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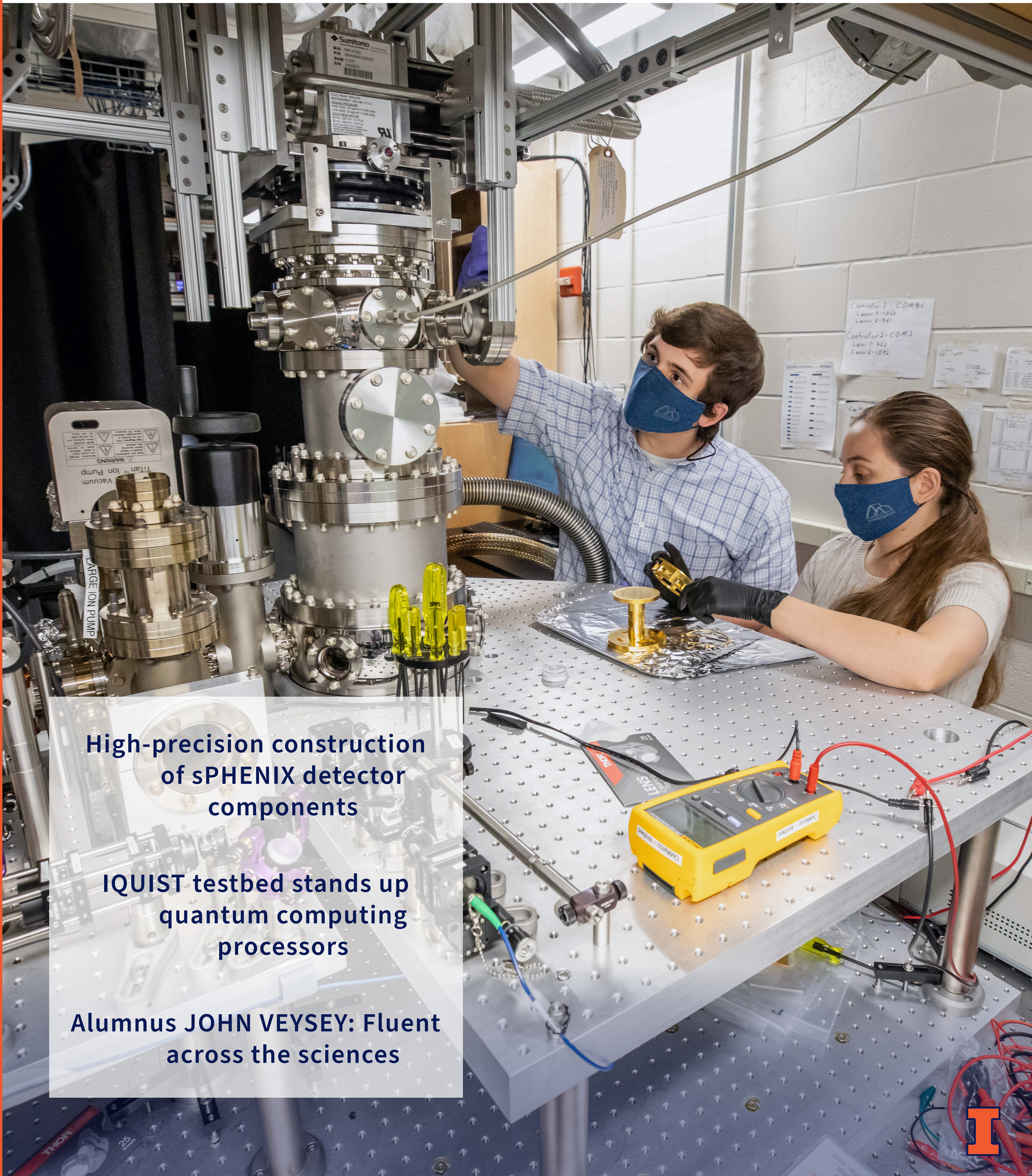
ILLINOIS PHYSICS condensate

THE NEWS MAGAZINE *of the* DEPARTMENT OF PHYSICS



High-precision construction of sPHENIX detector components

IQUIST testbed stands up quantum computing processors

Alumnus JOHN VEYSEY: Fluent across the sciences

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ILLINOIS PHYSICS CONDENSATE

is a semiannual publication of the Department of Physics at the University of Illinois Urbana-Champaign.

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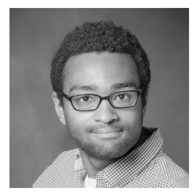

GARRETT WILLIAMS *is an Illinois Physics Ph.D. candidate and science writer. He has been recognized as the winner of the 2020 APS History of Physics Essay Competition and as a finalist in the 2021 AAAS Science and Human Rights Essay Competition. He was also an invited author in the 2021* #BlackinPhysics Week *series published by* Physics Today *and* Physics World.

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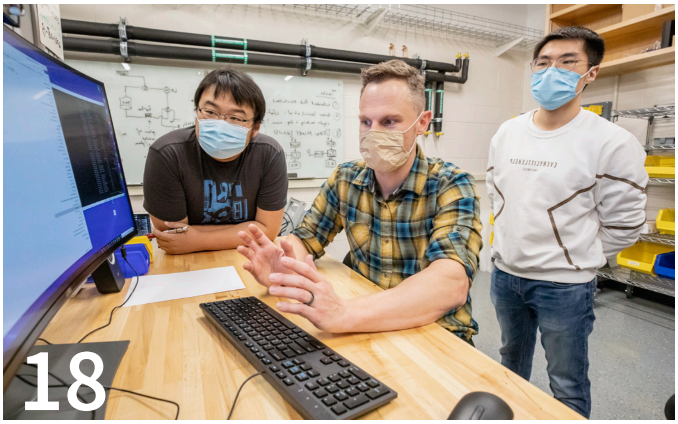

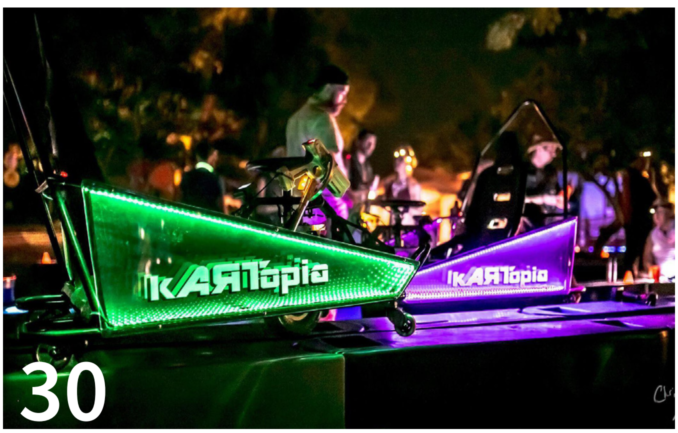

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OUTREACH

DEPARTMENTAL NEWS

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Cover image: Illinois Physics graduate students Will Christopherson (left) and Mari Cieszynski work to assemble a quantum processor experiment based on trapped atomic ions, at the IQUIST testbed in the basement of the Engineering Sciences Building. Christopherson and Cieszynski are members of Illinois Physics Professor Brian DeMarco's team. Credit: L. Brian Stauffer, University of Illinois Urbana-Champaign

Back cover image: Illinois Physics introductory-course learning assistants support undergraduate students in an iOLab-assisted laboratory exercise during a laboratory class meeting at the Campus Instructional Facility on the Bardeen Quad. The iOLab is a hand-held laboratory device loaded with sensors students can use to measure physics phenomena in experiments they design themselves, invented by Illinois Physics Professor Emeritus Mats Selen. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

WELCOME

FROM OUR *Department Head*

MATTHIAS GROSSE PERDEKAMP

Dear Physics Family,

I want to thank our faculty, staff, postdocs, and students for their resilience, hard work, and dedication that made it possible to maintain our top-level educational and research programs throughout the COVID-19 pandemic. I am also very grateful for the continuing generosity of our alumni; your support has been instrumental in helping us to do what we do well—even better. The funds we have received enable high-priority or time-critical programs, such as student diversity initiatives and our COVID-related research. We have overcome many challenges together and have exciting initiatives underway at Illinois Physics.

Over the past two years, our faculty led the launch and build-up of two new interdisciplinary centers. IQUIST, the Illinois Quantum Information Science and Technology Center, is an integral part of a statewide push to maintain a leading position in a growing quantum technologies sector. And the Illinois Center for Advanced Studies of the Universe (ICASU) is addressing unanswered fundamental questions about the universe. Both centers progressed admirably against significant challenges, as is reflected in a 20 percent increase in our faculty's total external research support between fiscal years 2020 and 2021, to $27.6M. A special thanks to the faculty who have joined the department recently. All have done a

wonderful job establishing exciting research programs under difficult conditions and still have provided exemplary support for the students taking their classes.

The iOLab, the latest innovation of our physics education research group, has revolutionized laboratory instruction in introductory courses at Illinois and in physics classes across the country. The iOLab makes it possible to depart from using ready-prepared and narrowly scripted instructional laboratory setups. Instead, students devise, set up, and carry out their own experiments to test and demonstrate the physics studied in class. The iOLab stimulates students to independently study the connection between physics concepts and experiment, encouraging them to solve experimental challenges on their own. With the move of our intro teaching laboratories to four classrooms in the new Campus Instructional Facility (CIF), our students now have access to a modern instructional space for their iOLab-based experimental learning. CIF can also be used for workshops or events. Make sure to pay a visit to CIF on your next stop in town!

Our faculty and graduate students contributed significantly to COVID-19 research. For example, Nigel Goldenfeld and Sergei Maslov led an interdisciplinary team of researchers who provided epidemiological modeling support as input to science-based policy decisions, keeping our campus and community safe. At the beginning of this semester, University of Illinois System President Timothy Killeen honored Nigel and Sergei with the Presidential Medallion in recognition of their extraordinary service.

In addition to COVID-19-related research, the pandemic inspired the faculty to explore new technologies for research and teaching. These innovations include pioneering online and hybrid formats for scientific and professional meetings and moving upper-division laboratories to fully remote operation, as well as developing COVID-safe practices and technologies for in-person experimental research.

This year, we are celebrating the 100th birthday of our alumna Rosalyn Sussman Yalow, the first American-born female Nobel laureate in physiology or medicine. Dr. Yalow's groundbreaking achievements were instrumental in initiating societal changes leading to greater opportunities for women in science. Today, 28 percent of the faculty at Illinois Physics are women. In honor of Dr. Yalow and with the generous support of the Heising-Simons Foundation, Nadya Mason has been named the inaugural Rosalyn Sussman Yalow Professor in Physics. I am proud to share with you that Nadya has also been elected this year to the National Academy of Sciences and to the American Academy of Arts and Sciences.

In recognition of Gordon Baym's remarkable career, the American Physical Society (APS) awarded him the 2021 APS Medal for Exceptional Achievement in Research, the largest research award the society confers. This well-deserved honor highlights the significance of Gordon's contributions to many areas of physics, including condensed matter theory, neutron stars, quark-gluon plasma, and ultracold gases.

I also want to congratulate Charles Gammie, who was named Donald Biggar Willett Chair in Physics. Charles and his students continue to make vital contributions to the Event Horizon Telescope Collaboration that imaged the supermassive black hole in the center of the elliptical galaxy Messier 87.

In closing let me express my wishes that you have all kept safe and well during the pandemic! We are looking forward with confidence to good days to come, as we know we can count on your support and the extraordinary talents and work of our students, faculty and staff.

With kind regards,

ILLINOIS PHYSICS Spectrum

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

JAKI NORONHA-HOSTLER

NUCLEAR PHYSICS

My work focuses on studying the smallest bits of matter—quarks and gluons—at the most extreme temperatures and densities known to humanity. By colliding two specks of gold at 99.9999 percent of the speed of light, we are able to produce a tiny droplet of the primordial liquid called the quark-gluon plasma that existed microseconds after the big bang. These collisions reach the highest temperatures ever produced on Earth and are well described by relativistic viscous fluid dynamics. Unlike the plasma found in the Sun, which carries only electric charge, the quark-gluon plasma is made up of quarks that carry three different charges: baryon number, electric charge, and strangeness. My group performs large-scale simulations of how the quark-gluon plasma flows like an extremely tiny droplet of fluid. Using these simulations and making direct comparisons to experimental data from heavy-ion experiments, we are able to look for new phases of matter. Specifically, we are searching for the critical point of the strong force, which may be possible to locate using low-energy heavy-ion collisions.

Illinois Physics Professor Jaki Noronha-Hostler poses in her office, in the Loomis Laboratory of Physics. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

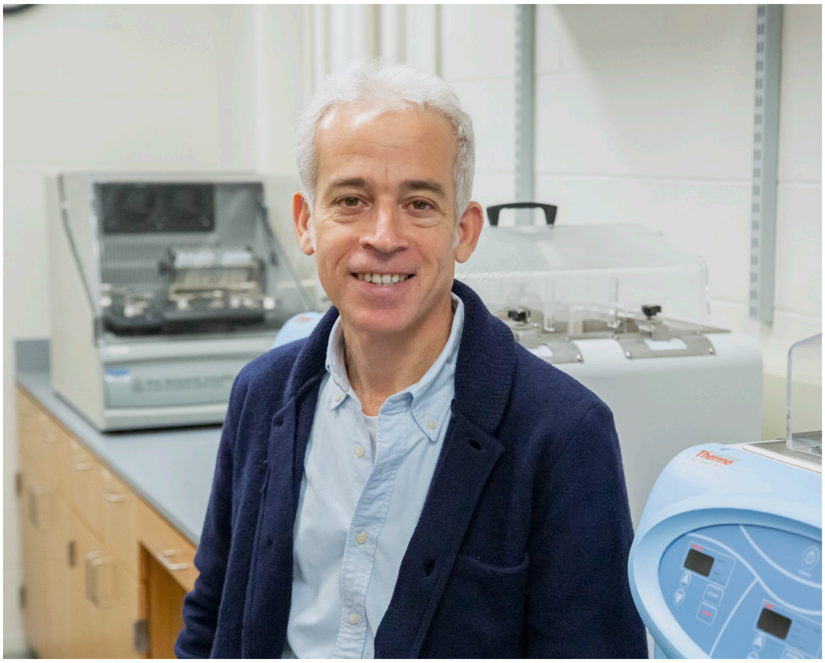
The other thrust of my research focuses on the study of the interior of neutron stars. At a neutron star's very core, it may be possible to squeeze matter to such extreme densities that quarks become the relevant degrees of freedom. This state of matter would look very different from the quark-gluon plasma found in heavy-ion collisions, because it would appear at much lower temperatures and much higher densities. I am interested in finding observable signatures of quark matter in the core of neutron stars and finding connections between heavy-ion experiments and neutron star mergers.

Research in the Noronha-Hostler lab is supported by the U.S. Department of Energy, Office of Science, Nuclear Science Grant No. DESC002063 and by the National Science Foundation's support of the MUSES collaboration under grant no. OAC-2103680, and by an Alfred P. Sloan Foundation Research Fellowship. The findings presented are those of the researcher and not necessarily those of the funding agencies.

IDO GOLDING

BIOLOGICAL PHYSICS

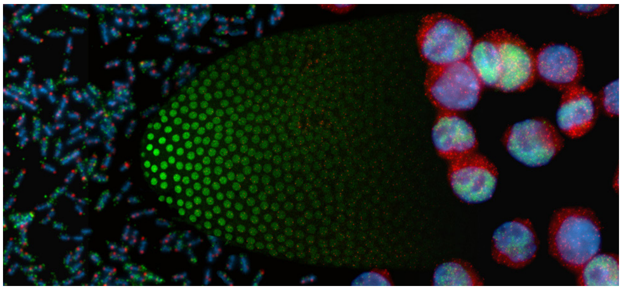
How do viruses decide the fate of an infected cell? This is one of the central questions my lab pursues. Upon infection of a living cell, viruses often make a choice between one of two routes: rampant reproduction, ending with the death of the host and the release of many new viral particles; or dormancy, in which the infected cell survives with the latent virus hiding inside, ready to awaken at a later time. The "algorithm" that each virus uses for making this life-or-death decision is encoded in its tiny genome, but deciphering how these algorithms work has proven elusive. Individual infected cells, even if they appear completely identical, may nevertheless undergo different fates following infection. Consequently, we cannot predict for a given infection event whether the outcome will be cell death or viral dormancy.



Illinois Physics Professor Ido Golding in his laboratory at Loomis Laboratory of Physics. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

To elucidate the origin of these cell-to-cell differences, we devise microscopy experiments where we follow individual viruses and cells during infection. To interpret our observations, we use theoretical methods inspired by statistical physics, whereby the molecular randomness of the biophysical processes underlying infection is taken into consideration. These theoretical models allow us to predict not just the average behavior of cells within a population, but also the degree to which individual cells will differ from each other in the outcome of infection.

Viral decision-making is just one of countless examples of the astonishing ingenuity of evolution. By both constraining and enabling evolutionary progression, the laws of physics drive the organization of molecules into cells, of cells into organisms, and of organisms into communities. After spending centuries tackling the behavior of inanimate matter, it is time for physicists to turn our full attention to understanding life, the ultimate physical phenomenon.



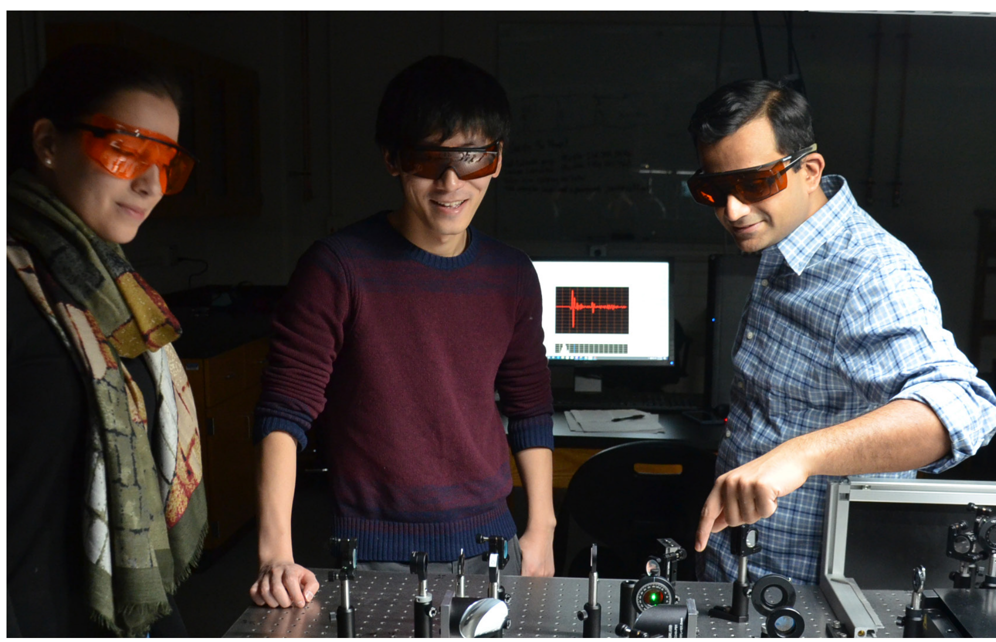
Work in the Golding lab is supported by the National Institutes of Health, Grant No. R35-GM140709. The findings presented are those of the researcher and not necessarily those of the funding agencies.

FAHAD MAHMOOD

CONDENSED MATTER PHYSICS

I am a condensed matter experimentalist who develops new measurement techniques based on light-matter interaction to understand, exploit, and control the remarkable emergent properties of quantum materials. These emergent properties are governed by collective behavior and interactions that tend to occur over short time scales (a few picoseconds or less) or at low energy scales of a few meV (≈ THz range frequencies). This necessitates developing tools that can probe such phenomena at their intrinsic time and energy scales.

My group develops these "ultrafast" spectroscopic tools, such as time-resolved photoemission and time-domain THz spectroscopy, to examine light-matter interaction in materials over a wide part of the electromagnetic spectrum, ranging from sub-terahertz (THz) to extreme ultraviolet light. Using these tools, we probe the underlying collective rules governing macroscopic quantum behavior with the goal of engineering this behavior to sustain emergent properties, such as superconductivity, interacting topological phases, and fractional particles, at much higher temperatures than is currently possible.



Illinois Physics Professor Fahad Mahmood works with students in his lab in the Frederick Seitz Materials Research Laboratory. Photo by Siv Schwink for Illinois Physics

A few of our ongoing research projects include understanding the interplay between topological Weyl physics and correlations in the charge-density wave material $(TaSe_4)_2I$; using Floquet engineering to modify the electronic band structure of the magnetic topological insulator $MnBi_2Te_4$; and resolving the THz-scale dynamics of spin quasiparticles in antiferromagnetic materials. Additionally, we are currently pioneering the extension of THz- and photoemission-based tools to a new "multidimensional" regime in which pairs of entangled photons or electrons are used to explicitly measure previously inaccessible two-particle spectral functions and higher-order susceptibilities. We will use this approach to solve some of the most fundamental problems in condensed matter physics, such as direct detection of fractional particles known as spinons, the Cooper-pair structure of unconventional superconductors, and the nature of electronic correlations in strange metals.

In the Mahmood group, work on Weyl-CDW is supported by the Center for Quantum Sensing and Quantum Materials, an Energy Frontier Research Center funded by the U. S. Department of Energy, Office of Science, Basic Energy Sciences, under Award DE-SC0021238. The work on antiferromagnetic topological materials is supported by the National Science Foundation MRSEC program under NSF Grant No. DMR1720633. The findings presented are those of the researcher and not necessarily those of the funding agencies.

HELVI WITEK

GRAVITATION AND THEORETICAL ASTROPHYSICS

Once upon a time, in a far-away small town where the night sky is so clear that one can see the faintest stars, there was a young girl. She was so full of energy that her parents could think of no better way to make her sleepy than to show her the stellar constellations on long evening walks, which sparked her curiosity about the wonders of the universe. This excitement stayed with the girl, and she grew up to become a "gravity detective." As you may have guessed, this girl was me, and nowadays, my research employs black holes and the gravitational waves they emit during their cosmic dance to solve long-standing mysteries in fundamental physics. This has become possible with the first breakthrough detection of gravitational waves in 2015 and more than 90 events since then. It is fair to say that we have now entered an era of precision gravitational physics.

Illinois Physics Professor Helvi Witek. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

In my group, we perform high-performance computing simulations of colliding black holes and their gravitational wave emissions, which aid in the identification and interpretation of a detected signal. We are developing the open-source Canuda code for numerical relativity, which enables us to investigate the interaction between black holes and new ultra-light particles that are popular dark matter candidates and that cannot be probed with particle colliders. We design new investigative tools to probe the very nature of gravity in its nonlinear, strong-field regime, which unfolds during the collision of black holes, by computing the gravitational radiation in extensions of Einstein's general relativity. These extensions are motivated by quantum gravity paradigms, such as string theory. We have discovered new nonlinear phenomena that will enable us to probe for—or constrain—such extensions.

On a global level, I am the co-PI of the Einstein Toolkit, an open-source software infrastructure for computational astrophysics with more than 340 members from 43 countries. I am also playing a leadership role in the Laser Interferometer Space Antenna (LISA) mission designed by ESA and NASA. LISA will be a space-born detector listening to gravitational waves from entirely new sources, such as supermassive black holes at the center of galaxies, extreme mass-ratio inspirals, stochastic "background" signals from inflation, or condensates of ultralight bosons around black holes. My group is making the theoretical predictions necessary to interpret these upcoming measurements.

Work in the Witek group is supported by the National Science Foundation, Grant Nos. OAC-2004879 and PHY-2110416; and by the Royal Society UK Research Grant RGF\R1\180073. The findings presented are those of the researcher and not necessarily those of the funding agencies.

The sPHENIX Experiment

Anne Sickles

Caroline Riedl

Eric Thorsland

RESEARCH

High-precision construction of sPHENIX detector components wraps up at NPL

GARRETT WILLIAMS
for Illinois Physics Condensate

A team of scientists and research technicians at Illinois Physics has played a key role in the construction of the upcoming sPHENIX experiment at Brookhaven National Lab (BNL), by manufacturing the new electromagnetic calorimeter (EMCal) for the sPHENIX detector system.

The sPHENIX experiment is a collaboration of about 300 scientists who are exploring some of nature's most basic and intriguing phenomena through study of the quark-gluon plasma (QGP). The QGP—an extremely hot and dense liquid that filled the universe for a few millionths of a second after the Big Bang—can only be produced in the high-energy collisions of heavy ions such as gold or lead. The planned sPHENIX experiment's new sophisticated detectors will enable the search for more detailed descriptions of the physics governing the QGP.

Illinois Physics Professor Anne Sickles comments, "The new sPHENIX detector is designed to enable us to measure the properties of the QGP in ways that we haven't been able to achieve before. The QGP is the high temperature state of matter where protons and neutrons centrally melt, and the matter is composed of free quarks and gluons. This matter lives for an extremely short time, about 10-22 of a second [that's 1 /10,000,000,000,000,000 ,000,000!], so studying it is extraordinarily difficult and requires highly specialized detectors. The new detector will enable us to do the same kind of measurements at RHIC that we could previously only do at the Large Hadron Collider (LHC) at CERN."

Work on the major upgrades to the detectors could easily have ground to a halt early in the effort as a result of manufacturing challenges. When it became apparent that private companies would be unable to manufacture at sufficiently high quality the necessary specialized components for the EMCal subsystem of the sPHENIX detector, Sickles proposed to the collaboration that the components be built at the Nuclear Physics Lab (NPL) at the University of Illinois Urbana-Champaign campus.

"We have an extensive history of building large detector components at high quality," Sickles notes. "NPL is one of the only university labs in the country that can build things like this—we have both the technicians and facilities."

After sPHENIX tested 16 UIUC-produced prototype blocks at Fermilab in 2018, Illinois Physics Research Professor Caroline Riedl and Research Engineer Eric Thorsland put together a team to construct

Continued on page 14. ▶

Top: Illinois Physics Research Professor Caroline Riedl examines a detector block her team manufactured for the sPHENIX EMCal detector. The team constructed more than 5,000 tungsten and scintillating-fiber blocks in all.

Middle: Illinois Physics undergraduate student Eric Hoshaw extracts an EMCal fiber set from the assembly fixture, before it is inserted into a molding form.

Bottom: Illinois Physics undergraduate student Mina Mazeikis and postdoctoral researcher Tim Rinn discuss EMCal block qualities. Every EMCal block was quality assured at several test stands prior to shipping to BNL.

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

Illinois Physics research engineer Eric Thorsland discusses the EMCal block machining process with technician helper Clayton Curry.

Illinois Physics technician assistant Saad Altaf casts a tungsten and scintillating-fiber EMCal block using epoxy resin.

Studying the quark-gluon plasma and proton structure

The sPHENIX collaboration has scheduled first collisions for February 2023. The overarching goal of sPHENIX is to understand the microscopic structure of the plasma and how its strong interactions arise from the underlying quantum chromodynamics.

The quark-gluon plasma (QGP) generated in the sPHENIX experiment will come from the collision of the nuclei of large gold atoms. The collisions result in jets—sprays of subatomic particles that aren't stable and evolve into other particles as the jet is occurring. The detector registers the particles and a trigger system decides which data to store on BNL computer disk and tape systems. Electronic devices on the detector front-end convert the analog signal from the detector response to digital form, which can be processed by computers.

"The sPhenix experiment will provide state-of-the-art capabilities for studies of the strongly interacting QGP," Riedl notes. "The sPHENIX detector is an optimized jet detector. Jets are sprays of particles that emerge in a cone-like structure from the collision interaction point. The EMCal is designed to measure the properties of these jets."

Sickles adds, "We want to measure how these jets are modified by their interaction with the quark gluon plasma."

Sickles describes in more detail how the tungsten blocks work in the EMCal's detection of the particle-spray, or high-energy jets, of heavy-ion collisions:

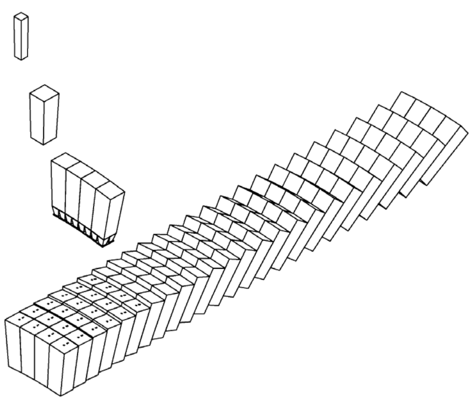
"Electromagnetically interacting particles traveling through a tungsten block cause an electromagnetic shower, a cascade of *bremsstrahlung*—high energy photons—and electron-positron pairs produced from photons. Some photons are then guided by the scintillating fibers toward the detector, where their energy is converted to an electrical signal. Tungsten is used because it's dense and stops the particles over a short distance. The EMCal is one of several sPHENIX detectors that measures the position and energy of particles in order to characterize the collisions," says Sickles.

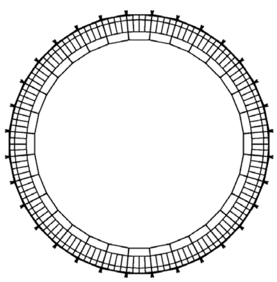
Riedl notes that the physics of interest to members of the sPHENIX collaboration comes in the form of two separate projects. With the future collisions of transversely polarized protons in RHIC, Riedl and her sPHENIX colleague, Illinois Physics Professor and Head Matthias Grosse Perdekamp, are interested in investigating proton structure: Where does the proton spin come from? Do quarks and gluons in the proton undergo orbital angular motion? What is the multi-dimensional proton picture in transverse-momentum and position space? Whereas this line of inquiry in nuclear physics is referred to as "cold QCD," Sickles is interested in the QGP of "hot QCD" at high temperatures.

Sickles explains, "How does this low-viscosity fluid arise from the fundamental interactions of quarks and gluons—that's the question we are trying to answer. The measurements sPHENIX takes will help us to understand the temperature dependence of the quark-gluon plasma. There are currently only two places on Earth where such measurements can be taken, and the LHC is hotter than RHIC, we operate at comparatively moderate and low temperatures. Comparing our measurements with those at the LHC will help us to understand the properties of quark-gluon plasma—an exotic state of the strong nuclear force. One of the fundamental forces, the strong nuclear force is responsible for over 99 percent of visible mass, but is one of the hardest forces to investigate experimentally."

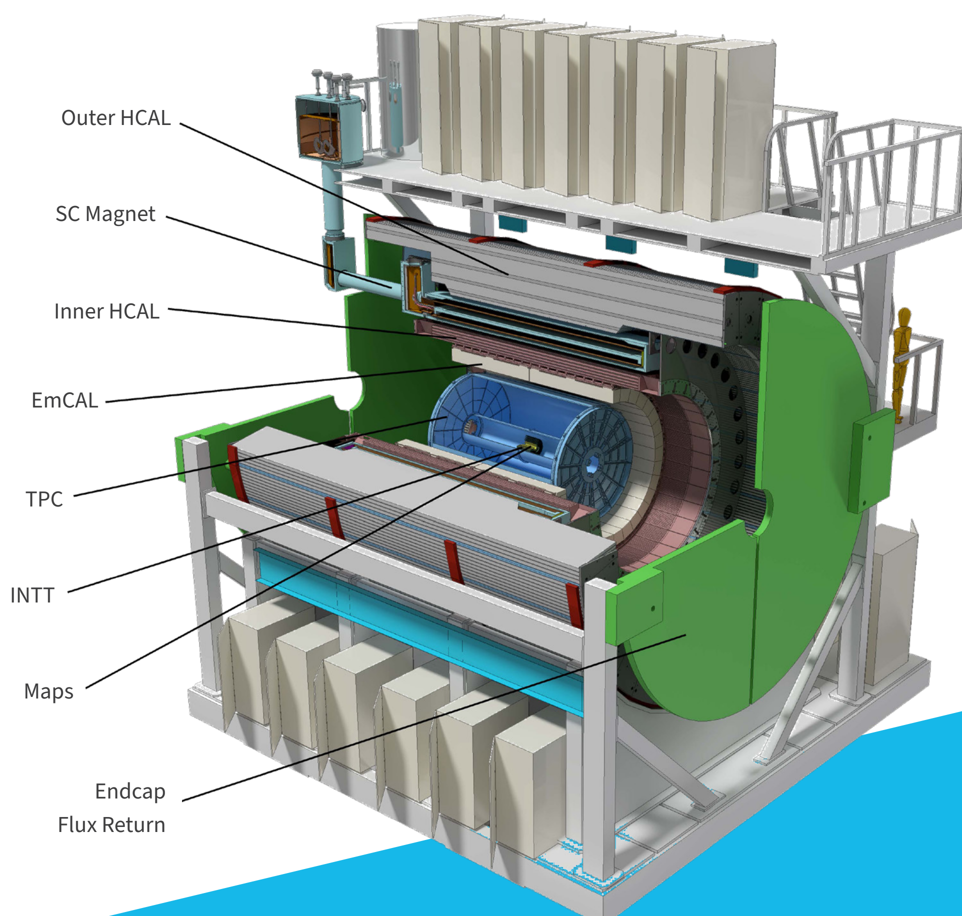
Illinois Physics lab mechanic Adam Wehe machines an EMCal block. Wehe machined over 4,500 blocks throughout the project. Photos by L. Brian Stauffer, University of Illinois Urbana-Champaign

The sPHENIX Detector





Above: Sketch of an entire EMCal sector of 96 tungsten–scintillating-fiber blocks; 4 blocks equipped with light guides and front-end electronics; and a cross section of the EMCal barrel showing 32 sectors.



Right: Sketch of the new sPHENIX detector, cut open to illustrate the onion-like structure of a typical collider-experiment. The beams of gold ions or protons will collide, starting in 2023, in the center of the barrels. From inside to outside, various tracking detectors will reconstruct the trajectories of charged particles, together with a superconducting (SC) magnet for momentum reconstruction, the electromagnetic calorimeter (EMCal), and two hadronic calorimeters (HCal) for energy measurement and particle identification. Credit: sPHENIX/BNL

The Illinois sPHENIX team poses at the Nuclear Physics Lab, together with several crates used to pack the EMCal blocks for shipment to BNL. Pictured from left to right are Caroline Riedl, Jeremy Larson, Saad Altaf, Eric Thorsland, Nick Talbert, Adam Wehe, Erin Cook, and Gautam Pakala. Photo submitted.

the more than 5,000 detector blocks for the EMCal. The two have overseen the day-to-day operations and coordinated the prototyping and materials acquisition for the project.

“My work with the sPHENIX project began in late 2014,” Thorsland says, “and as we wrap everything up now at the end of 2021, I can say, it has been quite the effort. There were early development and R&D challenges with several prototypes. I worked to develop a literal factory at the Nuclear Physics Lab, creating a process for manufacturing thousands of functioning calorimeter blocks. When Dr. Riedl came on board, we were fortunate to employ many students from UIUC and an excellent group of technicians recruited from the Parkland College Industrial Technology Program.”

The COVID-19 pandemic brought extra challenges to an already daunting production schedule, but Sickles, Riedl, and Thorsland made sure work moved forward with every safety measure in place to protect the team.

“Everyone worked extremely hard—even throughout the COVID lockdown—to keep the calorimeter production going,” notes Thorsland.

Sickles adds, “We were one of the first labs to open up after the COVID closures, having developed rigorous safety protocols. We have been working safely since May 2020 and have not had to close the lab for COVID infections at any time. Timeliness of production is very important to the progress of the experiment, and where many research projects slowed down during COVID, this team kept going.”

Each calorimeter block has been constructed from scratch by the group’s team of about 20 workers—technicians, undergraduate and graduate students, postdocs, and faculty. The blocks are made of tungsten, a heavy metal, with embedded scintillating fibers. NPL’s block-production protocol was developed and overseen by Thorsland. Once the blocks passed a rigorous inspection—high precision being essential to the successful operation of the new calorimeter—they were shipped to BNL to be assembled to sectors of the calorimeter.

Riedl notes, “We had in total 72 UIUC students working on this project, mostly undergraduates, though three were physics graduate students. Some stayed with us for more than 3 years. We could not have done it without them. It was not only their sheer number, it was also that a small hand-selected group was trained to take over the coordination of tasks.”

Thorsland sums up, “One of the best parts of the experience has been being able to work with such a dedicated group of students, technicians, grad students and researchers. It has made an exhausting effort enjoyable over the past six years. I’m looking forward to seeing the detector in its final form.” ■

The sPHENIX Experiment, operations at RHIC, and Brookhaven National Laboratory are supported by the U.S. Department of Energy’s Office of Science. Anne Sickles’ sPHENIX research is additionally funded by the National Science Foundation, under Grant No. 2111046. The findings presented are those of the researchers, and not necessarily those of the funding agencies.

From top right, clockwise: Illinois undergraduate student Mason Housenga demonstrates the quality-assurance data base, which logs more than 100 quantities for each EMCal block. Photo submitted.

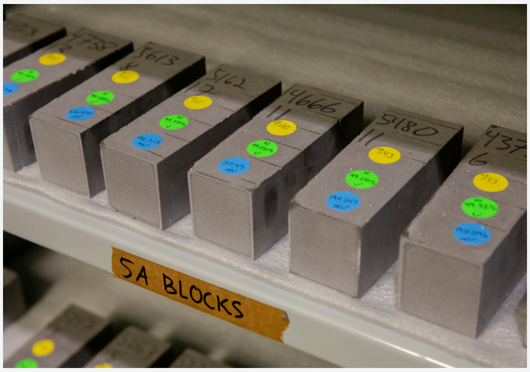
Illinois Physics undergraduate student Erin Cook wraps an EMCal block for shipment to BNL. Up to 72 blocks were shipped per week.

Illinois Physics undergraduate student Fyodor Dugger assembles an EMCal fiber set using six layers of photo-etched brass meshes.

Scintillating fibers are illuminated inside a tungsten block, which contain 2,668 fibers per block.

Boxes of fibers: about 45 blocks could be constructed from each.

EMCal blocks with quality tests completed are ready for shipment to BNL. Each block has a 4-digit unique identifier written on its surface. Photos by L. Brian Stauffer, University of Illinois Urbana-Champaign



THE LOOMIS CONFESSIONS

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

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

Professor Emeritus Mats Selen

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

If I have to pick something that I know I can actually do then I would probably be some sort of engineer, likely aerospace or marine. If I had to pick something totally different and be granted the luck and talent to make a living doing it, then this becomes a much harder question. When I was younger I wanted to be a photographer (still a hobby), and then a pilot (settled for RC planes), and then a farmer (which I was for several years when my family owned a sheep farm). I have worked as a machinist (loved it) and a truck driver (loved it). Like most people, in my youth I had had some jobs that I didn't exactly love but basically just liked enough to do for a while (bartender, pizza delivery, landscaping, newspaper delivery). To be honest, I think I could be happy doing just about anything so long as I liked the people I worked with.

What is your favorite place?

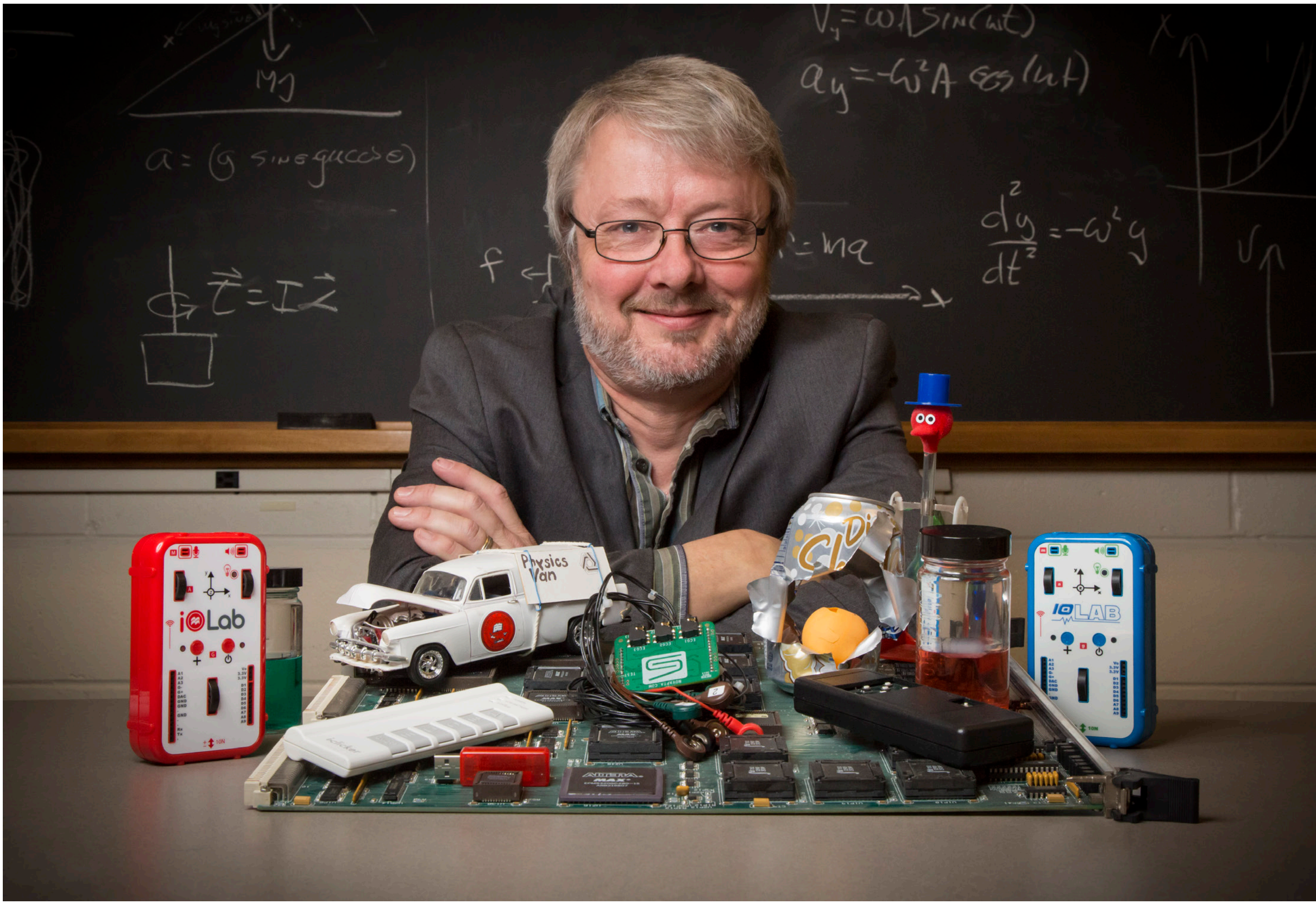
I love traveling but nothing beats coming home.

What is the greatest scientific blunder in history?

Hubris. The tendency of scientists to underestimate the intelligence of non-scientists. This is not a single catastrophic event but a continuing mistake which slowly erodes the trust that society has given us. We need to understand that we aren't smarter than everyone else, just luckier, and we need to do a better job engaging with the people whose taxes pay our salaries. I am extremely fortunate that communicating science has been encouraged and rewarded by the Department of Physics during my entire career at UIUC.

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

This is a really hard question. I love all art though I spend more time with books than with visual art and music, so I will focus this answer on literature. I think I could be totally content if I had the works of the following writers to keep me company (in each



Illinois Physics Professor Emeritus Mats Selen, local news station WCIA's original Why's Guy, founder of the Physics Van, inventor of the i>clicker and iOLab, former associate head for undergraduate programs, and 2016 Carnegie Foundation U.S. Professor of the Year. Photo by L. Brian Stauffer, University of Illinois Urbana-Champaign

case I list a great example of their work, though I love almost all of their books): Douglas Adams (*Hitchhiker's Guide* series), Frans Bengtsson (*Röde Orm*), Mikhail Bulgakov (*The Master and Margarita*), Charles Dickens (*David Copperfield*), Fyodor Dostoevsky (*The Idiot*), Umberto Eco (*Baudolino*), Astrid Lindgren (*Emil i Lönneberga*), Patrick O'Brian (the Aubrey–Maturin series), Thomas Pynchon (*Mason & Dixon*), John Steinbeck (*Cannery Row*), J.R.R. Tolkien (*The Hobbit*), David Foster Wallace (*Infinite Jest*), Bill Watterson (*Calvin and Hobbes*).

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

My father, Charles Darwin, Isaac Newton, Albert Einstein, Thomas Sowell, Elon Musk.

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

Self-serving politicians and ambulance-chasing lawyers.

What is your idea of happiness?

Road-trips with my wife, just winging it day by day, occasional inspirations from *Atlas Obscura*, with no details planned ahead.

What is your idea of misery?

Life without the people and things that I love.

What quality do you most admire in others?

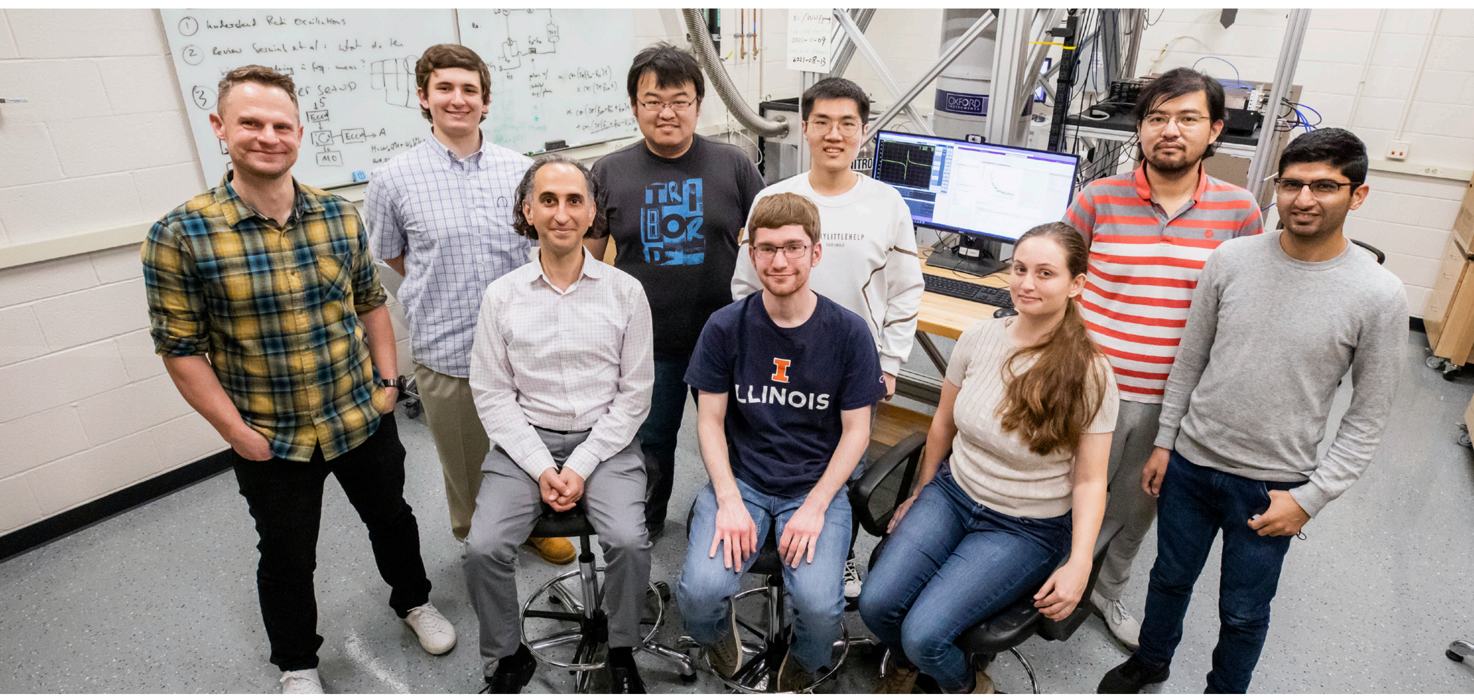
Honesty, intelligence, objectivity, integrity, humor, patriotism, work ethic, love of life.

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

What exactly is consciousness and how does it fit into the framework of science. ■

IQUIST testbed stands up quantum computing processors

Research and training initiative at IQUIST leads the broader campus, state, and national investments in growing a quantum research and development sector.



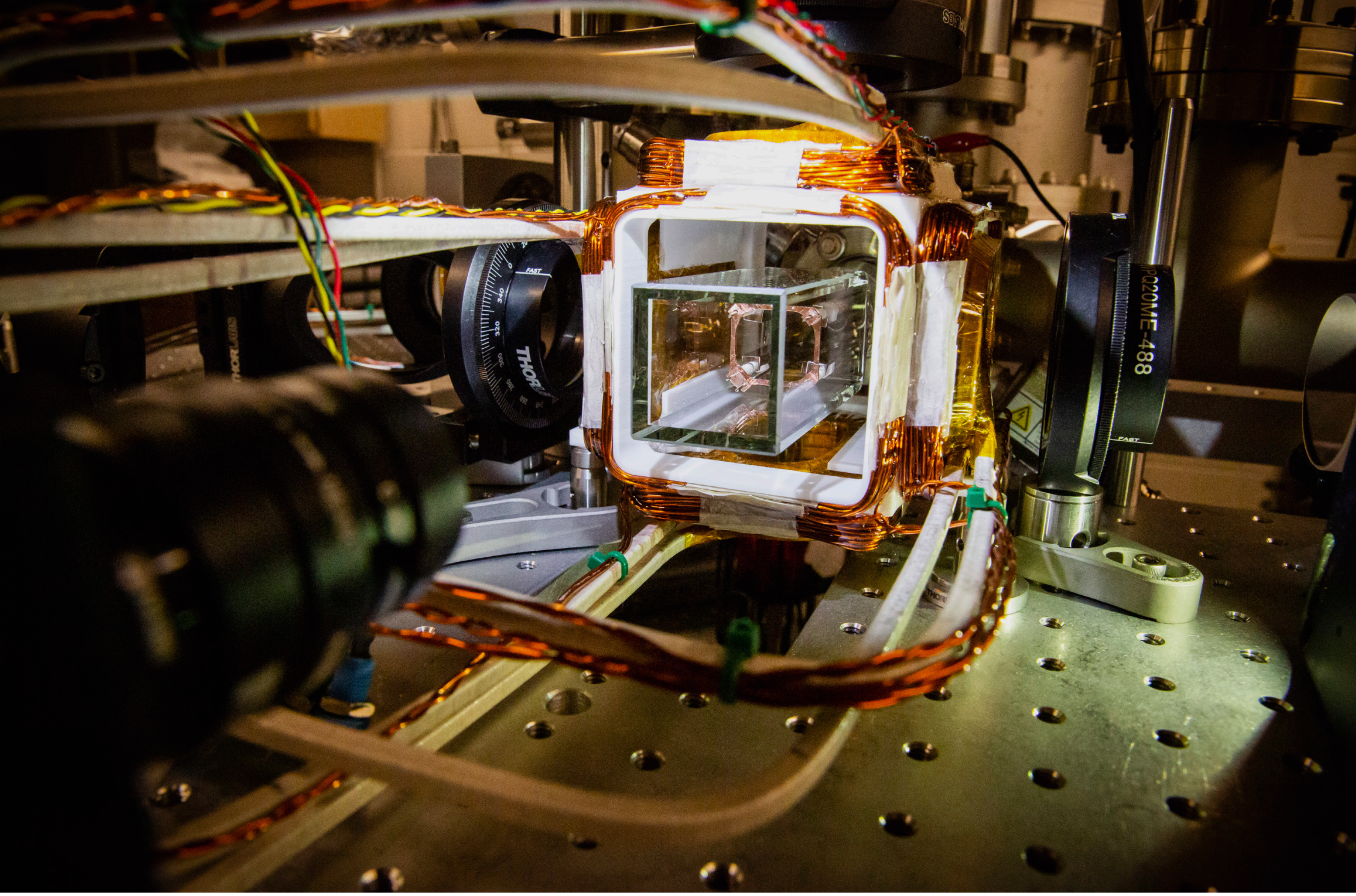
SIV SCHWINK
for Illinois Physics Condensate

At The Grainger College of Engineering's IQUIST quantum testbed, a collaboration of researchers is hard at work assembling quantum processors based on today's leading quantum bit (qubit) technologies—superconducting circuits and trapped atomic ions.

The state-of-the-art IQUIST quantum testbed is led by Illinois Physics Professors Wolfgang Pfaff and Brian DeMarco and will explore novel ways to hybridize quantum hardware and scale it to high performance systems.

IQUIST—the Illinois Quantum Information Science and Technology Center—was launched in 2018 to bring together the diverse expertise at UIUC needed to accelerate the development of quantum science and technologies, to train a quantum-ready workforce for the State of Illinois and the nation, and to build strategic partnerships with industry to develop a robust supply chain for emerging quantum technologies. Although quantum-computing research and development has a growing presence in industry, many open scientific and technological questions remain that are best solved by academic labs. The IQUIST quantum testbed is providing a venue for quantum experts to address problems collaboratively, and even to work with industry partners.

DeMarco comments, "The goal of the IQUIST testbed facility is to build and test small quantum processors for interdisciplinary research and education. We are planning activities that bring together researchers at all stages from



Above: Close-up of the trapped atomic ion quantum processor at the IQUIST testbed, part of the experiment led by Illinois Physics Professor Brian DeMarco. Photos by L. Brian Stauffer, University of Illinois Urbana-Champaign

Opposite page: Two teams of researchers at the IQUIST testbed pose for a photo in front of the superconducting quantum processor experiment. Pictured left to right, front row (seated) Illinois Physics Professor Brian DeMarco, graduate student Michael Mollenhauer, graduate student Mari Cieszynski; back row, Illinois Physics Professor Wolfgang Pfaff, graduate student Will Christopherson, postdoctoral researcher Xi Cao, graduate student David Ding, postdoctoral researcher Lintao Li, and graduate student Abdullah Irfan.

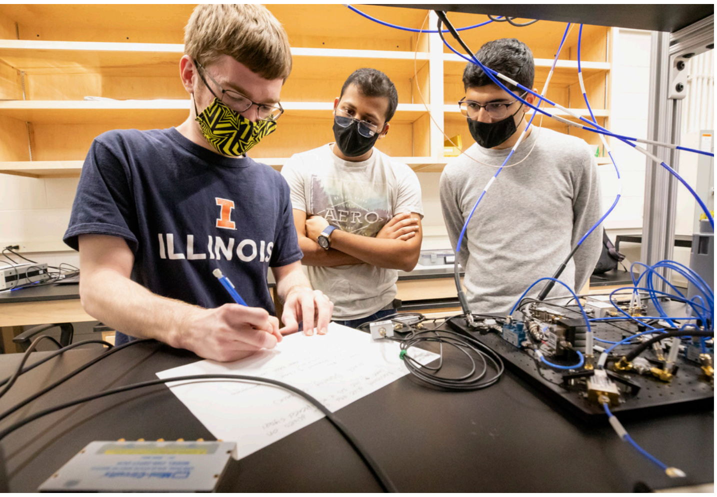
leading Illinois programs, including Computer Science, Electrical and Computer Engineering, Physics, Materials Science, Mathematics, and more."

The current plan is for students to access the IQUIST quantum testbed through quantum computing classes, where they write and run small quantum programs. IQUIST welcomes current and future industry partners to take advantage of the testbed once it's operational, to plug in devices they are developing.

That program will roll out over multiple years. But first, the teams must build and test the devices that exploit quantum mechanics to process information in new ways. At the heart of these processors are qubits (rather than bits) that can store information as a 0, a 1, or as a superposition of a 0 and a 1. Superposition, along with entanglement, are the quantum features that enable quantum computing to solve certain problems more efficiently than conventional high-performance computers.

The trapped-ion architecture is led by DeMarco, who is also the director of the National Science Foundation's Quantum Leap Challenge Institute for Hybrid Quantum Architectures and Networks (QLCI–HQAN), and, along with IBM project manager Kayla Lee, is co-lead of the quantum information thrust of the newly launched IBM–Illinois Discovery Accelerator Institute (IIDAI). DeMarco's team uses strontium atoms as qubits. A primary goal of the NSF QLCI HQAN research program is to investigate distributed quantum information processing architectures and protocols. These systems employ not just one kind of quantum hardware or qubit—instead quantum information is stored, manipulated, and processed using different modalities. Currently, the IQUIST quantum testbed researchers are focusing on trapped-ion and superconducting hardware as the first step.

DeMarco explains, “In trapped-ion quantum processors, an array of single atoms is suspended by electric fields inside a metal and glass enclosure that is evacuated to provide isolation from the environment. Each atom stores a qubit that can be used in a quantum calculation. An advantage of trapped ions compared with other technologies is the absence of manufacturing variations—every atom of a certain species and isotope is identical.”



(Top) Illinois Physics Professor Wolfgang Pfaff works with postdoctoral researcher Xi Cao (right) and graduate student David Ding at the IQUIST testbed.

(Bottom) Illinois graduate students Michael Mollenhauer (left) takes notes on the superconducting quantum processor, in conversation with Illinois Physics undergraduate student Shreyans Jain (center) and graduate student Abdulla Irfan, at the IQUIST testbed.

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

In trapped-ion systems, cutting-edge laser systems generate light that cools the ions and controls the state of each qubit. The information is read out by snapping a picture of the atoms using a camera that can detect single photons of light.

“Small quantum processors, or registers, will be formed by trapping groups of 5 to 10 atoms in separate regions of a chip trap,” DeMarco continues. “The chip is about one centimeter wide and fabricated using CMOS-technology processing techniques by collaborators at the Massachusetts Institute of Technology Lincoln Laboratory, a federally funded research and development center sponsored by the U.S. Department of Defense. The qubit registers are separated on the chip by 100 microns, which is about the diameter of a human hair.”

DeMarco says that the quantum algorithms that would normally be executed on a single processor are distributed across qubit registers through quantum entanglement.

“This distributed approach to quantum computing has barely been explored,” DeMarco adds. “Our goal is to understand how to develop new protocols for secure information transfer and processing and measure the potential advantage of this technique.”

In a separate room of the testbed laboratory, Pfaff is leading a team in the design, building, and testing of superconducting quantum circuits.

Pfaff explains, “The superconducting quantum circuits we are developing are oscillators that are similar to those used for Wi-Fi, resonating in frequency ranges of a few gigahertz. They are paired to a powerful tool condensed matter physicists use to study superconductivity called the Josephson junction.”

Superconductors are a promising material for developing quantum circuits because they carry current with zero resistance, meaning current can flow with no loss. Pfaff explains that the Josephson junction circuit is like a revolving door on a superconducting wire that allows researchers to impede and control the flow of electrons, allowing only one pair through at a time.

Pfaff continues, “The Josephson junction is the quantum element of our system. This component doesn’t exist in conventional electrical circuits, which are made up of a resistor, a capacitor, and an inductor.”

With the Josephson junction, researchers can build special circuits that mimic atoms having two distinct states that, similar to atomic qubits, store the qubit.

Continued on page 22. ▶

Notes from the IQUIST testbed's superconducting quantum processor team

ILLINOIS PHYSICS POSTDOCTORAL RESEARCHER XI CAO

"Working at the IQUIST testbed has been a great experience. I like that we can easily interact with people from other labs who have different backgrounds. It's exciting to be part of IQUIST's hybrid quantum research. I'm eager to learn all I can, even beyond the superconducting quantum circuits. As a new postdoc, I am also growing in this role, teaching and working with young students on a big project. This experience is invaluable for success as a postdoc—and maybe someday as a professor."

ILLINOIS PHYSICS GRADUATE STUDENT ÁLE BAPTISTA

"I always like to think of our work as a mom-and-pop shop that specializes in quantum information. The scale is small, but the attention to detail and autonomy makes the work feel more personal and rewarding. We are involved in a slew of technical areas from nanoscale fabrication to superconducting theory to best coding practices in Linux. I've even done some basic vacuum plumbing! It's satisfying to look at the broad suite of skills I have learned for the lab and exciting to see how much more I can learn. My focus has been in developing fabrication recipes for our samples. After working on a small part of industry-scale semiconductor manufacturing, it has been humbling and empowering to work on all aspects of manufacturing for our smaller operation. Working alongside other students to establish best practices and get our samples to work in our cryogenic setups can be challenging. But when it does work, the feelings of personal accomplishment and independence are unparalleled."

ILLINOIS PHYSICS GRADUATE STUDENT MICHAEL MOLLENHAUER

"While I have learned immensely about our strange quantum world in my quest to improve quantum information transfer, being in this lab has taught me there is more than just scientific knowledge to be gained from being an experimental physicist. Whether it's assembling a small power supply or going into the cleanroom to develop stripline resonators, knowing that all these things I make will become the foundation for my Ph.D. feels rewarding. Finally, being under the guidance of an excellent adviser and working with amazing lab mates has shown me what it means to be a better graduate student and researcher, and they have given me the motivation to help shape our lab into something incredible."

Notes from the IQUIST testbed's trapped atomic ion quantum processor team

ILLINOIS PHYSICS GRADUATE STUDENT WILL CHRISTOPHERSON

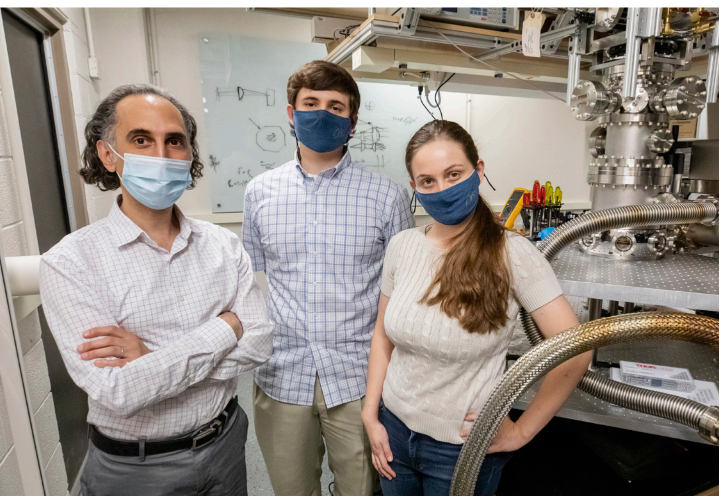
"My favorite aspect of working in the testbed is the variety of ways I can make progress: I can endlessly cycle through practicing hands-on skills with optics, signal processing and electronics, even bits of machining and plumbing. But I also have a laundry list of topics in theory, design, and communication to learn and practice, which helps immensely with handling roadblocks and avoiding burnout. One of my primary interests within the applications of science are those developments that allow for sharing experiences and that connect people whose struggles, ideas, and values otherwise go unheard. To this end, the broad and exciting prospects of QIS in communications and materials science make the skills I am developing at IQUIST priceless for the hopefully long journey I have ahead in R&D."

ILLINOIS PHYSICS GRADUATE STUDENT MARI CIESZYNSKI

"Building a quantum information experiment has been very rewarding for me. Over the course of this experiment, I have expanded my skill sets, knowledge, and interests while pursuing fascinating research goals. I think this experience will be a spectacular steppingstone for my future career: I am confident that I will leave with the knowledge and curiosity to kickstart a fruitful career."

Pfaff says one advantage of superconducting circuits in quantum computing is that they could be printed on chips in the same way that conventional computer microchips are fabricated, though they would be slightly larger. But one barrier is manufacturing chips that are identical, a key ingredient for scalable quantum computing. Because such precision is an unsolved problem, Pfaff's research project focuses on the development of innovative error-correction strategies that will mitigate minute differences in the chips.

"In quantum computing, the qubits have to be much more precise than in classical computing, with an error margin of no more than one in a million, if that," notes Pfaff. "So the big challenge is making chips that are within specification to that accuracy. My team will focus on strategies for how to assemble circuits to accommodate differences among qubits."



Top: Illinois Physics Professor Brian DeMarco meets with graduate students Will Christopherson (center) and Mari Cieszynski (right) at the IQUIST testbed.

Bottom: Christopherson and Cieszynski work on the trapped atomic ion quantum processor at the IQUIST testbed. Photos by L. Brian Stauffer, University of Illinois Urbana-Champaign

The scaling strategy that the UIUC team is pursuing hinges on communication between qubits that are not directly connected to each other, to the extent that they can be located on separate chips. Instead of performing a quantum computation by controlling how qubits interact with each other, the UIUC team will equip their qubits with a quantum communication link through signals that travel via transmission lines. In that way, qubits that may have been considered incompatible can still be used together if they can exchange signals.

DeMarco also stresses the importance of the scalability of the two experiments: "Our teams are pursuing a modular approach to quantum processing. This novel method for scaling to larger qubit counts and new applications mirrors modern high-performance computing architectures."

In addition to the two current experimental approaches, the IQUIST quantum testbed, located in the basement of the Engineering Sciences Building, has a control center that will be used for operating the testbeds. And it will eventually incorporate a multi-node cross-campus quantum network currently being developed by Physics Professor Paul Kwiat. IQUIST plans to eventually connect that quantum network to the Illinois Express Quantum Network (IEQNET) that spans the metropolitan Chicago area.

The IQUIST quantum testbed also houses a machine shop for the fabrication and design of mechanical and electronic components to support the experiments. According to DeMarco, the IQUIST testbed researchers have also been collaborating with companies locally, including Wagner Machine Company in Champaign, to complement in-house capabilities and help develop the national quantum supply chain.

IQUIST Executive Director Emily Edwards comments, "IQUIST's mission is to advance quantum science and technology through innovative, translational research and education. The quantum testbed exemplifies this, and we expect to grow the facility in size and capability in the coming years." ■

The IQUIST testbed is supported by IQUIST and by two National Quantum Initiative funded QIS Research Centers: the National Science Foundation's Quantum Leap Challenge Institute for Hybrid Quantum Architectures and Networks (QLCI–HQAN), under grant no. 2016136; and the U.S. Department of Energy's Next Generation Quantum Science and Engineering (Q-NEXT) center at Argonne National Laboratory, grant no. 9J60012. Pfaff's research is also funded by the newly launched IBM–Illinois Discovery Accelerator Institute (IIDAI). The findings presented are those of the researchers and not necessarily those of the funding agencies.

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

ILLINOIS PHYSICS Time Dilation

New model accurately describes COVID-19 waves and plateaus: adding random nature of social activity to traditional model, graphs match waves and plateaus of regional U.S. data.

SIV SCHWINK *for Illinois Physics*

Dec 14—A team of scientists has developed an epidemiological model that encompasses the randomness and dynamic variability of individual social interactions, as well as individual differences in the size of social networks. The new model shows COVID-19 will be endemic, sticking around like the flu and the common cold.

Elizabeth Goldschmidt: creating quantum memories

LEAH HESLA *for Q-NEXT*

Dec 2—In their quest to make the perfect qubit for storage, Professor Elizabeth Goldschmidt and her team are identifying and growing new kinds of crystals containing different rare-earth atoms, tracking how they respond to the passage of photons, assessing their memory-storage capabilities, and improving them. This story was first published on the Q-NEXT website at https://www.q-next.org/.

Limitless: Celebrating women in science and condensed matter physics

DANIEL INAFUKU *for Illinois Physics*

Nov 23—Limitless, a mural designed by celebrated artist Amanda Phingbodhipakkiya and painted with the help of local high school students, is inspired by Illinois Physics Professor Nadya Mason. The work is part of a series titled FINDINGS, created in partnership with the Heising–Simons Foundation (HSF). The series celebrates the contributions of women in science and examines the convergence of identity and community through a fusion of artistic and scientific lenses.

Self-annealing photon detector brings global quantum internet one step closer to feasibility

SIV SCHWINK *for Illinois Physics*

Oct 13—A quantum communications experiment was launched into low orbit around Earth from the International Space Station (ISS). CAPSat (Cool Annealing Payload Satellite) contains single-photon detectors, which can be used as receivers for unhackable quantum communications. The experiment is a collaboration of the University of Illinois Urbana-Champaign and the University of Waterloo.

University of Illinois researchers part of $15M institute developing real-time artificial intelligence to accelerate discovery in data-driven science

Illinois Physics

Sept 28—The National Science Foundation (NSF) announced its launch of the $15M Accelerated AI Algorithms for Data-Driven Discovery (A3D3) Institute, as part of its $75M investment in five new Harnessing the Data Revolution Institutes across the U.S. The primary mission of the A3D3 Institute is to lead a paradigm shift in the application of real-time artificial intelligence at scale to advance scientific knowledge and accelerate discovery.

ICASU researchers awarded $4.4 million for cyberinfrastructure to solve long-standing problems in fundamental physics

JESSICA RALEY *for ICASU*

Sept 17—Three Illinois Physics and Illinois Center for Advanced Studies of the Universe (ICASU) professors lead a team of researchers who recently received a $4.4 million grant from the Office of Cyberinfrastructure for Sustained Scientific Innovation (CSSI) of the National Science Foundation (NSF). The Modular Unified Solver of the Equation of State, or MUSES, will provide scientists with an open-source cyberinfrastructure that can be used to generate equations of state (EoS). The new cyberinfrastructure will provide novel tools for answering interdisciplinary questions in nuclear physics, gravitational wave astrophysics, and heavy-ion physics.

FUTURE-MINDS-QB to increase participation from underrepresented groups in biomedical data science and quantitative biology

SIV SCHWINK *for Illinois Physics*

July 8—FUTURE-MINDS-QB, a bridge program streamlining a path from a master's degree at Fisk University, a historically Black university in Nashville, to a doctoral degree at University of Illinois Urbana-Champaign, has received a T32 training grant from the National Institute of General Medical Sciences (NIGMS) of the National Institutes of Health (NIH).

KRISTEN SCHUMACHER

SHARING THE BIG, OPEN PHYSICS QUESTIONS

NSF Graduate Research Fellow Kristen Schumacher founded POINT, an outreach program for high schoolers that will use virtual reality to teach about general relativity, the fabric of space-time, and gravitational waves. She hopes her efforts will inspire curiosity about fundamental science and nudge young people to consider pursuing a degree in physics.

JESSICA RALEY
for Illinois Physics Condensate

Illinois Physics graduate student and National Science Foundation Graduate Research Fellow Kristen Schumacher did not grow up gazing at the stars and dreaming of unlocking their mysteries. She didn't spend her free time taking her toys apart to see how they worked. She liked math and solving puzzles, but she didn't know she wanted to be a physicist when she grew up. In fact, she didn't know that was an option.

Schumacher came to physics purely by chance. In high school, she was placed in *AP Physics* instead of *AP Biology* because of a scheduling error. She stayed in the class and—to her surprise—she loved it.

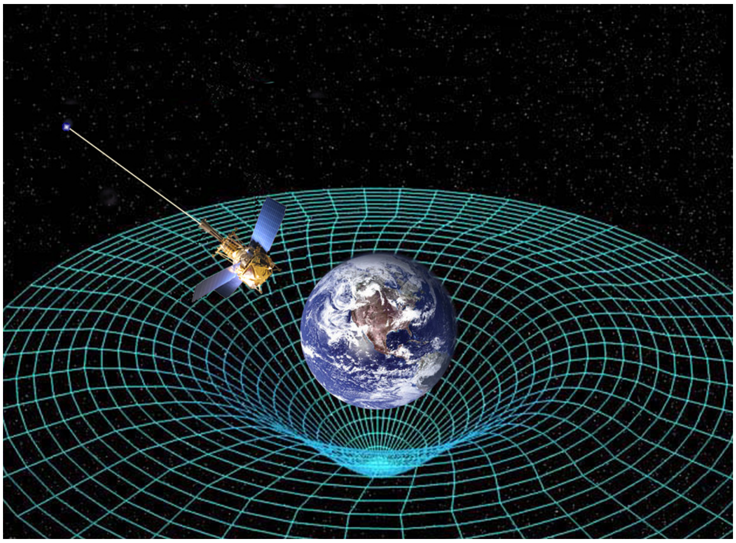
"I never would have discovered physics if I hadn't accidentally taken that class in high school," Schumacher says. "When I went to college, I signed up for a seminar called 'Origins of the Universe.' We read Stephen Hawking's *A Brief History of Time* and we discussed big, open questions about the universe. That's when I decided to major in physics. But I don't think I would have signed up for the seminar if I hadn't taken that AP class."

While Schumacher serendipitously landed in the wrong class at the right time, she worries about the students who might never consider a career in physics because they aren't exposed to those big, open questions.

"If we want students to be interested in physics, we need to talk about the cutting-edge research and the open questions, because that's what's really exciting about it. Students shouldn't have to wait for a college seminar to be exposed to the big ideas in physics today. We should teach that from a young age," Schumacher says.

Now a graduate student in Illinois Physics Professor Nicolas Yunes's group, Schumacher studies Einstein's theory of general relativity (GR), as well as experimental tests of modified theories of gravity.

Artist concept of Gravity Probe B orbiting Earth to measure space-time, a four-dimensional description of the universe including height, width, length, and time. Credit: NASA



“Even though Einstein’s theory has been incredibly successful—it has passed every test we have devised so far—there are good reasons to think it’s incomplete. Just as general relativity was an extension of Newtonian gravity, an extension to general relativity might be needed to make it compatible with quantum mechanics,” Schumacher explains.

One way to modify gravity is to remove one of the underlying assumptions of the theory. In particular, Einstein’s theory says that gravity is Lorentz invariant, which means that the outcome of an experiment is the same regardless of the frame of reference. The specific theory Schumacher studies—Einstein-æther theory—breaks Lorentz invariance.

Schumacher explains, “Einstein-æther theory is a very general Lorentz-invariant theory of gravity, which makes it a good candidate to test GR. In my research, I use experimental data from LIGO to search for signatures of Einstein-æther theory in gravitational waves.

“When people ask me what I study, it can be hard to explain. A lot of people don’t really understand general relativity. So, if I say, ‘I’m studying theories beyond general relativity,’ that doesn’t mean anything. You have to be able to conceptualize general relativity first.”

This realization became the inspiration for a new outreach program called Physics Outreach at Illinois through New Technologies (POINT). Schumacher plans to use virtual reality (VR) to help middle school and high school students engage with GR and gravitational waves.

“With VR, we could teach students in an immersive and interactive way how objects curve space-time and how other objects move in response to that curvature.”

Schumacher couldn’t find an existing VR simulation addressing specifically the curvature of space-time, so she and a team of volunteers are creating a new VR experience to fill that gap.

“Our plan is to simulate the fabric of space-time by creating a grid that warps around objects,” she says. “Students will be able to play with objects of different masses to experience how they affect space-time differently. Once students understand space-time as a fabric, they can start to understand gravitational waves as ripples in that fabric.”

The work Schumacher is doing—in research and in outreach—is funded through a National Science Foundation Graduate Research fellowship, which she received in the spring of 2021. The award provides funding for three years, during which time Schumacher will not have teaching responsibilities. Still, Schumacher says she would not be able to do the project all on her own. She is building a team of volunteers with interests in physics education, VR, or coding.

“This is a big project, and we need people with a lot of different skill sets. Some of our volunteers are interested in working directly with students. Others want to learn to code in Unity. Work is already underway, but we welcome anyone who is interested to reach out via email.” ■

Schumacher’s project is funded by the National Science Foundation National Science Foundation Graduate Research Fellowship Program under Grant No. DGE–1746047. If you’d like to help Schumacher and her growing team with her GR and gravitational waves outreach project employing VR, the POINT organizers can be reached at phys-pointvr@illinois.edu.

JOHN VEYSEY

FLUENT ACROSS THE SCIENCES

Illinois Physics alumnus and National Science Board Executive Officer John Veysey, on how his graduate student experiences prepared him to communicate in service of science.

KARMELA PADAVIC-CALLAGHAN
for Illinois Physics

John Veysey is an integrator. In his role as the executive officer and office director for the National Science Board (NSB), the governing board for the National Science Foundation (NSF), Veysey is constantly absorbing, sifting through, and interweaving a broad range of new information from diverse scientific disciplines—opinion, scientific research findings, and science policy. This is not new for Veysey–he has always enjoyed traversing the boundaries between different fields, even going back to his time as a physics doctoral student at Illinois. Fifteen years ago, he was wrapping up a dissertation that combined insights from microbial ecology, fluid mechanics, geochemistry, and fieldwork he had done at Yellowstone National Park. Now, collaborating with experts covering an even broader and more diverse range of disciplines is a key part of the work he does every day.

The National Science Board that Veysey supports comprises 24 presidential appointees and the NSF Director. Collectively, the board members represent all areas of science and all regions of the country. The board has advisory responsibilities to Congress and to the U.S. President and governance responsibilities to the Foundation. Veysey, who regularly holds conversations with scientists of all backgrounds, points out that each field brings its own set of concerns and its own lexicon to the table. He has to be conversant across the sciences.

A dissertation that transcended

“Having done interdisciplinary research I think really prepared me to be able to talk to people across disciplinary boundaries and do some of that integration of viewpoints, which is just so important for what I do at NSF,” Veysey underscores. “Cultures talk in different ways, and that experience really has helped me at NSF where I’m working in a position that touches on all the directorates and divisions.”

Photo spread, left to right: John Veysey stands by a sign pointing the way to the travertine terraces of the Mammoth Hot Springs, when he was an Illinois Physics Ph.D. student.

Veysey (right) and his doctoral advisor Illinois Physics Professor Nigel Goldenfeld climb the stairs to a wooden boardwalk at the terraces.

The research team left to right: Thomas Schickel, Illinois Geology Professor Bruce Fouke, Kelly Zimmerman, Veysey, and Goldenfeld.

Veysey and Schickel measure Ph in the hotsprings. Photos submitted.

As Veysey wrote in his doctoral thesis, his work as a researcher included everything from running Monte Carlo simulations on a computer to traipsing around hot springs with pH probes in the middle of the night. Ultimately, this interdisciplinary approach proved that microbes are not the only important ingredient for the formation of the striking large-scale carbonate terraces at Yellowstone.

“The microbes speed up the process about fivefold, which is arguably important--if not to a geologist. But it will happen either way,” Veysey notes.

Studying these terraces was a rich problem, a problem that required speaking the language of more than one science, and a problem that could really require getting one’s hands dirty. Veysey loved it.

“It was really eye-opening for me,” he says of translating some of the more abstract mathematical work Illinois Physics Professor Nigel Goldenfeld’s group is known for to the very real world of Yellowstone. “I was hooked. I was drawn to science and to physics in particular because I wanted to understand how the world works, and understanding comes in the form of predictions and descriptions and equations.“ At Illinois, he also collaborated with Bruce Fouke, a professor of geology and microbiology.

Even while he was performing the research, Veysey was aware that getting at the answer to some scientific questions requires stepping over the lines that separate different disciplines. Comparing the content of his discoveries to the mode of work that produced them in his thesis, he said so himself. “I view the fundamentally interdisciplinary nature of this work as a harder and more important achievement,” he wrote.

Years spent in Washington, D.C., pursuing a career in policy rather than researching the physics of complex systems have not changed his mind one bit.

"As a graduate student, I got to work with people in different departments and at different universities. This taught me that I like working with people and using information to solve problems—and that's what I see as a common thread in what I do now. The information changes, the problems change—the nature of the current problems is very different. But I'm still working with people, they're still working with people in teams, analyzing complex information and applying it to shed new light on those problems.

"Having done interdisciplinary research I think really prepared me to be able to talk to people across disciplinary boundaries and do some of that integration of viewpoints, which is just so important for what I do at NSF."

Communicating science in service of society

Veysey also recognizes the value of the early training he got in communicating science in a clear and compelling way, regardless of his audience's foundational knowledge. While a Ph.D. candidate at Illinois, he was awarded a Mass Media Science & Engineering Fellowship by the American Association for the Advancement of Science (AAAS). He spent three months writing for the Milwaukee Journal Sentinel as a science reporter. In this work, he had to bridge a sizable gap: the highly specialized scientific knowledge and interests he had gained as a physics Ph.D. student often proved to be very different from the more accessible, practical knowledge that the general public seemed to care about. Veysey's Journal Sentinel articles that made the greatest impact were not always those that would have garnered the most excitement had he presented them to a group of academic physicists. He recalls one of his stories on the topic of tornadoes having been especially well received.

"The amount of feedback I got back from the article really showed me that writers can have an impact," he remembers. "But at the same time, this work had nothing to do with my hard-earned scientific expertise, so I started to wonder if there was a way to have an influence on broader society with scientific expertise."

After completing his fellowship at the Milwaukee Journal Sentinel, Veysey served as a TA for Illinois Physics Professor Fred Lamb in his long-running Nuclear Weapons, Nuclear War, and Arms Control course.

Veysey recalls, "I found that a valuable experience. That course is a special offering at UIUC, combining physics, policy, and writing."

Following the end of his Ph.D. program in 2006 and a short stint as a postdoctoral researcher at the UIUC Department of Microbiology, that desire to engage on the topic of science with broader society, beyond academic research communities, led Veysey to the AIP (American Institute of Physics)/AAAS Congressional Science & Engineering Fellowship program. Here, Veysey was met with just the kind of challenge he had hoped for: the chance to use his scientific expertise to help policymakers in Washington, D.C. Consequently, he never left.

As a fellow, Veysey assisted Senator Bob Menendez from New Jersey with policy work on climate change as it related to energy production and agriculture. After the fellowship ended, Veysey went on to work with former Congressman Dan Lipinski of Illinois, then Chair of the House Science, Space, and Technology Committee's Subcommittee on Research and Education, as a science staffer. He wrote speeches, wrote legislation, dealt with stakeholders and constituents, and helped prepare the congressman for hearings. In this work, the critical thinking and analytical skills he learned as a student, the problem-solving abilities he gained as a researcher, and the ability to communicate complex information that he honed by science reporting all got put to work at once. Later, he took this same set of tools to the NSF.

Thinking broadly and thinking ahead

Today, in his work with the NSB, Veysey is continuallly challenged to think about science not only broadly, but strategically, with great enthusiasm for future developments. In the past year, the board released the NSB's Vision 2030 report assessing some of the trends driving science and engineering right now and offering a roadmap for the coming decade's science and technology policy, all deeply informed by challenges and opportunities that are on the horizon.

Veysey is optimistic. "It's something I'm proud of and the board is proud of," he shares. "And it's off to a very good start."

The Senate-passed Endless Frontier Act and the House-passed NSF For the Future Act, two bipartisan bills that will set funding levels and authorize new NSF activities, further gives Veysey hope for realizing the 10-year plan he and the board laid out. These bills are headed to conference in early December.

"What excites me is that [Congress and the Biden administration] is responding to some of the same challenges and opportunities the board identifies in its Vision Report and are attempting to position the country to seize the opportunity to meet these challenges."

The part of the Vision Report he particularly wants to highlight? Evaluating the broader impacts criterion in the merit review process for NSF research funding.

"How is the research that NSF is funding benefiting Americans and people globally?" He asks, then immediately goes on to break it down, as a scientist does when faced with a complex problem.

John Veysey (front row, far right) stands with members of the National Science Board (NSB) and the President's Council of Advisors on Science and Technology (PCAST) under the Trump administration, in the Eisenhower Executive Office Building in Washington, D.C. Pictured are (front row, left to right) Julia Phillips (NSB), Geri Richmond (NSB), Diane Souvaine (then NSB chair), Kelvin Droegemeier (then director of the White House's Office of Science and Technology Policy, PCAST chair), Catherine Bessant (PCAST), and John Veysey; (Row 2) Sethuraman Panchanathan (now National Science Foundation director, then NSB), K. Birgitta Whaley (PCAST), France Córdova (former NSF director and NSB); (Row 3) John Anderson (NSB, now president National Academy of Engineering), Shannon D. Blunt (NSB), Roger Beachy (NSB), Anneila Sargent (NSB); (Row 4) Maureen Condic (NSB), Suresh Garimella (NSB), Arthur "Artie" Bienenstock (NSB), Maria Zuber (NSB, now chair of PCAST); (Row 5) Dan Reed (NSB), Steven Leath (NSB), Bob Groves (NSB), Dorota Grejner-Brzezinska (NSB), Ellen Ochoa (then NSB vice-chair, now chair); (Row 6) Shane Wall (PCAST), Sharon Hrynkow (PCAST), Vicki Chandler (NSB), A.N. Sreeram (PCAST); (Row 7) G.P. "Bud" Peterson (NSB), Victor "Vic" McCrary (now NSB Vice-Chair), W. Carl Lineberger (NSB), Ed McGinnis (PCAST executive director). Photo submitted

"One is competitiveness–how is the funded research contributing to the economy? And the other is broadening participation—how are we developing the workforce, including full representation of women and underrepresented minorities?"

Future science by and for everybody

Veysey approaches the future of science and technology in the U.S.—a complicated, multi-layered issue—with the full belief that, as such, it will not yield to a single approach or a single group of people. As has been the case throughout his career, Veysey is interested in facilitating conversations between disciplines and communities and combining their most valuable tools. His experience working on teams of experts who have mastery of distinct languages within science and technology has taught him that the return on investment into scientific research does not stop with the work that scientists produce while funded by the NSF. He explains, part of the benefit of investing in fundamental research comes from the eventual development of patents and commercial enterprises and teaching students.

"The benefit to society of NSF research funding also takes the form of people who can carry out commercialization, which really happens when you have researchers who are passionate, who get it done, researchers who wants to try to start a company, whatever that is," he asserts. "We cannot neglect the domestic workforce and the people who haven't had the opportunity to be part of the STEM workforce of our country. And whether that's because they're from parts of the country that don't have opportunities or it's because they're from underrepresented groups and also don't have opportunities are different problems—but we need those people in our workforce."

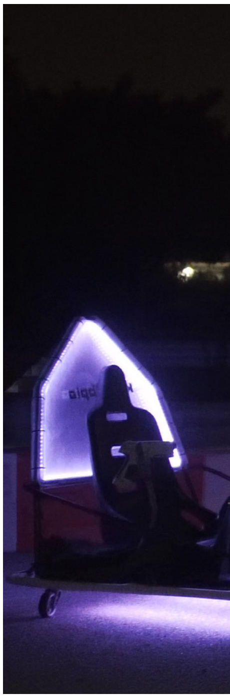
And as he hopes more people, and more different people, will be brought into the fold of science in the future, Veysey himself is still itching to expand the number of scientific languages he speaks and to integrate more academic tools into his policy-and-advocacy kit.

"I fully recognize that there are many intellectual tools I don't have, because I don't have a formal education in public policy. Now, I'm always grasping at the offerings," he admits.

In many ways, throughout his success in the science policy world, Veysey has continued to carry the sentiment that first drew him to Illinois as a young physicist.

"You have a certain breadth of intellectual exposure in your first year there," he remembers with appreciation. "This is enormously helpful in relating to people across disciplines." ■

SCOTT SCHARFENBERG



JESSICA RALEY

for Illinois Physics Condensate

Illinois Physics alumnus Scott Scharfenberg has driven his career path in a homemade RV—with side trips in a laser-tag go-kart. Now a microscopy physicist at Quantum Design (QD) in San Diego, Scharfenberg graduated from the University of Illinois Urbana-Champaign in 2010 and stayed on to earn a master's degree in physics in 2012.

During his time at Illinois Physics, Scharfenberg worked in Illinois Physics Professor Nadya Mason's lab, where he used atomic force microscopy (AFM) to study the mechanical properties of graphene. Today, he uses the same AFM skills he developed as a student in his work at QD, a company that manufactures scientific instruments for research institutions. His current project is building a system that incorporates an atomic force microscope within a scanning electron microscope.

Scharfenberg says, "I work on prototyping and testing. So, it's my job to make sure the thing we're building is actually a good instrument. I make sure we're meeting all requirements and that the instrument works as well as it possibly can."

In addition to his AFM knowledge and skills, Scharfenberg says the most important things he learned as a physics major are how to solve problems and how to learn.

"Working in research and development, every day is a little different, but it's all problem solving. I come in, I figure out what's not working, and I try to make it work," says Scharfenberg.

Scharfenberg remembers, "I developed a habit of asking, 'How do I prove that this is going to work? How do I test this?' I try to approach everything that way."

Before landing his current position at QD in 2019, Scharfenberg worked for Asylum Research in Santa Barbara, first as a test engineer and later as a consultant.

"That was a great experience," he recalls. "I got to be really hands-on at work and also filled in some gaps in my knowledge. I had a lot of training in physics, but I didn't take full advantage of the engineering learning opportunities at U of I. So, the job at Asylum really helped me fill in my electrical engineering and software engineering experience."

Motivated by the high rent prices in Santa Barbara, Scharfenberg decided to put his skills to work converting a wheelchair-accessible bus into a custom RV.

"I had lived in Illinois my whole life, so I had sticker shock when I moved out to Santa Barbara and rented a place," he says. "I was paying $600 a month to share a bedroom. So, I bought my bus and spent the next year and a half or so customizing it. I ended up living in it for a few years."

Free from the burden of paying rent, Scharfenberg took some time to explore other passions. He left his position at Asylum in part so he could spend time traveling. When Asylum offered him a job doing part-time consulting, it seemed like an ideal fit. The new consulting job offered Scharfenberg the opportunity to travel around the world training clients on AFM technology and conducting field repairs on equipment.

"I got to spend a month in China and a week in South Korea," he says. "I went to Colombia for a while. And because it was part time, I was also able to spend a lot of time rock climbing, which was important to me."

His part-time work schedule and rent-free housing also afforded Scharfenberg the freedom to become cofounder of a startup company called Kartopia. "The aim of the company is to bring the experience of a video game to real life. Imagine electric go-karts with laser tag built into them," Scharfenberg says.

Scharfenberg and his cofounders have created four prototypes so far and a test track in Corning, CA.

"The go-karts have position trackers, so the game system knows where you are on the track. And we can set it up so that if you drive through a certain zone, you get a pickup, like extra ammo or a speed boost. If your kart gets shot, it dies, just like in a video game."

Although the COVID19 pandemic slowed their progress, the Kartopia team members look forward to taking the next step with their company.

"Once we're able to safely start bringing people together again, we'll be able to have people come demo the track and the karts. We'll need to start attracting some investors to get the company off the ground," notes Scharfenberg.

Although Scharfenberg is back to working full time–and paying rent–he plans to continue his work with Kartopia. He says he values the creative outlet it provides.

"I always liked physics and always thought of myself as a creative person, but I haven't always been good at finding the connection between those two things," he says. "Working with this startup allows me to do that. " ■

REDUCING A UNIVERSITY'S HELIUM FOOTPRINT

Loomis Lab's Liquid Helium Facility team's recycling efforts conserve a precious resource while supporting leading-edge research

Opposite page: The Illinois Physics Liquid Helium Facility team poses for a photo in the main facility on the first floor of Loomis Lab. Pictured left to right are cryogenics technician Kelly Sturdyvin, research engineer Eric Thorsland, cryogenics programmer Nikki Colton, and Illinois Physics undergraduate Anna Przybyl.

Right: Illinois Physics Professor Jeff Filippini stands in front of SPIDER, a balloon-borne cosmic microwave background (CMB) telescope, and on the launch pad at McMurdo Station, Antarctica. SPIDER is a cryogenic payload filled with over 1,000 liters of liquid helium. Credit: SPIDER Collaboration

JENNIE Z. ROSE
for Illinois Physics Condensate

Illinois Physics Professor Jeff Filippini and his research group in the Loomis Laboratory of Physics develop astronomical instruments that observe faint light from the early universe. The instruments are mounted to massive helium balloons and launched from Antarctica. His team uses the observations collected in this way to shed new light on the universe's history and the fundamental physics at work within it.

"Our observations are made at millimeter and sub-millimeter wavelengths—in between traditional radio astronomy and infrared astronomy," Filippini explains.

The work in Filippini's lab needs very cold temperatures that can be achieved only using liquid helium.

"This work requires sensitive superconducting detectors, cooled to a fraction of a degree above absolute zero, to reduce instrument noise," he says. "Most of our instruments are launched on stratospheric balloons, where a heavy, power-hungry mechanical cooler is impractical. We use liquid helium to cool our balloon-borne instruments. We use smaller laboratory cryostats for pre-flight testing and technology development."

Filippini's team—like many other research groups on campus—orders liquid helium from the Helium Liquefier Facility on the first floor of Loomis Lab. Built in 1958 to support expanding research efforts in what was then called solid state physics—now known as condensed matter physics—the liquefier has since expanded its client base to include researchers across the sciences on the UIUC campus. Liquid helium has also become essential to chemical and biomedical sciences, as a cooling agent for superconducting magnets in magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) spectroscopy.

Filippini points out that in recent years, some applications requiring helium cryogenics have transitioned to mechanical cryocoolers having a closed-circuit configuration using high-pressure gas. But liquid helium is still irreplaceable in many applications, where the complexity, mass, vibration, and electrical-power needs of a cryocooler are impractical.

Filippini doesn't take for granted the access his lab has to this critical resource.

"Helium is an irreplaceable and non-renewable resource," he comments. "We obtain helium as a byproduct of drilling for natural gas. It slowly accumulates in porous rock formations over geological time scales as a byproduct of radioactive decay. Once released to the air, however, helium escapes to space—we don't get it back. It's imperative that we steward our supply carefully."

The flow of liquid helium out of the liquefier plant was interrupted during the last global helium shortage in 2012 and 2013. Massive price hikes and delivery delays threatened research progress. as many UIUC researchers were faced with what some referred to as a "trilemma": pay high prices, shut down facilities temporarily, or find a substitute for helium. Research budgets were strained to cover increased costs, if helium could be delivered at all.

At that time, Illinois Physics researchers were recycling about half the helium being ordered in-house, thanks to a recovery pipeline system that had been installed throughout the Frederick Seitz Materials Research Laboratory and Loomis Lab in 2007. But the pressure was on to do better. Jerry Cook, then the facilities manager at Loomis Lab who oversaw operations at the liquefier plant, reached

Left: Illinois Physics research engineer Eric Thorsland checks on the compressors installed in the basement of Loomis Lab.

Below: Illinois Physics cryogenics programmer Nikki Colton watches as undergraduate student worker Anna Przybyl solders.

Opposite page, left: Illinois Physics graduate student Rong Nie stings a helium dewar in the Filippini lab.

Opposite page right: Illinois Physics cryogenics technician Kelly Sturdyvin works on the machinery in the liquefier plant. Photos by L. Brian Stauffer, University of Illinois Urbana-Champaign

out to other universities having liquefiers, to get help improving the UIUC plant's recycling and efficiency.

In 2014, the Helium Liquefier team was given the go-ahead to extend recycling efforts to buildings beyond Loomis Lab, under the supervision of Illinois Physics research engineer Eric Thorsland. Now, a helium return pipeline runs from both the Nuclear Physics Laboratory (NPL) and the Chemistry and Life Sciences Laboratory (CLSL) to the liquefier plant. A recovery system to handle the increased recycling load was installed in the basement of Loomis.

Before this effort, Thorsland had already installed a basic, stand-alone helium recycling system at NPL, under his own initiative.

Thorsland notes, "The inspiration to build the NPL stand-alone system came from need and from the reality that we were letting all the helium used at NPL into the atmosphere, and it was unrecoverable. This was not acceptable to me, and I wanted to recover the helium gas for sustainability reasons as well as to be eligible for the recovery credit given to labs already on the system in Loomis."

It wasn't long afterward that then–Head of Department and Professor Dale Van Harlingen tapped Thorsland to begin the multi-phase process of expanding the Loomis Lab recovery system beyond the Physics complex.

Thorsland worked with a team of facilities staff and faculty to plan, design and execute the project. In 2017, 1750 feet of long underground recovery line was run to CLSL. A team at Illinois Chemistry worked to connect its three facilities, while Thorsland worked with Illinois Chemistry Professor Dean Olsen—who uses helium for his own research—on the main collection system in CLSL. Another 10,000 feet of underground small-bore medium pressure line was installed through the steam distribution tunnels under Green Street and Goodwin Avenue in 2020, connecting the pipeline to NPL.

In 2017, Illinois Physics cryogenics programmer Nikki Colton, an alumna of the department who began working at the liquefier as a student worker, started installing a digital helium-recovery monitoring system, instrumenting diaphragm gas meters with credit-card-sized Raspberry Pi computers to collect data. This effort increased the efficiency of the total system by identifying the location of leaks, which were quickly repaired.

Since that time, Colton has worked with Thorsland to continually refine the helium-recovery monitoring system, installing Raspberry Pis on humidity sensors and rewriting the computer programs, originally written in LabVIEW code, in Python. Colton worked with Illinois Physics undergraduate student Anna Przybyl, a student worker in the liquefier plant, to develop the new code.

Thorsland notes, "The addition of Nikki Colton to the team and her work on adding electronic monitoring of the recovery metering system for data collection has been a major tool in improving the recovery rate. We have real-time data on gas flow, humidity, and pressure in the system, and this has helped significantly in our ability to quickly troubleshoot loss and contamination and to swiftly


take action. Nikki's help in mentoring our student workers and her effort to document the recovery system have been a key part of the operation and contributed to our ability to make the system sustainable."

More efficiencies in helium production and recycling have been introduced through maintenance and upgrades to the plant itself. Most recently, these have been under the direction of cryogenics technician Kelly Sturdyvin, who took over day-to-day operations in the plant in 2019. Sturdyvin's mechanical intuition—as he calls it, "keeping an ear for the liquifier machine"—keeps the Liquid Helium Facility's cryogenic compressors and operations running optimally, with outputs above manufacturer's recommendations. Sturdyvin says the ongoing rapport with technicians and engineers at other liquefier plants using recovery systems has been critical to his success.

The liquefier team has been supported in their stewarding efforts by a faculty-staff task force appointed in 2019 by Illinois Physics Head and Professor Matthias Grosse Perdekamp. The task force—initially led by Illinois Physics Professor Liang Yang and including Filippini and Illinois Physics Professor Vidya Madhavan, Cook (then the facilities manager), Sturdyvin (then the assistant facilities manager), Thorsland, and Illinois Physics business manager Steve Knell—reviewed many years of budget details and consulted with representatives of comparable liquefier plants at several other universities to make recommendations to the department, including increased staffing, hardware upgrades, and an annual audit of the plant.

Filippini led the team that conducted the first annual audit.

"The first audit found that work had begun on a number of our recommendations," notes Filippini. "With the help of additional staffing, the team has carried out a program of improvements to the recovery system, as well as reviews of the lab practices of each user group. These have led to a much more leak-tight system, improving efficiency and reducing costs. The largest capital investments were delayed during the COVID-19 crisis but are still being pursued."

Currently, the liquefier team is continuing this program of support and upgrades to the facility and its services. Looking forward, the task force is also studying the feasibility of expanding helium services and recovery systems to more users on and off campus. ■

A new timeline written by Illinois Physics cryogenics programmer Nikki Colton details the Helium Liquefier facility improvements: https://physics.illinois.edu/research/facilities/helium-liquefier-timeline.

Historical data analysis on several dozen recovery meters, two humidity sensors, and two pressure transducers is made available online to the campus community here: https://heliumrecovery.web.illinois.edu/

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