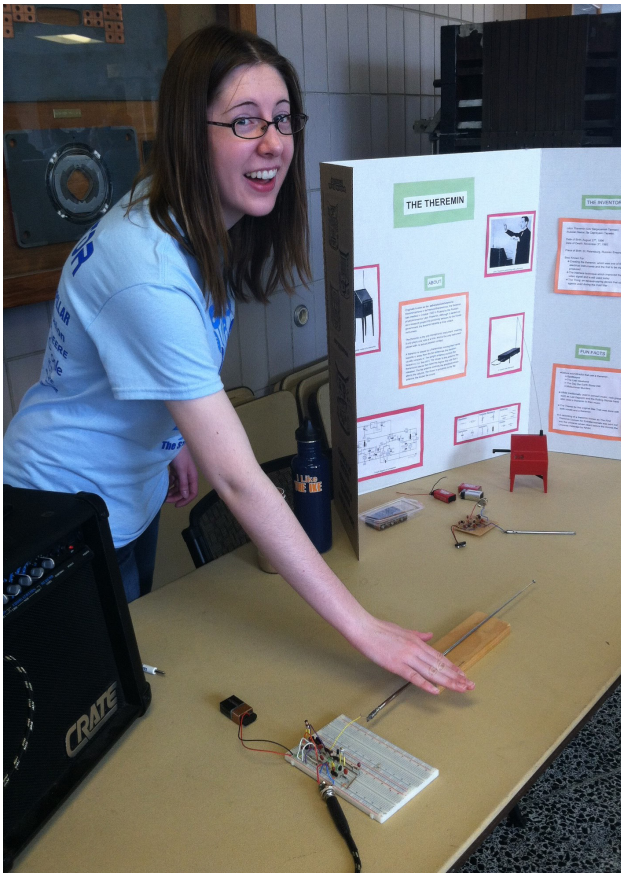
Helping organize the SPS Zone Meeting my sophomore year—there was more than a little bit of sleep deprivation in the week leading up to the meeting. The attendees seemed to find it fun and helpful, which made me very happy.

In these groups, you did some outreach. What did you enjoy about that?

I really liked sparking people's interest in science and critical thinking. One of SWIP's fan favorite demonstrations was "marshmallow peeps in a vacuum." The peeps expanded. It was always great fun watching kids' eyes go wide and be like, "THAT MARSHMALLOW IS SO BIG CAN I EAT IT!?"

The summer after freshman year, you did research with Kevin Pitts high energy physics group. You later did a summer REU program at University of Florida in AMO physics. What did you take from these research opportunities?

The research I did at Illinois and Florida really helped me narrow down my interests. I came into college thinking maybe I'd do theory in particle physics or astrophysics, and now I'm in grad school doing experimental AMO physics! I also took horrible sunburn from research experience in Florida (I'm pretty sure I still have tan lines).



What advice do you have for new students at Physics Illinois?

Talk to people as much as you can (undergrads, faculty, grad students, etc.)! I have learned so much from others it's ridiculous. It is also very nice having a network of people you can reach out to. Also, please check your emails—a lot of good opportunities come through there!

What is your ultimate career goal, and how did your time here influence that goal?

I would love to be a crazy inventor, but I don't think that is a legitimate job title (yet). I think ultimately I want to do something that helps people (perhaps through a startup). While at Physics Illinois, I learned about different career paths people have taken and actually heard quite a bit of life advice from the faculty, whiched helped me shape my goals.

What made you choose atomic molecular optical physics for your graduate studies?

I love the hands-on aspect—it's a mix of computer work and then you can tinker. There aren't huge collaborations, but your individual work does connect to a larger picture, other people are doing the same type of explorations, and collaborating is part of what advances the work.

Were you involved in other extracurricular clubs during your time at Illinois?

I made it my goal to try something new every year. I signed up for many things the first two years, got a taste test, then narrowed my interests. Some highlights, I was a DJ freshman year for Pizza FM. Joined Archery Club (I was so bad—but it was fun). Also joined the sky diving club, but had other commitments every opportunity for dives, so didn't get to do that. It's still on my bucket list.

What will you miss most about Physics Illinois?

The people, my physics family. Coming in, I didn't know anyone, and I have gotten to know Mats, Celia, Dale—to the point where it's just super casual. Our conversations weren't just about physics, they were about life. The quality of the people here definitely spilled into the quality of the physics. I've learned a lot about how to approach both physics and life. I learned it's important to take the time out to do something you really want to do. ■

AMERICAN CHEMICAL SOCIETY'S 2017 CHEMICAL BREAKTHROUGH AWARD RECOGNIZES 1951 DISCOVERY BY GUTOWSKY, MCCALL, AND SLICHTER

With each passing year, scientists working at the leading edge of fundamental science take strides forward, pushing against the boundary of the yet undiscovered. With each new glimmer of understanding uncovered, illuminating some aspect of why our world is what it is, the boundary shifts—and new questions also come to light. But it's largely in retrospect that we discern how particular strides into the unknown opened entirely new directions in scientific research.

The American Chemical Society (ACS), through its Division of History of Chemistry, has an award that acknowledges these greatest of strides: the Chemical Breakthrough Awards are presented annually in recognition of "seminal chemistry publications, books, and patents that have been revolutionary in concept, broad in scope, and long-term in impact." These awards are made to the department where the breakthrough occurred, not to the individual scientists or inventors.

This year, the ACS honored the discovery of "J-coupling" (also known as spin-spin coupling) in liquids, a breakthrough that enabled scientists to use nuclear magnetic resonance (NMR) spectroscopy to identify atoms that are joined by a chemical bond and so to determine the structure of molecules.

The discovery occurred 60 years ago at the University of Illinois at Urbana-Champaign and is the work of the late Herbert S. Gutowsky (1919-2000), an emeritus professor and former head of the U. of I. Department of Chemistry; the late David W. McCall (1928-2002), a former director of chemical research at AT&T Bell Laboratories in Murray Hill; and Charles P. Slichter, a U. of I. emeritus professor of physics.

The citation reads: "For first observation of spin-spin coupling, in liquids, a crucial step in transforming NMR spectroscopy into one of the most powerful tools in chemical science."

The groundbreaking work was published in 1951—very early in the scientists' careers—in the journal Physical Review [84, 589], in the article "Coupling among Nuclear Magnetic Dipoles in Molecules."

Slichter and Gutowsky had attended graduate school at Harvard together. In 1951, only three years had passed since Gutowsky had received his doctoral degree, and just two years since Slichter had received his. Each would eventually receive the National Medal of Science for their pioneering application of NMR to the study of the structure of matter, Gutowsky in 1976 and Slichter in 2007 (among numerous other recognitions in their long, highly productive careers).

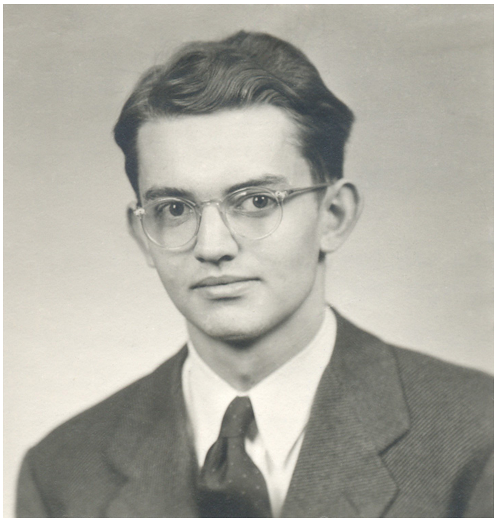
Martin Gruebele, the James R. Eiszner Endowed Chair in Chemistry and current head of department, comments, "The paper is one of two or three key papers in the history of NMR spectroscopy that turned the technique from a curiosity into a method for determining the structure of molecules."

"The magnetic fields of two atoms connected by just a few bonds influence how the atoms absorb radio waves," Gruebele explains. "The resulting pattern of peaks in a spectrum of radio waves (in the 100s MHz range, just like the FM dial on your radio at 101.1 FM for WILL) at one glance tells a chemist how many atoms of a given kind there are."

The 2017 ACS Chemical Breakthrough Award is on display at the U. of I. Chemistry Library in Noyes Laboratory.

On October 6, 2017, the U. of I. Department of Chemistry at the University of Illinois at Urbana-Champaign celebrated the Chemical Breakthrough Award with a well-attended reception. Slichter, having been asked to share the history behind his collaboration with Gutowsky and McCall, prepared an account with the help of his wife, Anne FitzGerald Slichter, who read it at the reception. Here is that account. (Slichter's own modesty in the framing of this history is typical of him, as his physics colleagues would attest.)

Portrait of a young Herbert S. Gutowsky, undated.



Portrait of a young Charles P. Slichter, dated around 1948.

Herb Gutowsky was an amazing scientist. Today's recognition singles out only one of his many accomplishments, the discovery of "J coupling," which enables one to identify atoms that are joined by a chemical bond.

My formal background as a chemist is a one-semester college-level beginners course that I took at Cal Berkeley in the summer of 1941 just after graduating from high school.

But I had the good fortune to be around many chemists during the Second World War to work on a project headed by E Bright Wilson that was populated by a number of very talented chemists, including Bob Cole (of the Cole-Cole plots), George Frankel, Bill Schneider, Al Redfield (who was then in high school), and Don Hornig. That contact taught me great respect for chemists and chemistry.

But my deepest education in chemistry was by Herb, and his students.

Herb and I met in 1946 when we were both graduate students at Harvard. Herb and my brother Bill were both students of the renowned physical chemist George Kistiakowsky.

My thesis advisor was Edward Purcell, who, in 1945, had led the Harvard group that invented nuclear magnetic resonance.

I was Purcell's third student.

His first was the Dutch student Nicholaas Bloembergen, who studied the hydrogen NMR signal from liquids.

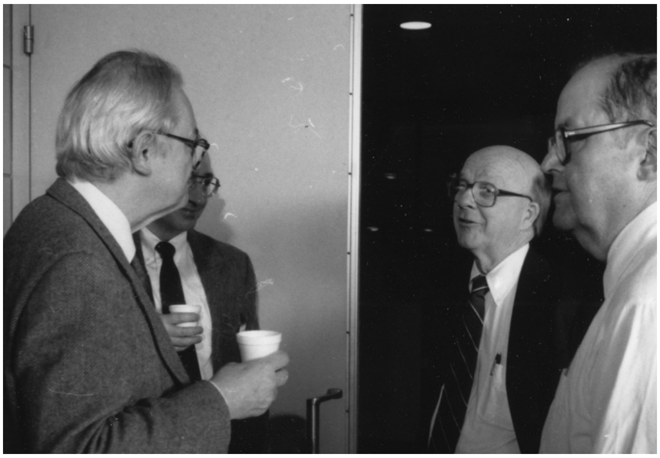
Purcell's second student was George Pake who, for his thesis, studied water frozen in solids.

Pake discovered that the proton signal from water of hydration was a doublet arising from the magnetic dipolar interaction between the two protons in the water molecule. From the splitting frequency of the doublet, he found he could determine the H-H distance and orientation.

A few days after this discovery, Purcell went to the Harvard Faculty Club for lunch where he happened to encounter Kistiakowsky. Purcell told him about Pake's finding. Kistiakowsky immediately asked if one might be able to use hydrogen NMR to solve a problem of long standing, the structure of diborane (H_2B_6). He asked if Herb could join Pake to try the experiment.

They did not succeed in finding the structure of diborane but Herb learned how to use an NMR apparatus and recognized its power.

Herb came to Illinois in 1948. At that time, no company manufactured NMR apparatus. In an act of great insight, imagination, and courage, Herb resolved to enter the field of nuclear magnetic resonance. With the help of an electrical engineering student, Herb built an NMR apparatus and embarked on a program of NMR studies.



I got my PhD in June 1949 and that fall came to Illinois with the rank of Instructor in physics. Herb now had an NMR apparatus and was hard at work with it.

In spring 1950, Herb came over to the physics building to tell me that he had discovered NMR evidence that the atoms of solid metallic Na were rapidly diffusing in space. From the temperature dependence, he could determine the barrier height for diffusion of the Na atoms.

Next, he studied ^{19}F chemical shifts in diatomic molecules and found that the fluorine chemical shift was a simple function of the electronegativity difference between the fluorine and the second atom to which it was bonded. I was stimulated to give an explanation. It was published in 1954 with Herb's student Apollo Saika.

Then he came to tell me about his work with Dave McCall on ^{19}F and ^{31}P splittings in molecules containing both ^{19}F and ^{31}P atoms. There were a number of competing theories.

Stimulated by the work that I later published (with Saika), Herb, Dave, and I came up with an explanation. It constitutes the paper we honor today.

Shortly thereafter, Purcell and Ramsey gave an explanation that filled in the details.

In 1952, the Swedish Academy awarded the Nobel Prize to Purcell and Felix Bloch. In his Nobel Lecture, among other things, Purcell cites the discovery of J coupling. So Herb and this paper played a role in the selection of NMR for the Nobel Prize.

— Charlie Slichter

Above: (L-R:) Charles Slichter, David McCall, and William Slichter (Charles' brother) converse at a meeting, undated. Department of Physics, University of Illinois at Urbana-Champaign, courtesy of Emilio Segrè Visual Archives of the American Institute of Physics

Below: (L-R) Unknown, David McCall and Charles Slichter converse, undated. Department of Physics, University of Illinois at Urbana-Champaign, courtesy of Emilio Segrè Visual Archives of the American Institute of Physics

FRADKIN, GRUEBELE, APPOINTED CENTER FOR ADVANCED STUDY PROFESSORS

The Center for Advanced Study (CAS), comprising the U. of I.'s most prominent faculty scholars, has elected two from the Department of Physics to its membership. Eduardo Fradkin and Martin Gruebele are among the seven campus faculty members to be named CAS Professors this year, selected for their outstanding contributions to their respective fields. A permanent appointment as a CAS Professor is one of the University's highest academic honors.

Fradkin is an internationally recognized leader in theoretical physics, working at the interface between quantum field theory and condensed matter physics. He has made numerous lasting contributions. In particular, Fradkin was one of the first theorists to use gauge theory concepts in the theory of spin glasses and to use concepts of chaos and non-linear systems in equilibrium statistical mechanics of frustrated systems. Fradkin also pioneered the use of Dirac fermions for condensed matter physics problems, particularly in two spatial dimensions.

Fradkin has recently developed a theory of electronic liquid crystal phases in strongly correlated systems and formulated a mechanism of high-temperature superconductivity based on this new concept.

Fradkin is the Donald Biggar Willett Professor of Physics. He serves as the director of the Institute for Condensed Matter Theory at the U. of I. He is a member of the National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, a Simon Guggenheim Foundation fellow, and a fellow of the American Physical Society. He is the recipient of numerous awards.

Fradkin received his *licenciado* (master's) degree in physics from Universidad de Buenos Aires (Argentina) and his doctoral degree in physics from Stanford University in 1979. He came to the University of Illinois in 1979 as a postdoctoral research associate and joined the faculty in 1981.

Gruebele's research uses experiments and computational modeling to study a broad range of fundamental problems in chemical and biological physics. A common theme is the use of state-of-the-art laser techniques to manipulate complex molecular systems. The results are contributing to a deeper understanding of the way that proteins fold into functional 3-D molecules; the details of how chemical bonds are broken by vibrational motion and how this can be controlled; and the switching of energy flow in large molecular structures on surfaces. He has published more than 250 articles on topics ranging from quantum computation, to RNA and protein folding in the test tube and inside cells, to fish-swimming behavioral studies.

Gruebele is the James R. Eiszner Endowed Chair in Chemistry and currently serves as the head of the chemistry department. He holds an additional appointment at the Center for Biophysics and Computational Biology and is a member of the Beckman Institute, both at the U. of I. He is a member of the National Academy of Sciences and of the National Academy of Arts and Sciences, and of the German Academy of Sciences Leopoldina. He is a fellow of the American Chemical Society, the American Physical Society, and the Biophysical Society. Gruebele is the recipient of numerous awards.

Gruebele received his bachelor's degree in 1984 from the University of California, Berkeley, with the University Certificate of Distinction and Department Citation for Highest Honors. He stayed on to complete his doctoral degree at Berkeley in 1988. After working as a postdoctoral fellow at the California Institute of Technology, he joined the faculty of the University of Illinois in 1992. ■

NEW CLASS OF INSULATING CRYSTALS HOSTS QUANTIZED ELECTRIC MULTIPOLE MOMENTS

SIV SCHWINK

for Physics Illinois Condensate

Researchers at the University of Illinois at Urbana-Champaign and Princeton University have theoretically predicted a new class of insulating phases of matter in crystalline materials, pinpointed where they might be found in nature, and in the process generalized the fundamental quantum theory of Berry phases in solid state systems. What's more, these insulators generate electric quadrupole or octupole moments—which can be thought of roughly as very specific electric fields—that are quantized. Quantized observables are a gold standard in condensed matter research, because experimental results that measure these observables have to, in principle, exactly match theoretical predictions—leaving no wiggle room for doubt, even in highly complex systems.

The research, which is the combined effort of graduate student Wladimir Benalcazar and Associate Professor of Physics Taylor Hughes of the Institute for Condensed Matter Theory at the U. of I., and Professor of Physics B. Andrei Bernevig of Princeton, was published in the July 7, 2017, issue of the journal *Science*.

The team's work began with identifying a quadrupole insulator, but it soon became obvious that there were deeper implications.

Benalcazar explains, "One of the new models the work presents has a quantized electric quadrupole moment. It's an insulator unlike all previously known topological insulators. It does not have gapless, low-energy surface states—the hallmark of such systems—which may be why these systems have avoided discovery for so long."

"But remarkably," he continues, "even though the surfaces of the quadrupole insulator are gapped, they are not insignificant. In fact, they form a lower-dimensional topological insulator phase! Our calculations can predict when a system will harbor such boundary topological insulators—whether at the surfaces, hinges, or corners. Surprisingly, this property in its most basic form is related to the higher electric multipole moments."

Revolutionary work in the 1990s and 2000s by Vanderbilt, King-Smith, Resta, Martin, Ortiz, Marzari, and Souza, made it possible to define the dipole moment of a crystal through a particular application of the Berry phase—a mathematical quantity that characterizes the evolution of electron wave functions in the momentum space of the lattice. That work represented a huge advancement in our understanding of topological electromagnetic phenomena in crystalline materials. It provided a link between a physical quantity (dipole moment) and a topological one (Berry phase). According to Hughes and Bernevig, the current research started as an effort to generalize the dipole moment theory to higher multipole moments.

Hughes recounts, "At the earliest stages, Andrei and I were discussing the idea of extending the work on crystalline dipole moments to quadrupole moments. But it turns out, while the question seemed somewhat obvious once asked, the mathematical solution wasn't. Calculating multipole moments in a quantum mechanical system of electrons is challenging, because the electron, a quantum mechanical particle, is a wave, not just a particle, and its location in space is uncertain. Whereas the dipole moment can be accessed by measuring just the electron displacement, a vector quantity, the quadrupole moments are trickier."

To address this issue, the scientists had to invent a new theoretical framework. In addition, they needed to build models with the right properties by which they could benchmark their new analytical technique. But in fact, things happened in just the opposite order: Hughes and Bernevig credit Benalcazar with finding the correct model, a generalization of a dipole insulator with a quantized dipole moment. From there, it took an entire year to build the full theoretical framework.

Existing mathematical tools—the solid-state Berry phases—could resolve the position of the electron in only one direction at a time. But for the quadrupole moment, the team needed to determine its position in two dimensions simultaneously. The complication stems from the Heisenberg uncertainty principle, which usually states that both the position and momentum of an electron cannot be measured at the same time. However, in the new quadrupole insulators, a different uncertainty principle is at work, preventing simultaneous measurement of the electron's position in both the *x*- and *y*-directions. Because of this, the authors couldn't spatially resolve the electron locations using existing theoretical tools.

"We could pin it down in one direction, but not the other," Benalcazar recalls. "To get both directions simultaneously, we created a new analytical paradigm, essentially by separating the quadrupole moment into a pair of dipoles."

Hughes adds, "At first, we ran every test we knew how to run on the models we proposed and kept coming up with nothing. The problem is, when two dipoles are on top of each other, they cancel each other out. To see the quadrupole, you need some spatial resolution to determine if the dipoles are actually separate. In the end, it turned out we needed to look at the Berry phases one layer deeper, mathematically speaking."

Finding a way to spatially resolve that second dimension represents a significant theoretical breakthrough. The authors devised a new paradigm for calculating the location of electrons that is an extension of the Berry-phase formulation. First, they use a conventional technique to theoretically split up the electron wave into two charge clouds, separated in space. Then they show that each cloud has a dipole moment. This two-step, nested procedure can reveal two spatially separated, opposing dipoles—a quadrupole.

Bernevig remarks, "The topological insulators we have become used to in the past decade are all essentially described by a mathematical procedure called 'taking the Berry phase' of some electronic states. The Berry phase of the interior of a sample, in effect, knows about the edge of a system—it can tell you what's interesting about the edge. To go one step beyond and solve what is potentially remarkable about the corner of a system or sample, you have to take, in effect, a Berry phase of a Berry phase. This leads to the formulation of a new topological quantity that describes the quantized quadrupole moment."

In the last decade, the classification of topological phases of matter has been substantially developed. Significantly, this new work shows the yet unexplored richness of the field. It predicts an entirely new class of phases and provides the model and theoretical means to test its existence. Perhaps one of the most exciting aspects about the field of topological insulators is their experimental relevance. In the journal article, the team suggests three possible experimental setups to validate their prediction.

Hughes acknowledges that a quantum simulation—an experimental technique that, for example, uses finely tuned lasers and ultracold atoms to replicate and probe the properties of real materials—would be the most immediately accessible.

"It's exciting that, using current experimental technology, our model can be looked at right away," Hughes affirms. "We are hoping we or someone else will eventually find an electronic, solid-state material with these kinds of qualities. But that's challenging, we don't yet have a chemical formula."

The authors indicate that the conditions to get this effect are fairly general, and as such there are many potential candidates in many classes of materials.

"Or the realization could one day come from left-field, from some other utterly ingenious implementation idea that someone might devise," Bernevig quips.

Benzalcazar is convinced that "this new understanding may open a whole collection of materials that have this hierarchical classification."

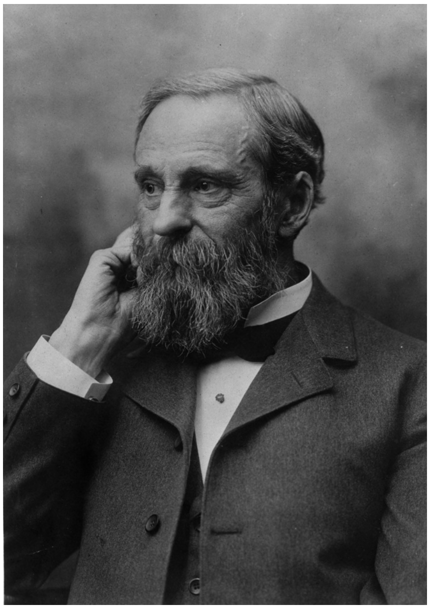
This is fundamental research, and any potential applications are still a distant matter of conjecture. Because quantized observables allow for exquisitely precise measurements, it is conceivable that the novel electrical properties of this new phase of matter will be useful in metrology, electronic technologies, or in designing materials with prescribed bulk/surface/edge/corner properties.

The authors agree, this work opens up many possibilities for new topological systems that were hidden before—hidden within the nested structure of the Berry phase mathematics. These hidden topological phases have a sharp connection to real physical observables—and there may be other physical phenomena in these materials that would be interesting to explore. ■

This work is funded by the National Science Foundation, by the U.S. Department of Energy, and by the Sloan Foundation, the Simons Foundation, the Packard Foundation, and the Schmidt Fund for Innovative Research. The conclusions presented are those of the researchers and not necessarily those of the funding agencies.

OUR Richly Layered History

Among her many vital roles in the Department of Physics, Celia Elliott is our resident historian. Here are some excerpts from the timeline she created for our website's History of Excellence page. You can find the full timeline under the "People" tab on our website.



Stillman W. Robinson. Image courtesy of University of Illinois Archives

1870

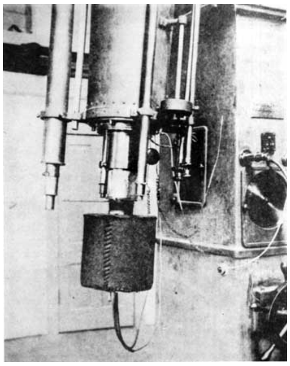
As a cornerstone of engineering education, Dean and Professor Stillman Robinson introduces and teaches a course in physics, believing that a knowledge of physics is fundamental to the education of every engineer.

Samuel W. Stratton. Department of Physics, University of Illinois at Urbana-Champaign, courtesy of AIP Emilio Segrè Visual Archives

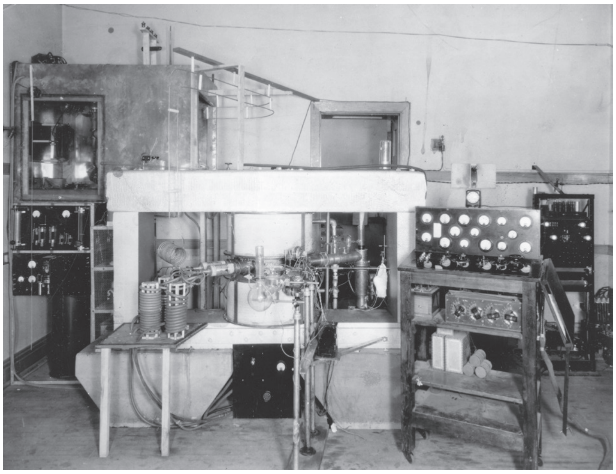
1889

A separate Department of Physics is created as part of the College of Engineering, and Theodore B. Comstock, Professor of Mining Engineering and Physics, is appointed head. When Comstock inexplicably fails to return to campus after summer vacation, Regent Peabody appoints Physics Assistant Samuel W. Stratton as head.

> *"Physicists are always looking forward, to the next problem to solve. But I think it's instructive for our students to look back once in a while, to get a sense of where we started out and to consider how far we've come. I believe that science is a collaborative, cumulative social endeavor, and I've tried to capture a sense of that in the timeline. I also think that our department suffers from 'Midwesterner disease' (look at the floor and mumble, "Aw shucks, it's no big deal"), and many of our students don't realize what a treasure of physics this department is."* —*Celia Elliott*



Selenium cell photometer mounted on the 12-inch refractor at the University of Illinois Observatory, 1910. Image by Dr. John Dickel, courtesy of National Park Service



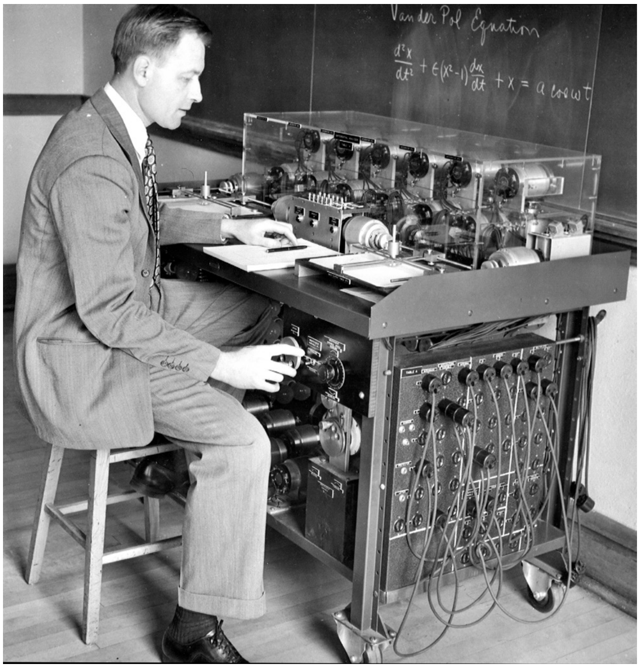
World's third cyclotron, built by P. Gerald Kruger and his students at the University of Illinois in 1936. Department of Physics, University of Illinois at Urbana-Champaign, courtesy of AIP Emilio Segrè Visual Archives

1907

Professor Fay C. Brown begins working with Professor Joel Stebbins (Astronomy), director of the University of Illinois Observatory, to use selenium cells to the measure the brightness of the moon—the first time in America that electricity is used to measure astronomical brightness.

1936

Professor P. Gerald Kruger and his students G. Kenneth Green (BS, 1933; MS, 1935; PhD, 1937) and Frederick W. Stallmann (PhD, 1940) build the world's third cyclotron—the first to be built outside of Berkeley and the first to have an external beam.



Arnold Nordsieck seated at the controls of his analog computer, the Nordsieck Differential Analyzer. Nordsieck's machines used electrical connections rather than mechanical shafts. Department of Physics, University of Illinois at Urbana-Champaign, courtesy AIP Emilio Segrè Visual Archives

Rosalyn Sussman Yalow at the Nobel Banquet in Stockholm, December 14, 1977. Photo by Keystone, printed with license from Getty Images (Hulton Archive, 3251882).

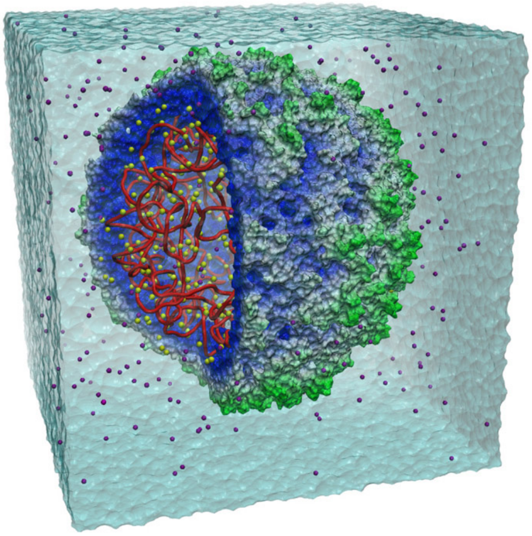
1950

Arnold T. Nordsieck finishes building his "differential analyzer"—an analog computer capable of solving complex equations and drawing curves—out of $700-worth of war surplus materials. Clones will subsequently become the first computers at the California Radiation Laboratory (later Lawrence Livermore National Laboratory) and at Purdue University.

1977

Alumna Rosalyn Sussman Yalow (PhD, '45) receives the Nobel Prize in Physiology or Medicine for the development of radioimmunoassays of peptide hormones.

Astronaut Dale A. Gardner, getting his turn in the Manned Maneuvering Unit, prepares to dock with the spinning WESTAR VI satellite during the STS-51A mission in 1984. Gardner used a large tool called the Apogee Kick Motor Capture Device to enter the nozzle of a spent WESTAR VI engine and stabilize the communications spacecraft sufficiently to capture it for return to Earth in the cargo bay of the space shuttle Discovery.
Image courtesy of NASA



An overall computer-simulated view of the satellite tobacco mosaic virus. Image created with VMD software, by Anton Arkhipov, University of Illinois at Urbana-Champaign

1983

Alumnus Dale A. Gardner (BS, Engr Phys, '70) becomes the first Illini in space as the commander of the space shuttle Challenger's September 30–October 5 mission. (Gardner will command the Discovery November 1984 mission as well.)

2006

Klaus J. Schulten's group carries out the first atom-by-atom simulation of an entire life form, the satellite tobacco mosaic virus.

JEREMIAH D. SULLIVAN

1938-2016

Emeritus Professor of Physics and former Department Head Jeremiah David Sullivan was a theoretical particle physicist and leading arms control expert who made significant and lasting contributions to national security and the international peace effort through his scientific research and through his service at and beyond the University of Illinois at Urbana-Champaign. With an ever courteous demeanor and a rare ability to guide rancorous debate to productive dialogue, Sullivan earned a reputation for strong consensus-style leadership.

Starting in 1974, Sullivan served as a member of JASON, an elite team of scientists tasked with advising the government on highly classified national security matters. Sullivan was appointed to the Advisory Committee of the National Nuclear Security Administration and led its Nuclear Nonproliferation Subcommittee; the Board of Directors of the Arms Control Association; the Distinguished External Advisory Committee on Arms Control and National Security of Sandia National Laboratories; the External Review Committee of the Nonproliferation, Arms Control, and International Security Directorate of Lawrence Livermore National Laboratory; and the Review Committee of the National Security Directorate of Pacific Northwest National Laboratory. Sullivan also served on the Committee on International Security and Arms Control of the American Academy of Arts and Sciences; and on the Committee on International Security and Arms Control of the National Academy of Sciences. In 2001, Sullivan was appointed to a four-year term as the U.S. representative to the Advisory Panel on Security-Related Civil Science and Technology, a subcommittee of the NATO Science Committee.

At the U. of I., Sullivan served as director of the Unit on Technology for Peacekeeping, of the Arms Control & Domestic and International Security (ACDIS) group.

In his research, Sullivan made wide-ranging, lasting contributions to arms control and international security, including important detailed calculations of shock wave profiles from underground tests (with Illinois Physics colleague Professor Fred Lamb) and studies of technologies for enhancing the effectiveness of peace operations, comprehensive nuclear test ban issues, science-based stockpile stewardship, technology and policy of ballistic missile defenses, arms control verification, military and civilian uses of space, and science and public policy. His contributions were recognized by the 2000 Leo Szilard Award of the American Physical Society.

In the early years of his career, Sullivan made significant contributions to particle physics, specifically in quantum electrodynamics, including elucidating electromagnetic interactions, photon structure functions, the Drell–Yan process, and hadron-hadron processes at high energy. His work earned him an international reputation and led to his selection for influential committee work, including the U.S. Department of Energy's High Energy Physics Advisory Panel; the Lawrence Berkeley Laboratory Particle Data Group Advisory Panel; and an appointment as acting head of the Theoretical Physics Division at the Fermi National Accelerator Laboratory in 1972.

Sullivan was a Fellow of the American Physical Society and of the American Association for the Advancement of Science.

Sullivan was born on November 15, 1938, in Norwood, Massachusetts. His parents were both high school teachers who instilled in him a deep appreciation for education. Sullivan received a bachelor's degree in physics in 1960 from Carnegie Institute of Technology, now Carnegie Mellon University and a doctoral degree in physics from Princeton University in 1964. After completing postdoctoral work at the Stanford Linear Accelerator Center (SLAC), he joined the faculty at Physics Illinois in 1967. Sullivan served as its ninth head of department, a position he held for six years.

He is survived by his wife Sheila (Bonar) Sullivan, his daughter Maureen E. Sullivan, his son and daughter-in-law, Jeremiah J. and Jennifer Sullivan, and a granddaughter, Lily S. Sullivan. He was preceded in death by his parents, Jeremiah F. Sullivan and Doris Nutton Sullivan, his sisters, Doris Ann Bradbury and Mary Ellen Hanley, and a brother, David Hall Sullivan.

In his spare time, Sullivan enjoyed sailing, international travel, carpentry and home-improvement projects, music, gardening, and time spent in nature. He was a voracious reader of history, current events, and broad-ranging science. He is remembered by friends and colleagues for his commitment to teaching, his easy smile and friendliness, and his superb sense of humor. ■

KLAUS J. SCHULTEN

1947-2016

Professor of Physics Klaus J. Schulten was a great innovator of computational methods to study the physical and chemical basis of biological processes. Schulten was a Swanlund Professor of Physics, the Director for the NIH Center for Macromolecular Modeling at Beckman Institute, and co-Director of the NSF Center for the Physics of Living Cells. He was also affiliated with the Department of Chemistry and the Center for Biophysics and Computational Biology. While at the University of Illinois, he trained 77 graduate students in physics, biophysics, and chemistry.

Schulten led the Theoretical and Computational Biophysics Group, which he founded at the Beckman Institute for Advanced Science and Technology in 1989. With a background in chemical physics and a keen understanding of the potential of powerful computers to model biological structures and the physics and chemistry that drives them, Schulten led the development of software that enables scientists around the world to observe how molecules behave and interact at the atomic scale. These include the program VMD for the interactive display, animation and analysis of large biomolecules, and the large-scale molecular dynamics simulation program NAMD, which is capable of moment-by-moment chemical interactions of as many as 100 million atoms. Schulten built his own massively parallel computer when they were not yet available commercially, and he was among the first to use the Blue Waters supercomputer at the National Center for Supercomputing Applications for research.

Schulten's group made fundamental contributions to numerous areas of biology, most recently to understanding photosynthesis, force generation in cells, membrane channel dynamics, and large-scale cellular organization. He and his colleagues revealed the precise chemical structure of the HIV capsid, revealed new details of the dynamic assembly of the ribosome, and contributed to a deeper understanding of the chemistry of odor detection. One of his long-term interests was in animal vision, studying the effect of Earth's magnetic field on the migration of birds. He will be remembered not just for his groundbreaking development of computational approaches to biology, but for the many important biological insights that emerged from these approaches, in fields as wide-ranging as neuroscience and molecular biology.

Among his many honors and awards, he received the Nernst Prize (1981), Humboldt Award of the German Humboldt Foundation (2004), Award in Computational Biology of the International Society of Quantum Biology and Pharmacology (2008), the IEEE Sidney Fernbach Award (2012), and the Distinguished Service Award of the Biophysical Society (2013). He was a fellow of both the American Physical Society and the Biophysical Society.

Schulten was born on January 12, 1947 in Recklinghausen, Germany. He graduated from the University of Muenster with a degree in physics in 1969, and obtained a doctoral degree in chemical physics from Harvard University in 1974.

Schulten was a physics professor at the Technical University of Münich before joining the University of Illinois Department of Physics as a professor in 1988. ■

BOB I. EISENSTEIN

1939-2016

Professor Emeritus of Physics Bob Eisenstein was an experimental particle physicist who made important contributions to our understanding of the properties and fundamental interactions of subatomic particles, in particular, inelastic baryon-exchange reactions, the depolarization of muons in solids, the weak interactions of *B* mesons, and the properties of quarks.

Eisenstein's appreciation for the beauty and order of physics was reflected in a systematic approach that began with first principles. He was an expert at creating algorithms that could sift through noisy data sets to cull relevant information. He was a member and often played a key role in the success of collaborative research efforts, including at Fermi National Accelerator Laboratory, the Wilson Synchrotron Facility at Cornell University, the Stanford Linear Accelerator Center (SLAC), and CERN in Switzerland. At SLAC, he developed Monte Carlo simulation programs for the Mark III detector, to compare fundamental physics hypotheses with the data obtained in experimental runs. At Fermilab, he participated in the discovery of the top quark.

Eisenstein will also be remembered as a dedicated teacher with a wonderful imagination for explaining difficult topics. Students consistently ranked him one of the top in the department, not only in courses designed for physics majors, but also in general engineering physics courses. He taught courses at all levels and played an important role in the departmental effort to revise the introductory calculus-based course sequence. He guided graduate students' work closely, but gave each the freedom to work on topics that most interested them. He was the first member of the physics faculty to win the College of Engineering's William L. Everitt Undergraduate Teaching Excellence Award.

Eisenstein received his bachelor's (1959), master's (1961), and doctoral degree (1964) in physics from Columbia University. He completed a postdoc at Harvard University before he joined the faculty at Physics Illinois in 1967.

Eisenstein was born and raised in the Bronx, NY. In Champaign-Urbana, he was active in the Jewish community, serving as a trustee on the boards of Sinai Temple and the Champaign-Urbana Jewish Federation.

He is survived by his wife, Joyce Nagel Eisenstein, and her children Brenda Levin and Robert Nagel, by his children, Matthew Eisenstein and Alissa Eisenstein and stepson Erik Wright, as well as by his sister, Judith Eisenstein of Brooklyn, N.Y. He was preceded in death by his first wife, Laura Eisenstein, and by his son, Joshua Eisenstein. ■

HARVEY J. STAPLETON

1934-2016

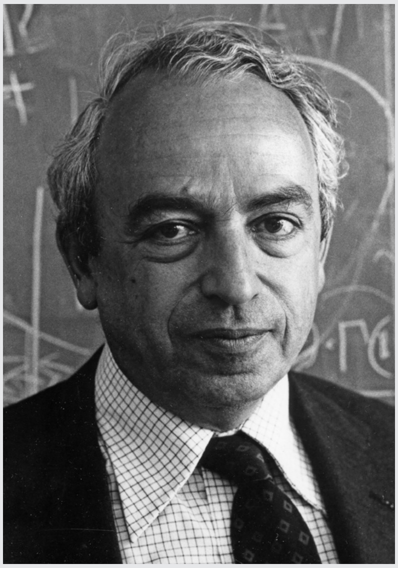
Professor Emeritus of Physics and former Associate Vice Chancellor for Research Harvey Stapleton was an experimental condensed matter physicist. His work involving electron spin resonance and relaxation to measure the low temperature properties of solids and biomolecules was widely published. He studied paramagnetic resonance and relaxation in rare earths, actinides, and metalloproteins. The work on metalloproteins, which revealed their fractal nature, had a major impact on the development of biophysics.

Stapleton was known for having a level head and a cheerful attitude. He provided thorough training to his students; during his tenure at Illinois, he led 25 graduate students to their doctoral degrees. These former students went on to careers at major research institutions. Over his career, Stapleton authored or co-authored more than 50 papers. He was an Alfred P. Sloan Fellow and a fellow of the American Physical Society.

Stapleton received a bachelor's degree in physics from the University of Michigan in 1957 and a doctoral degree in physics from the University of California, Berkeley in 1961. The same year, he joined the faculty of Physics Illinois as an assistant professor of physics and progressed rapidly though the faculty ranks to become a full professor in 1969. In 1980, Stapleton took a half-time administrative position as associate dean of the Graduate College, while continuing his research in physics. In 1985, he was named executive secretary of the Campus Research Board, and in 1986, he was appointed an associate vice chancellor for research, also on a halftime basis. In 1987, after a nationwide search, both of these administrative appointments were made fulltime. He retired from the U. of I. in 1995. ■

EDWIN L. "NED" GOLDWASSER

1919-2016



Emeritus Professor of Physics Ned Goldwasser was both a distinguished high-energy physicist and a deeply respected science and university administrator.

Goldwasser attended the Horace Mann School in New York City from 1930 to 1936. He enrolled in physics at Harvard College in 1936, earning an AB degree in 1940. During World War II (1941–1945), he served as a civilian physicist with the US Navy, where he worked on methods to reduce ships' magnetic signatures, for evading mines. He received his doctoral degree from the University of California, Berkeley, in 1950.

In 1951, Goldwasser joined the Department of Physics as a research associate in nuclear physics, working on the 25-MeV and 300-MeV betatrons. He was promoted to research assistant professor in 1953, and to assistant professor in 1954. He was granted tenure as an associate professor in 1957, and was promoted to professor in 1959. Goldwasser was the author of numerous technical publications on the properties of cosmic rays, energy loss of charged particles, photon interactions, and elementary particle interactions. He took a leading role in efforts by a consortium of Midwestern universities in the 1950s and 1960s to strengthen their research facilities in high-energy physics and to locate a national accelerator facility in the central U.S.

A dedicated and inspiring teacher, Goldwasser wrote the then-influential introductory textbook *Optics, Waves, Atoms and Nuclei* (New York, W.A. Benjamin, 1965) and led the University of Illinois contingent of the Physical Science Study Committee, a collaborative effort by Illinois and the Massachusetts Institute of Technology to create a modern high-school physics curriculum. The resulting textbook and teacher's guide, PSSC Physics, to which Goldwasser was a major contributor, transformed the way that physics was taught in U.S. high schools post-Sputnik.

In 1967, with an Illinois site chosen by the US Atomic Energy Commission as the location of the nation's new "National Accelerator Laboratory" (now Fermi National Accelerator Laboratory), Goldwasser took a leave of absence from Illinois to serve as deputy director of the new facility. Goldwasser oversaw the construction of the accelerator complex, scheduled its experimental program, and implemented its groundbreaking equal-employment program.

Goldwasser returned to Illinois in 1978 as vice chancellor for research and dean of the graduate college. He was vice chancellor for academic affairs from 1980 to 1986. He took another leave that year to join the Central Design Group of the proposed Superconducting Super Collider, where he served as associate director until 1988. At that time, he returned to Illinois as acting director of the Office of International Programs and Studies, and he also served as director of the University of Illinois' Computer-assisted Education Research Laboratory. In 1990, following his retirement from Illinois, he was appointed a "Distinguished Scholar" at the California Institute of Technology to work on the LIGO project.

Goldwasser was a fellow of the American Physical Society and the American Association for the Advancement of Science. He received Fulbright and Guggenheim fellowships and served on the Atomic Energy Commission's General Advisory Committee and on the University of California's committees that oversee its three national laboratories. ■

Gadway selected for U.S. Air Force Young Investigator Research Program

SIV SCHWINK
for Physics Illinois Condensate

Assistant Professor Bryce Gadway of the Department of Physics at the University of Illinois Urbana-Champaign has been selected for the 2017 U.S. Air Force Young Investigator Research Program. Gadway is among 43 early-career scientists and engineers nationwide to receive this three-year award of $450,000. U.S. Air Force Young Investigators are selected based on demonstrated exceptional ability and promise for conducting basic research in scientific and engineering areas identified as strategic to the US Air Force mission.

Gadway is an atomic, molecular, and optical (AMO) experimentalist, who has developed novel quantum simulation techniques for probing electronic transport in condensed matter systems. Quantum-simulation is an approach to gaining insight into the behavior of complex systems by emulating them with an ideal, model setup. Gadway's group uses finely tuned lasers to trap ultracold atoms about a billion times colder than room temperature, creating a momentum-space lattice that replicates the properties and behaviors of electronic transport in real materials. AMO experimentation allows greater control over experimental parameters than could be achieved in real materials: these simulated materials are without defect, and individual variables can be finely tuned.

This award will support a new direction in Gadway's AMO research: he will be looking at the underlying dynamics of emergent phenomena that arise in complex systems of many interacting quantum particles. In other work, Gadway and his team have demonstrated the effectiveness of their unique "bottom-up approach" to Hamiltonian engineering, through novel explorations into topological and disordered lattice systems. In this new work, Gadway's team will refine their approach and study the role of strong interactions in topological and disordered atomic fluids.

Gadway received a bachelor's degree in physics from Colgate University in 2007 and a doctoral degree in physics from Stony Brook University in 2012. He was a National Research Council postdoctoral research fellow, completing his postdoctoral work at JILA in Boulder, CO, before joining the faculty at Physics Illinois in 2014. He is the recipient of Stony Brook University's President's Award to Distinguished Doctoral Students (2013) and of the American Physical Society's Leroy Apker Award (2007).

HOOBERMAN, SHELTON SELECTED FOR DOE EARLY CAREER AWARDS

Assistant Professor Ben Hooberman

Assistant Professor Jessie Shelton

Assistant Professors Jessie Shelton and Benjamin Hooberman of the Department of Physics at the University of Illinois at Urbana-Champaign have been selected for 2017 DOE Early Career Awards. They are among 65 early-career scientists nationwide to receive the five-year awards through the Department of Energy Office of Science's Early Career Research Program, now in its second year. According to the DOE, this year's awardees were selected from a pool of about 1,150 applicants, working in research areas identified by the DOE as high priorities for the nation.

Hooberman is an experimental high energy particle physicist working with the ATLAS experiment, a large-scale collaboration of more than 3,000 scientists at the Large Hadron Collider (LHC) particle accelerator at CERN, in Switzerland. In his research, he mines huge quantities of data obtained from millions of particle collisions, to uncover new physics beyond the standard model. His research group also contributed to the development of an upgraded ATLAS charged particle tracking detector and trigger systems, having performed extensive simulation studies to help guide the new design.

Hooberman specializes in the search for supersymmetric particles and evidence of extra dimensions of spacetime. In this same context, he is also working on one of the greatest puzzles in physics today—dark matter. The standard model, our best working model of the universe, falls short of explaining dark matter. Understanding the nature of physics beyond the standard model and its potential connection to dark matter is among the highest priorities of the LHC physics program and the focus of Hooberman's research. A discovery would transform our understanding of the composition and fundamental laws of the universe.

Hooberman received a bachelor's degree in physics from Columbia University in 2005 and a doctoral degree in physics from the University of California, Berkeley in 2009. From 2009 to 2014, he held a postdoctoral appointment at Fermi National Accelerator Laboratory, working as a member of the CMS collaboration at the LHC. He joined the faculty of Physics Illinois in 2014. He is a recipient of the CMS/LHC Physics Center Fellowship from Fermilab in 2013.

Shelton is a theoretical high energy particle physicist. Her research focuses on a broad range of unsolved problems in particle physics beyond the standard model. She uses the formal aspects of particle phenomenology, coupled with big data from particle accelerators, to generate mathematical models of the nature of matter and dark matter. She is particularly interested in dark matter, top quarks, and the Higgs boson. Her recent work has also focused on the physics of black-hole *p*-wave dark matter annihilation.

Shelton received a bachelor's degree in physics from Princeton University in 2000 and a doctoral degree in physics from MIT in 2006. She held postdoctoral appointments at Rutgers, Yale, and Harvard before joining the faculty at Physics Illinois in 2014. She is the recipient of MIT's Andrew M. Lockett Award for Excellence in Theoretical Physics (2006) and the LHC Theory Initiative Travel and Computing Award (2011). ■

Physics Illinois alumnus M. George Craford awarded IEEE Edison Medal

Portrait of M. George Craford, inventor of the first yellow LED. He was a student of Nick Holonyak, Jr., inventor of the first LED.

SIV SCHWINK

for Physics Illinois Condensate

Physics Illinois alumnus M. George Craford was selected for the IEEE Edison Medal of the Institute of Electrical and Electronics Engineers. The medal is awarded annually in recognition of a career of meritorious achievement in electrical science, electrical engineering, or the electrical arts. The citation reads, "for a lifetime of pioneering contributions to the development and commercialization of visible LED materials and devices."

Craford is best known for his invention of the first yellow light emitting diode (LED). During his career, he developed and commercialized the technologies yielding the highest-brightness yellow, amber, and red LEDs ,as well as world-class blue LEDs. He is a pioneer whose contributions to his field are lasting.

Raised in a farming community in Iowa, Craford received a master of science degree (1963) and a doctoral degree (1967) from Physics Illinois. As a student, he worked under Nick Holonyak, Jr., the inventor of the first visible direct band gap LED, an invention that enabled the evolution of the high performance LED technology now in use worldwide.

Craford began his professional career in 1967 at the Monsanto Chemical Company, where he quickly became the leader of the LED technology group for what was at that time the largest LED company in the world. He led the development of an improved new GaAsP:N LED technology in 1971 that yielded the first yellow LED and increased the performance of red LEDs by an order of magnitude. It became the dominant high performance LED technology for more than a decade.

In 1974, Craford was appointed Director of Technology for the Monsanto Electronics Division. When Monsanto sold its LED and compound semiconductor business in 1979, Craford took a position at Hewlett Packard, where he served as technology manager for the Optoelectronics Division, with the responsibility of maintaining leadership in LED technology. In 1990, Craford's team pioneered the development of another new LED technology that utilized the quaternary compound AlInGaP and yielded the world's highest performance red, orange, and amber LEDs. The first LED with performance of 100 lumens per watt was demonstrated. Devices of this type continue to be used in traffic signals, automotive lighting, and many other applications.

In 1999, Craford became chief technology officer of Lumileds Lighting, a joint venture between Agilent and Philips. The first high power white LEDs, with inputs of 1 W and higher, were developed at Lumileds Lighting and are now widely used in many types of lighting, including general illumination, automobile taillights, and cellphone flashes. Lumileds Lighting, which later became Philips Lumileds Lighting Company, today maintains its position at the forefront of LED technology.

Craford is currently Solid State Lighting Fellow at Philips Lumileds Lighting Company. He is a member of the National Academy of Engineering and a Fellow of the IEEE. He is the recipient of many honors, including the 2002 National Medal of Technology, the University of Illinois Alumni Distinguished Service Award, the IEEE Morris N. Liebmann Award, the IEEE Third Millennium Medal, the Optical Society of America Nick Holonyak Jr. Award, the International Symposium on Compound Semiconductors Welker Award, the Materials Research Society MRS medal, the Electrochemical Society Electronic Division Award, the Economist Innovation Award, the Strategies in Light LED Pioneer Award, and the International SSL Alliance Global Solid State Lighting Development Award. In 2014, he was inducted to the Engineering at Illinois Hall of Fame.

The IEEE Edison Medal was presented to Craford at the IEEE Honors Ceremony in San Francisco on May 25, 2017, during the IEEE Vision, Innovation, and Challenges Summit. The award includes a gold medal, a bronze replica, a certificate, and an honorarium. ■

ABOUT THE MEDAL

On October 21, 1879, Thomas Alva Edison succeeded in producing the first practical incandescent electric light bulb—the beginning of modern illumination. Twenty-five years later, on February 11, 1904, a group of Edison's friends and associates created a medal in his name to commemorate the achievements of a quarter of a century in the art of electric lighting. In their words, "The Edison Medal should, during the centuries to come, serve as an honorable incentive to scientists, engineers, and artisans to maintain by their works the high standard of accomplishment set by the illustrious man whose name and feats shall live while human intelligence continues to inhabit the world."

Four years later, the Institute of Electrical Engineers entered into an agreement with the founders to award the medal, adding IEEE to its designation. The IEEE Edison Medal has been presented annually since 1909 to a single recipient who, like Edison, has applied his imagination and desire to achieve a better standard of living through electrical advancements has bridged the gap between imagination and realization.

DEPARTMENT OF PHYSICS
University of Illinois at Urbana-Champaign
Loomis Laboratory of Physics
1110 W. Green Street
Urbana, IL 61801-3080

Proud of our students and alumni in the College of Engineering and the College of Liberal Arts & Sciences.