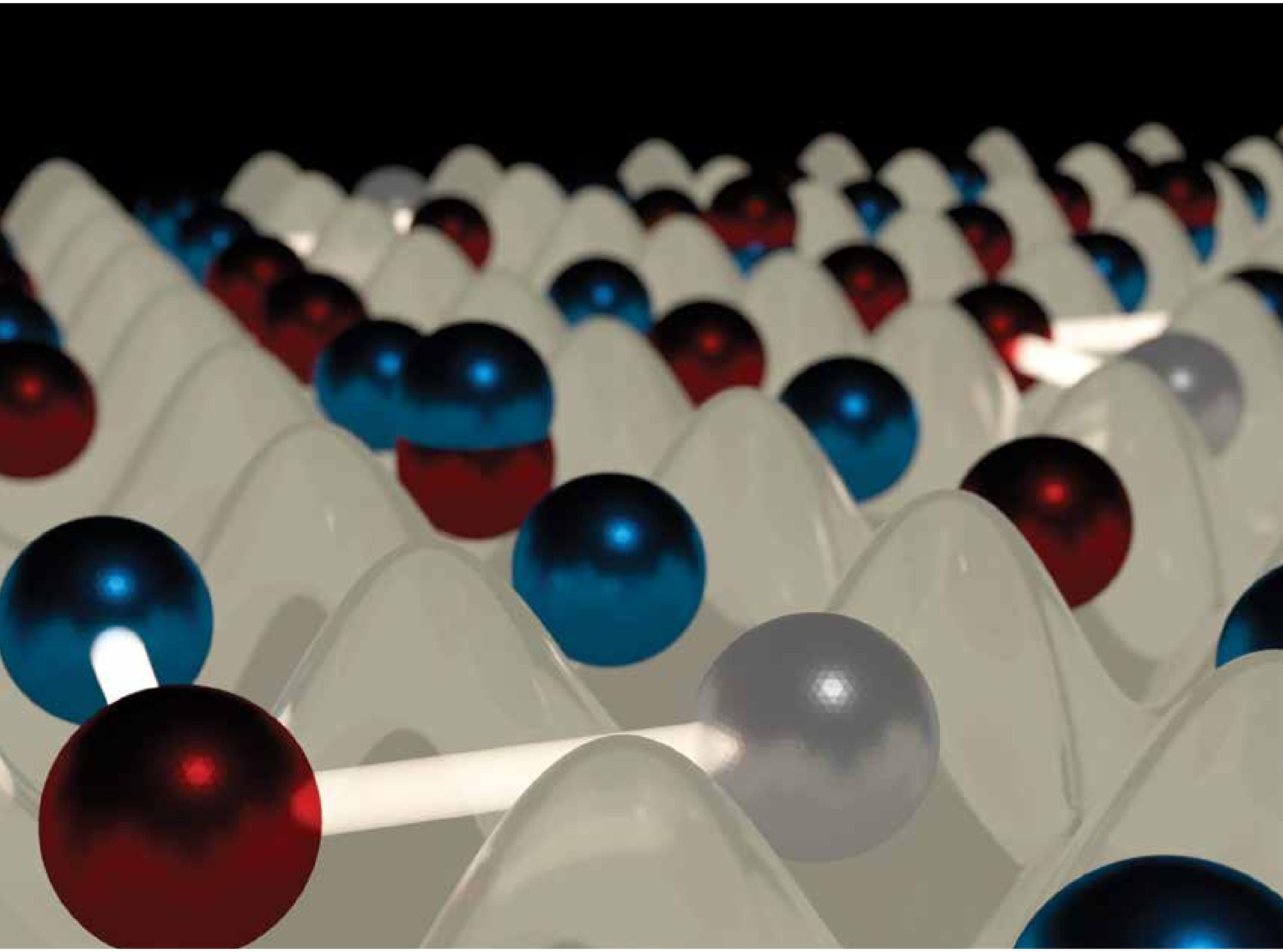
PHYSICS

Harvard University Department of Physics Newsletter

FALL 2019



A Microscopic Look At Quantum Materials

IT TAKES MANY PHYSICISTS TO SOLVE QUANTUM MANY-BODY PROBLEMS

HARVARD UNIVERSITY
Department of Physics

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An experiment-theory collaboration at Harvard investigates possible theories for how quantum spins (red and blue spheres) in a periodic potential landscape interact with one another to give rise to intriguing and potentially useful emergent phenomena. This is an artist's rendering of one such theory, the geometric string theory.

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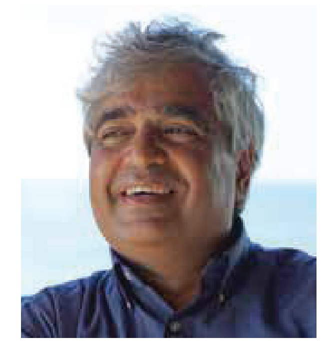
Letter from the Chair



Dear friends of Harvard Physics,

The sixth issue of our annual Physics Newsletter is here! Please peruse it to find out about the comings and goings in our department during the past academic year.

We are grateful to many of you who wrote to us last year about the previous issue of the Newsletter. We value both the accolades and the constructive criticism you have provided, and will strive to incorporate your excellent suggestions. You will find the letters on page 2, continued on the inside back cover.

I'm very pleased to announce the promotion of Matthew Reece to full professorship with tenure. His profile appears on page 3.

I am sad to report that we lost two colleagues and friends this year: Professors Roy Glauber and Jene Golovchenko. You will find their obituaries on pages 4-6.

For the cover article in this issue, we have chosen the experiment-theory collaboration between the groups of Professors Markus Greiner and Eugene Demler. Their collaboration has been studying the dynamics of strongly interacting quantum particles with unprecedented resolution, and their observations are impacting our understanding of quantum materials (pages 9-13). Our historical feature concerns nuclear magnetic resonance (NMR), which is intimately connected to magnetic resonance imaging (MRI) and was observed for the first time in December 1945, by Professors Robert Pound, Edward Purcell, and Henry Torrey right here in the Lyman Laboratory (pages 14-17).

I hope you enjoy the article about Professor Mara Prentiss, one of the busiest people in our department. In addition to doing research in biophysics and teaching, Prof. Prentiss serves as the Director of Graduate Studies and oversees the Harvard Physics machine shop and Physics Teaching Labs. Please read her profile on pages 18-21.

While Prof. Prentiss has been in our department since 1991 (she was the second female physicist to be awarded tenure at Harvard), our next article features a faculty member who joined our department only two years ago, Professor Roxanne Guenette (pp. 22-26).

On page 27, Clare Ploucha offers a brief introduction to the Harvard Quantum Initiative in Science and Engineering, which was launched last November. HQI is co-directed by Professors John Doyle, Mikhail Lukin, and Evelyn Hu (SEAS). Pages 28-32 are devoted to a survey of various initiatives within our department, formed over the years with the goal of building a strong community; this includes the most recent developments from the Committee on Equity and Inclusion. I am very please to announce that we have now hired our first Equity & Inclusion Administrative Fellow, Benita Wolff, who will be joining our department at the end of October.

Page 33 celebrates the promotions of Dr. David Morin and Dr. Jacob Barandes to the positions of Co-Directors of Undergraduate and Graduate Studies respectively. Pages 34-43 are devoted to our annual reports from Undergraduate, Graduate, and Research Scholar Programs, and p. 48 is dedicated to the Physics Department staff.

Last spring, we asked all of you to send us updates you might want to share with fellow Harvard Physics Alumni. These updates are compiled into Alumni Notes on pages 44-47. Please let us know what you think about this new feature of the Newsletter and keep the updates coming!

I would like to end this letter with an important announcement, which hopefully will be of interest to many of you: on April 3, 2020, our department is planning its next Graduate Alumni Reunion. Please watch our website for further details: www.physics.harvard.edu.

As always, do stop by when you are in town or drop us a note if you have any questions, would like to make a comment, or just want to say 'hi' to old friends.

Best wishes,

Subir Sachdev
Chair and Herchel Smith Professor of Physics

Photo by Pamela Davis Kivelson

Letters from Our Readers

We enjoy hearing from our readers. Here is what several had to say:

What a nice idea, the Newsletter is a good way for us to remain in touch with fellow students and friends.

ASHOK KHOSLA, Ph.D. 1970

Thanks very much for these terrific articles on so many important topics, particularly the cover story. I'm primarily writing to congratulate you on an excellent issue, as well as the long-standing leadership of the Harvard Physics department in launching outstanding women on careers in physics. I am grateful for the supportive culture that had been established by the time I arrived as a graduate student in 1992.

I did want to point out an ironic oversight, given the overall effort of the issue to highlight the accomplishments of women in physics. Near the end of the cover story, at the start of the section "The Way Forward," the seminal work of Hazari et al, was summarized in the discussion of factors that lead to women pursuing careers in physics. I found it unfortunate that the text discussion of this work mentioned only Phil Sadler by name among the authors, rather than also mentioning at least the first author, Zahra Hazari, who was a postdoc with Sadler. She has gone on to a stellar career and she is presently among the leading researchers in this area.

My goal in pointing this out is solely to call attention to the missed opportunity to highlight the work of the woman who is the first author on the study and was a Harvard postdoc at the time, which seems ironic given that the article was about the accomplishments of women in physics. I do not wish at all to minimize Sadler's essential contributions to the work and to the field; rather, I would just have recommended taking the opportunity to mention Dr. Hazari as well, as she is also someone of whom the greater Harvard community can be proud.

I appreciate that there was probably a desire for brevity and a desire to highlight the work of people such as Sadler who are known to the Harvard physics department, so I understand the possible sources of the omission, and do not suggest there were any but the best of intentions.

As I said at the start, congratulations on both a terrific issue and a terrific track record of supporting women in physics, and please take my critique in that context.

CATHERINE H. CROUCH, Ph.D. 1996
Professor of Physics, Swarthmore College

Chair's response:

Dear Prof. Crouch,

Thank you for your comments on our newsletter. We are always happy to hear from our graduates, and have received many positive remarks on this issue.

You do make an important point on the citation of the work by Hazari et al. We will try to be more vigilant on such issues in the future. The author of this article was highlighting connections to Harvard in particular, and hence the mention of Sadler.

Thank you again.

Sincerely,

SUBIR SACHDEV

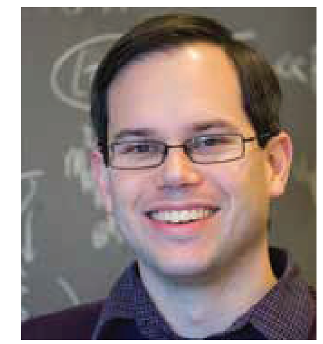
I am a member of the Harvard class of 2013 and wanted to share how grateful I am for your effort in organizing and writing this newsletter. It's a wonderful way to stay up to date on the Harvard physics community.

JULIANA CHERSTON, A.B. 2013

Continued on the inside back cover

Please stay in touch and let us know if you would like to contribute news items to the newsletter at: newsletter@physics.harvard.edu

Faculty Promotion



Matthew Reece, Harvard's Newest Full Professor of Physics, Explores a Universe of Possibilities

As a high school student, Matthew Reece was curious about many things. However, two books he read as a teenager—first *A Brief History of Time* by Stephen Hawking and later *The Elegant Universe* by Brian Greene—drew his attention toward physics. That budding interest was reinforced when Reece, as a University of Chicago undergraduate, was introduced to the experimental particle physicist Henry Frisch. Reece worked for four years in Frisch's lab, analyzing data for the Collider Detector at Fermilab (CDF) collaboration among other tasks.

While the experience gave Reece a great introduction to particle physics, he learned that he'd rather be a theorist than an experimentalist. With this goal in mind, he started graduate studies at Cornell in 2004, choosing the school because it seemed like a congenial place whose physics department was small enough to allow for frequent interactions between particle theorists working close to experiments and more abstract string theorists. He'd also have the chance to work closely with his advisor, Csaba Csaki, a new faculty member who hadn't yet accumulated a large group of graduate students.

Reece initially focused on electroweak symmetry breaking, testing out ideas involving extra dimensions. He had hoped to investigate theories related to the Large Hadron Collider (LHC), but that machine did not start operating until September 2008, and by then Reece had earned his Ph.D. and started a postdoctoral fellowship at Princeton. He became a postdoc at Harvard from 2011 to 2012, staying on as an assistant professor until his promotion to associate professor in 2016 and full professor with tenure this summer.

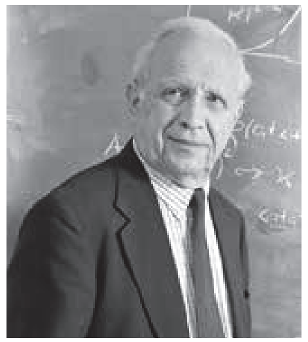
Since coming to Harvard, Reece has explored a broad range of topics under the heading of "physics beyond the Standard Model," including early-universe cosmology, quantum field theory, and quantum gravity. Reece has delved deeply into supersymmetry—an idea introduced in the 1970s that could resolve several longstanding puzzles tied to the so-called hierarchy problem. Many physicists thought the LHC would verify this theory by discovering supersymmetric particles, but none has been observed so far. Reece is one of the originators of a "stealth supersymmetry" model that offers an explanation for why these hypothetical particles have not yet been seen.

He's also given considerable thought to dark matter. Reece and his Harvard colleague Lisa Randall, for instance, have proposed that a small fraction of dark matter could interact strongly with ordinary matter, forming previously unsuspected "dark disks" around galaxies. Given that the nature of dark matter is still unknown, Reece says, "it's important to consider a wider range of possibilities for the forms it might assume."

He's excited by the prospect of the new telescopes being built to search for primordial gravitational waves, which offer, Reece says, "perhaps our best chance of learning about quantum gravity and probing energy scales close to the Planck scale." In work within a new area of theoretical physics called the "Swampland," he is pondering the vast number of potential string theory solutions, trying to identify common, universal features that a viable model should incorporate. On a more concrete level, he's making the case for future particle colliders, spelling out the pivotal contributions that could still be made.

In a sense, Reece got his start in physics with *A Brief History of Time*. Now he's grappling with the brief amount of time available each day to satisfy his curiosity within this exciting, fast-paced field. But that, he says, is a good problem to have.

IN MEMORIAM



Roy J. Glauber

by Peter Reuell

Roy J. Glauber '46, the pioneering theoretical physicist who received the Nobel Prize in 2005 and was one of the last living scientists to have been present for the dawn of the atomic age, died on Dec. 26, 2018. He was 93.

The research that set Glauber on the path to a Nobel began with his interest in a groundbreaking 1956 experiment that confirmed a key concept of quantum physics — that light was both a particle and a wave — and laid the groundwork for the field. His landmark 1963 paper, "The Quantum Theory of Optical Coherence," used quantum mechanical tools to transform science's understanding of light, which previously had only been studied using classical techniques.

"We really did not have a complete understanding of the quantum properties of light, and what Roy's work laid out was a framework for thinking about that," said Mikhail Lukin, the George Vasmer Leverett Professor of Physics and co-director of the Harvard Quantum Initiative is Science and Engineering. "It allowed us to think about these types of questions quantitatively … so I would argue that his work very much laid the groundwork for the field of quantum science and technology that people are talking about right now."

Lukin said the theories outlined by Glauber opened the door for many scientific discoveries as well as next-generation technologies, including quantum computers and networks and the use of quantum cryptography, which relies on quantum mechanics to create impossible-to-crack codes.

"Those ideas all grow out of this framework that he developed," Lukin said. "Some people refer to these new developments as the second quantum revolution — the first was about understanding the laws of quantum mechanics. But in this second revolution … the idea is that now that we understand the quantum world and we can actually control it, let's see what we can use it for. Can we build materials with properties which you design on demand? Can we build quantum computers? Can we build quantum networks where we can send information with absolute security from one side of the country to the other? These types of ideas very much depend on understanding where the classical world ends and the quantum world starts, and that's where these ideas Roy pioneered and developed become absolutely critical."

Glauber graduated from the Bronx High School of Science and entered Harvard as a 16-year-old freshman, but left as a sophomore when he was recruited to join the Manhattan Project, where he worked with future Nobel-winning physicist Richard Feynman to calculate the critical mass of the first atomic bomb. Glauber was later present at the first tests of the bomb.

Following World War II, he returned to Harvard to finish his undergraduate studies and later earn a Ph.D. After receiving his doctorate he was recruited to a position at the Institute for Advanced Study by Robert Oppenheimer, and worked there before returning to Harvard in 1952, where he spent the remainder of his career.

Though he was known for taking his scientific work seriously, friends said Glauber wasn't without a lighter side. For years, he was "keeper of the broom," clearing the stage of paper airplanes thrown during the annual Ig Nobel Prize ceremony recognizing unusual or trivial scientific achievements.

One of the few years Glauber missed the Ig Nobel ceremony was in 2005 — because he was in Stockholm collecting his real Nobel.

"I think he took real glee in his role at the Ig Noble ceremony," said Arthur Jaffe, the Landon T. Clay Professor of Mathematics and Theoretical Science. "He loved to describe with a smile his role as the janitor, sweeping the stage at the end of the performance."

In his spare time, Jaffe said, Glauber had great interest in classical music. He and his partner, Atholie Rosett, occasionally hosted events for one local performing group in their home.

"People consider him a father of … a huge area of physics that has been very prolific in modern life," Jaffe said. "He always had a very clear opinion about his evaluation of other scientists. Personally he remained modest; his character did not change at all after the Nobel Prize."

Irwin Shapiro, the Timken University Professor, knew Glauber for more than six decades, first as a student and later as his colleague. He credits Glauber with ensuring that he got his first job after receiving his Ph.D.

"He was only four years older than I, and he called the head of the MIT Lincoln Laboratory who was thinking of hiring me and suggested, with no uncertainty, that he do so," Shapiro said.

Though both had grown up in New York, they had never met before Shapiro became Glauber's first doctoral student.

"One anecdote that made him laugh when I told him was, when I first became his advisee in 1952, I told my mother about it and mentioned Roy's name as my adviser," Shapiro recalled. "She somehow mentioned it to her younger sister, who piped up and said, 'Oh, Felicia's little boy, Roy!' I don't know how my aunt knew Roy's mother, but somehow they had been friends."

Glauber is survived by his son, Jeffrey, a daughter, Valerie Glauber Fleishman; a sister, Jacqueline Gordon; Atholie Rosett, his companion of 13 years; and five grandchildren.

Reprinted with permission from The Harvard Gazette

Jene Golovchenko

by Edlyn V. Levine

In Pursuit of Discovery

"What do you think about this?" Jene Golovchenko turned to me with a twinkle in his eyes. We had been discussing whether a Z pinch can occur in strongly focused electrolytic currents. Jene had just brought up a case of exploding conducting wires heated by high-power current pulses. He wondered whether the same effect contributed to energy focusing in the exploding liquids of our experiments.

This was typical of Jene: he had a knack for turning simple systems on their head, often leading to new discoveries of the behavior of matter and revealing new insights into fundamental physics. Jene had a powerfully creative mind for experimental physics, and an incredible depth of theoretical knowledge that he wielded in pursuit of deeper understanding and inventiveness. His excitement and sense of adventure for scientific discovery permeated his research, his joy and enthusiasm were infectious, and his intensity demanded that rigor be applied to every experiment he undertook and every question he sought to answer.

Jene was the Rumford Professor of Physics and the Gordon McKay Professor of Applied Physics at Harvard University. His career spanned academia at Harvard and Aarhus University in Denmark, industry at Bell Labs, national laboratories at Brookhaven and Livermore, and at CERN in Geneva. He was renowned for seminal contributions to ion implantation, scanning tunneling microscopy, atomic and x-ray physics, and nanopore physics. But most importantly to his students, he was our teacher, mentor, advisor, and ultimately great friend.

Crazy Ideas that Just Might Work

Often Jene would come up with an idea for a novel experiment that was based on his strong intuition for new and interesting physics. He had an uncanny sense for good, albeit crazy ideas to pursue. My thesis grew from one of these ideas. Jene had a hunch that important physics could be learned from the study of first order phase transitions using nanopores to yield detailed information on nanoscale thermal physics and fluctuation phenomena revealed by nucleation rates.

This turned out to be more than true: we achieved record-breaking measurements approaching the liquid kinetic limit of stability and attained unprecedented control with spatial and temporal localization of the liquid-to-vapor phase nucleation. We effectively succeeded in harnessing the inherently random event of phase transformation into a quasi-deterministic system for studying fluctuations and first-time-to-passage phenomena in thermal physics.

My research with Jene represented only one field among a stunning variety to which he contributed in his career. He undertook a wide range of experimental projects using highly controlled electron, positron, atom, x-ray, ion, and laser beams to reveal new phenomena connected with radiation-matter systems. These experiments led to the development of new probes to study matter and new techniques to modify and transform it into new forms. It was all we could do as students to keep up and learn as much as possible during our time under his mentorship.

What Music Are You Listening to?

Jene was an exceptional teacher taking great joy in sharing his vast knowledge and instilling excitement in learning of new physics. He was equally energetic while teaching undergraduate students in freshman seminar as he was mentoring his Ph.D. students. Jene took great care to train his students to be rigorous and thorough in scientific work, holding a very high standard for research undertaken. Group meetings often took hours, with debates on the results presented and the methodologies used, and it was typical for his students to publish only a few, high quality papers during graduate tenure.

Jene also cultivated a collegial and fun environment for his group. He was an exceptional judge of character, which contributed to fostering close scientific and personal relationships between his graduate students and postdocs. He once found me in the student office wearing headphones and asked me what music I was listening to. He was quite amused when I said none so that I could focus. The very next week, everyone in the group found a new pair of sound-suppressing headphones on our desks so we could work together in peace.

This was one of many examples of the care Jene took to ensure we had an environment in which to succeed at our research. Music figured heavily into that environment, and it was not uncommon to hear Jene playing the keyboard in his office. Jene would discuss the creation of music as in the context of complex processes at play between physics, mathematics, electronics, and human perception, and he would explore the latest digital technologies for recording, playing, and synthesizing sound. These insights he shared with his freshman seminar, allowing his students to join him on his explorations of the physics of sound.

The Shoulders of a Giant...and a Friend

Jene passed away on 13 November 2018, leaving a tremendous legacy of physics in his wake. But his most important legacy is the people whose lives he touched, shaped, and influenced with his energy and kindness. He will be missed dearly by his family, friends, colleagues, and students. I am most grateful to Jene for the gift of curiosity that he instilled in me and that he shared with everyone who had the honor of studying with him. He imbued in all of us the wonderment and excitement for exploring the complexity of the physical world, and his legacy will be carried forward by our continued endeavors to learn, to discover, and to invent.

Current Progress in Mathematical Physics: Arthur Jaffe Celebrated at Three-Day Mathematical Physics Conference

By Zhengwei Liu

The conference, "Current Progress in Mathematical Physics," was held on December 10-12, 2018, primarily in the main lecture hall of Harvard's Jefferson Laboratory. The event, which showcased new and wide-ranging research in mathematical physics, was dedicated to Arthur Jaffe, the Landon T. Clay Professor Mathematics and Theoretical Science in the departments of mathematics and of physics.

In the course of his remarkable career, Jaffe has made crucial research contributions to the development of mathematics and physics, working in at least nine different subfields. He also served for 21 years (1979-2001) as chief editor of *Communications in Mathematical Physics*, the top journal in mathematical physics. In addition, he served as president of the American Mathematical Society (1997–1998) and as President of the International Association of Mathematical Physics (1991-1996). His career, clearly, has been dedicated both to the advancement of science and to the service of the scientific enterprise.

I organized the December 2018 conference in concert with Konrad Osterwalder (ETH), Victor Kac (MIT), Christopher King (Northeastern University), Eugene Wayne (Boston University), and Jonathan Weitsman (Northeastern University). Harvard physicist Christopher Stubbs, the Dean of Science at Harvard Faculty of Arts and Sciences, opened the meeting with an entertaining speech. We proceeded to have fourteen one-hour talks, presented by a number of leading mathematicians and physicists, on various topics related to mathematical physics. James Glimm—who founded the subject of constructive quantum field theory with Arthur Jaffe and was Arthur's long-time collaborator in the 1970s—gave the first talk. Other speakers included two Fields Medalists, Vaughan Jones and Edward Witten; two Harvard physics professors, Mikhail Lukin and Cumrun Vafa; and Jennifer Chayes, the Managing Director of Microsoft Research New England in Cambridge, Massachusetts. We also had six short talks that described the latest progress in the mathematical picture language program, including talks by two Harvard undergraduates who were writing senior theses with Arthur. More details can be obtained from the conference website: https://mathpicture.fas.harvard.edu/cpmp2018.

A celebratory dinner was held at the Loeb House on the night of December 11. John Ewing, the president of Math for America and former Executive Director of the American Mathematical Society, served as the master of the ceremonies at the banquet. The many attendees at this three-day gathering included students, postdocs, collaborators, and friends of Arthur who came from all over the world, including China, Italy, England, France, German, Japan, and Switzerland.

Two special musical events were held during the celebration involving performers who happen to be Arthur's close friends. Robert Levin, Emeritus Dwight P. Robinson Professor of the Humanities at Harvard, gave a public talk, "Who cares if classical music dies," on December 10 in Science Center C. The noted Swiss oboist, composer, and conductor Heinz Holliger organized a concert at the American Academy of Arts and Sciences on Wednesday evening, December 12. The next day a small ceremony took place during which Holliger signed the book that placed him among the Academy's International Honorary Members. Arthur himself has been a member of the Academy since 1978, as well as a member of the U.S. National Academy of Sciences since 2000.

We are grateful to the Templeton Religion Trust, the National Science Foundation, and the Departments of Physics and Mathematics at Harvard for helping to make this conference possible.

Faculty Prizes, Awards, and Acknowledgments*

American Academy of Arts and Sciences:
SUBIR SACHDEV

Breakthrough Prize In Life Sciences:
XIAOWEI ZHUANG

Clarivate Analytics 2018:
EUGENE DEMLER
PHILIP KIM
MIKHAIL LUKIN
HONGKUN PARK
ASHVIN VISHWANATH
DAVID WEITZ
AMIR YACOBY
XIAOWEI ZHUANG

DOE Early Career Awards:
CORA DVORKIN

NAS Award for Scientific Discovery:
XIAOWEI ZHUANG

National Academy of Sciences:
AMIR YACOBY

New Horizons In Physics Prize:
DANIEL JAFFERIS

I.I. Rabi Prize in Atomic, Molecular, and Optical Physics:
KANG-KUEN NI

J. J. Sakurai Prize for Theoretical Particle Physics:
LISA RANDALL

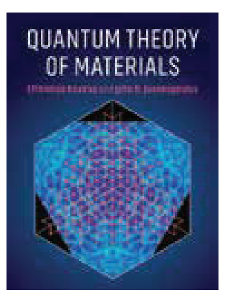
Star Family Prize for Excellence in Concentration Advising:
JOHN HUTH

Star-Friedman Challenge for Promising Scientific Research:
JENNY HOFFMAN

George E. Valley, Jr. Prize:
JULIA MUNDY

*Includes awards received since the publication of the 2018 Newsletter.

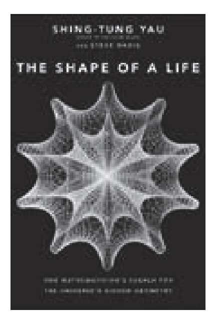
Books Published by Harvard Physics Faculty



Quantum Theory of Materials

Efthimios Kaxiras and John D. Joannopoulos
Cambridge, 2019

This accessible new text introduces the theoretical concepts and tools essential for graduate-level courses on the physics of materials in condensed matter physics, physical chemistry, materials science and engineering, and chemical engineering. Topics covered range from fundamentals such as crystal periodicity and symmetry, and derivation of single-particle equations, to modern additions including graphene, two-dimensional solids, carbon nanotubes, topological states, and Hall physics. Advanced topics such as phonon interactions with phonons, photons and electrons, and magnetism, are presented in an accessible way, and a set of appendices reviewing crucial fundamental physics and mathematical tools makes this text suitable for students from a range of backgrounds. Students will benefit from the emphasis on translating theory into practice, with examples explaining experimental observations, applications illustrating how theoretical concepts can be applied to real research problems, and 242 informative full-color illustrations.



The Shape of a Life

Shing-Tung Yau and Steve Nadis
Yale, 2019

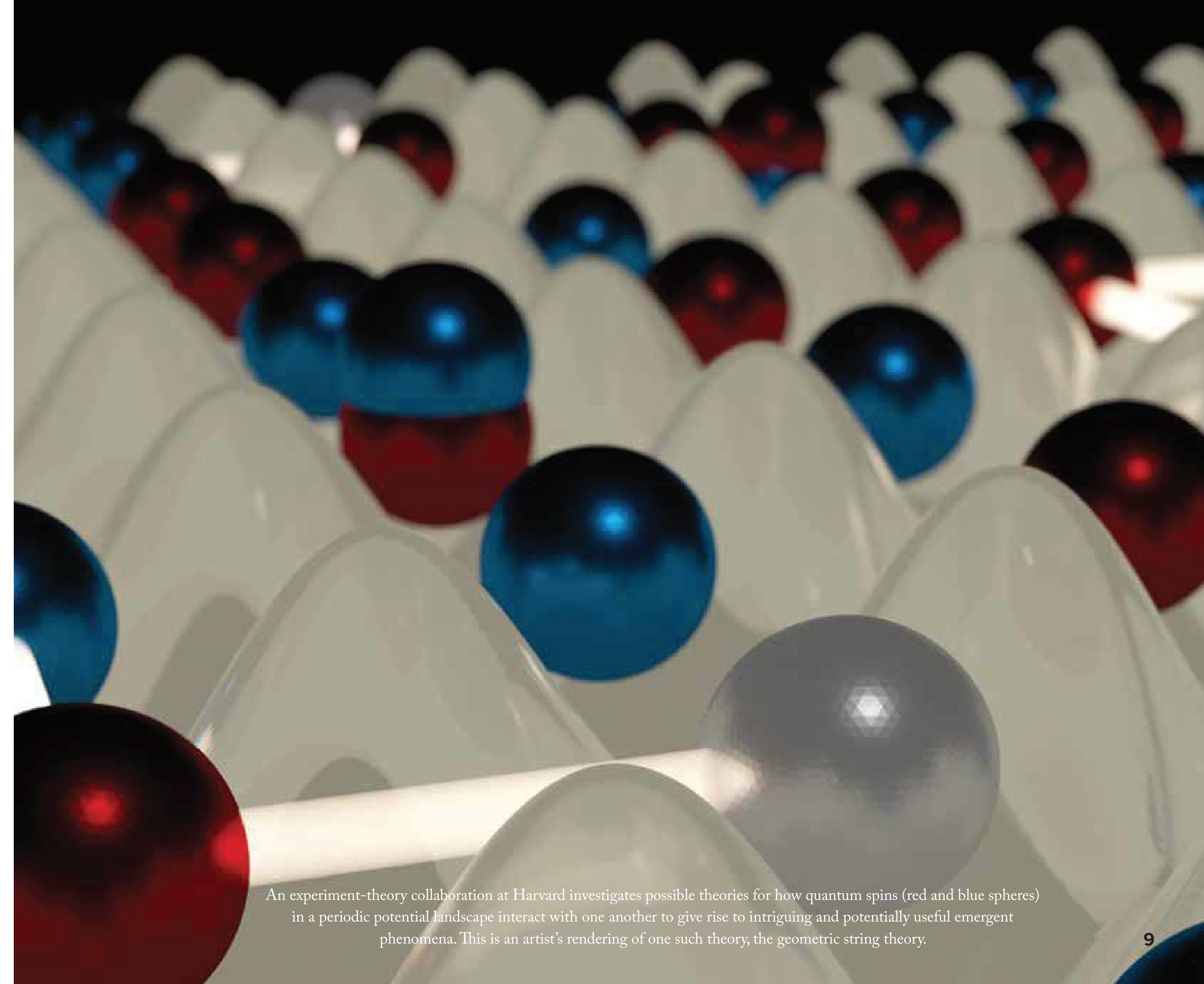
Harvard geometer and Fields medalist Shing-Tung Yau has provided a mathematical foundation for string theory, offered new insights into black holes, and mathematically demonstrated the stability of our universe. In this autobiography, Yau reflects on his improbable journey as a widely celebrated mathematician. Beginning with an impoverished childhood in China and Hong Kong, Yau takes readers through his doctoral studies at Berkeley during the height of the Vietnam War protests, his Fields Medal–winning proof of the Calabi conjecture, his return to China, and his pioneering work in geometric analysis. This new branch of geometry, which Yau built up with his friends and colleagues, has paved the way for solutions to several important and previously intransigent problems. With complicated ideas explained for a broad audience, this book offers readers not only insights into the life of an eminent mathematician, but also an accessible way to understand advanced and highly abstract concepts in mathematics and theoretical physics.

COVER STORY

A MICROSCOPIC LOOK AT QUANTUM MATERIALS:

IT TAKES MANY PHYSICISTS TO SOLVE QUANTUM MANY-BODY PROBLEMS

By Annabelle Bohrdt, Christie Chiu, Fabian Grusdt, and Eugene Demler



An experiment-theory collaboration at Harvard investigates possible theories for how quantum spins (red and blue spheres) in a periodic potential landscape interact with one another to give rise to intriguing and potentially useful emergent phenomena. This is an artist's rendering of one such theory, the geometric string theory.

Have you heard of the "Woodstock of Physics?" Likely, some of you were there.

On March 18, 1987, at 7:30 pm, at the American Physical Society March Meeting in New York, over two thousand physicists hastily squeezed into what was clearly a very popular and special session. The program was overstuffed, much like the room, with 51 speakers presenting their results past three in the morning.

What topic could have caused such a frenzy? High-temperature superconductors: materials that exhibit zero resistivity below a certain critical temperature, which can be high enough to be achieved by cooling with liquid nitrogen.

The discovery of high-temperature superconductors occurred only about a year before this March Meeting session, by Georg Bednorz and Alex Müller of IBM Zurich. And with this Nobel-prize-winning discovery, the field exploded. Teams of experimentalists searched for materials with higher and more easily achievable transition temperatures, while theorists sought to understand the underlying physics. The applications for materials with these properties are boundless, including high-efficiency electric power distribution and levitating trains. However, more than thirty years after their discovery, the physical mechanism for high-temperature superconductivity is still not understood. Today, this lack of comprehension stands as the main obstacle to developing high-temperature superconductors for practical use, where the biggest challenge is to raise the critical temperature.

We at Harvard are approaching these challenges from a new angle, and we are optimistic because we have a new set of tools that offer a unique perspective. In Professor Markus Greiner's group, we have built a quantum simulator to model high-temperature superconductors. With neutral atoms cooled down to temperatures of just a few billionths of a degree above absolute zero, and precise manipulation of a dozen lasers to control those atoms, we model the quantum behavior of electrons in a solid. Moreover, we have a microscope to image every one of those atoms. This ability to control and probe single atoms opens up completely new possibilities to tackle the problem.

In a close collaboration with theorists working with Professors Eugene Demler of Harvard Physics and Michael Knap of the Technical University of Munich, we have recently applied a pattern recognition algorithm to images of the atoms. In a second step, we used machine learning to decide which quantum theory describes the experimental data better. By developing new methods such as these to analyze the data in its entirety, we may achieve new insights into the longstanding question of high-temperature superconductivity.

But let's start at the beginning. What are strongly correlated quantum systems and why are they so difficult to understand? While a complete description of a single quantum mechanical particle is textbook physics, describing many interacting particles is much more challenging. In the same way, describing the flight path of a single bird is significantly easier than predicting the motion of every individual in an entire flock—knowing, of course, that this is an oversimplification.

A flock of birds sometimes seems to behave as a single entity that barely resembles its individual constituents. As a striking example, a flock does not turn as a whole, but instead its entire orientation changes as the front and back of the flock become the new flanks. While such complex behavior appears to be well-orchestrated by a central leader, it in fact emerges out of the interplay of many individual agents, each of which follows a simple set of rules. In the case of a flock of birds, there are three main rules: they avoid crowding their neighbors, they align with their neighbors, and they steer towards the average position of their neighbors.

In a way, the same is true of quantum many-body systems: each individual particle follows a set of rules prescribed by the system's Hamiltonian. Through the interplay of many particles, fascinating phenomena can emerge, which cannot be predicted from the consideration of a single isolated particle.

In certain regimes, effective single-particle or "mean-field" descriptions are sufficient. In this approximation, only the average effect of all the other parts of the system on a given particle is considered. Such a description is particularly useful to describe effects that do not depend on the exact details of the system. For example, we do not need to know how every bird flies and interacts with other birds to know how the flock moves. This is akin to the great successes of statistical mechanics in deriving macroscopic properties from the microscopic.

We focus on regimes where particles are so strongly correlated with one another that mean-field descriptions are insufficient. The most famous of these systems are high-temperature superconductors. How, then, can we understand the mechanism behind high temperature superconductivity? The most direct approach is to make measurements on real materials that exhibit unconventional superconductivity. That's how many important insights have been gained. However, these materials are very complex, and it is hard to capture all their properties. And it might not be necessary to get every detail right: it is widely believed that simpler models can capture all the interesting physics, too. One of those models—probably the simplest one—is the 2D Fermi-Hubbard Hamiltonian. Similar to the rules for the birds in a flock, it prescribes rules for the particles. At first glance, those rules are simple enough. The particles are fermions, which can have spin up or down. They live on the sites of a two-dimensional square lattice. Two fermions with the same spin cannot occupy the same site. Apart from that, they gain energy of the order of the parameter t when they hop from one site to another and experience an energy penalty given by the parameter U if two fermions with opposite spin sit on the same site.

If the temperature of the system is lowered, the particles have to decrease their energy according to the same rules. Even though we know those rules and they don't seem to be that complicated, it is surprisingly hard to predict the collective behavior that might emerge in this system. When there is one particle per site, each with spin up or spin down, a good way of minimizing the energy is—roughly speaking—to have alternating spins next to each other. This way, no energy penalty U is paid, which is usually much bigger than the hopping parameter t, but the particles can still move around a bit by hopping on top of each other for a brief period of time. This state is known as an anti-ferromagnet. However, once we go away from this limit by removing particles from the system, there is no agreement on what the picture looks like anymore.

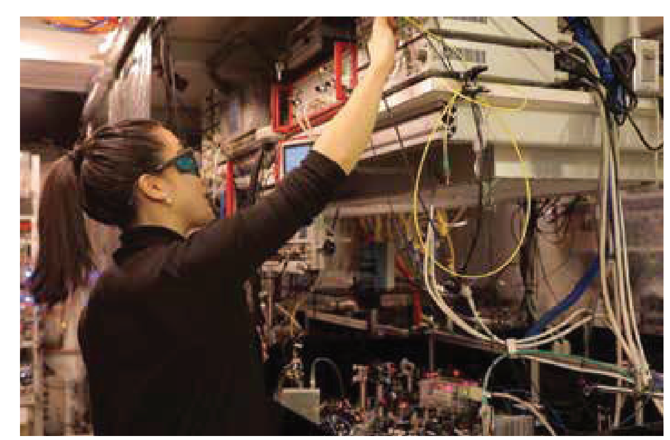
In 1982, even before the discovery of high-temperature superconductivity, Richard Feynman proposed the concept of quantum simulation, using an actual quantum system to simulate the quantum model of interest. During the last two decades, tremendous progress has been made in the field of quantum simulation with a variety of platforms, including superconducting qubits, trapped ions, and ultracold atoms and molecules.

In fact, the idea of using ultracold atoms in optical lattices as a quantum simulator for high-temperature superconductors was first suggested at Harvard. In 2001, Professors Mikhail Lukin and Eugene Demler attended an Aspen conference that brought together physicists from condensed matter and atomic physics to find connections between the two fields. While waiting for a delayed flight at the airport, Lukin and Demler came up with the idea of studying the most difficult problems in condensed matter physics with the most sophisticated experimental tool of atomic physics. The first version of their paper on this subject was turned down by the referees on the ground that in atomic physics, one does not do experiments for which theory can not make a definitive prediction. Fortunately, experimentalists in the field thought otherwise and were excited by the prospect of venturing into unknown territories. Since then, the idea of combining condensed matter physics and atomic physics has become mainstream.

In the Greiner group, we are turning this theoretical proposal into a reality. Our experiment cools neutral atoms down to 2 nanokelvin and holds them in a vacuum with an array of traps created with laser light. In this optical potential, atoms can tunnel between neighboring sites. Atoms with opposite spin, sitting more than one to a site, experience contact interactions—in short, they obey the rules stated by the Fermi-Hubbard Hamiltonian of condensed matter physics.

By using neutral atoms to simulate the electrons in real materials, we can work at time- and length-scales that are more accessible than in real materials. As a result, we enjoy a high degree of measurement and control over our system, while studying much of the same physics.

Our experiments go even beyond simulating the model of interest—they are quantum gas microscopes. This means that we can image the atoms with a resolution of a single site. Moreover, the measurements performed with a quantum gas microscope take into account one of the most intriguing properties of quantum systems: their ability to be in a superposition state. Loosely speaking, this means that different configurations of the particles on the lattice can be simultaneously



Left to right: Christie Chiu in the Greiner Lab; artist's rendering of the Quantum Gas Microscope.


Left to right: Eugene Demler, Fabian Grusdt, and Annabelle Bohrdt

realized. The wave function of the system contains the probabilities for all possible configurations, the number of which grows vastly with the size of the system. Every measurement with the quantum gas microscope provides a snapshot of this wave function, picking out one configuration according to this probability distribution. Strikingly, this means that repeating the same experimental procedure multiple times will almost certainly lead to as many different snapshots.

We achieved site-resolved imaging of fermions with lithium-6 in 2015. In the following year, we measured antiferromagnetic correlations over short distances, where a spin-up particle tends to have spin-down particles as neighbors and fellow spin-up particles as next nearest neighbors. As we pushed to lower and lower temperatures, these antiferromagnetic correlations spread across the entire system. We had realized the antiferromagnet, a celebrated achievement in the community. At this point, we were perfectly set up to tackle some open questions, such as: What happens when we remove some particles from the system and thus introduce holes?

Fabian Grusdt, then working with Eugene Demler, had been thinking about how to best describe a hole moving through an antiferromagnet since the advent of Fermi gas microscopy. This quantum impurity problem is at the heart of many strongly correlated quantum systems, laying bare an intriguing interplay of two key players: spin and charge degrees of freedom. It is hardly a new problem and has been studied extensively by the solid-state community, including the condensed matter theory groups at Harvard. Although they agreed on a starting point, through different approximations in the course of their individual analyses they arrived at different conclusions. But the prospect of new insights from quantum gas experiments raises a new perspective, and we can begin to resolve these conflicting theories.

Drawing upon earlier work dating back to the 1960s, Fabian had developed the geometric string theory. In this theory, a hole moves through the lattice by displacing the spins along its way. While the location of the spins changes quickly, their quantum state does not adapt to this modified geometry. The hole motion therefore leaves behind a memory in the spin system, a so-called string. At one end of the string, a spin-less excitation carrying the charge degree of freedom is found: the hole. At the opposite end, there is a charge-neutral spin excitation with a large effective mass: the spinon. In a nutshell, the geometric string theory describes how the hole moves around the heavy spinon, and how this motion is reflected in the surrounding spin environment. Much like a hyperactive dog on a leash, bound to its owner, the hole keeps returning to the spinon.

Along the path of the hole, all spins are displaced by one site. Their neighbors adjacent to the path, however, are not. This leads to the curious effect that an up spin suddenly finds itself to be neighboring another up spin, as opposed to a down spin. When enough holes move through the system, this effect is even visible in the average correlations over the entire system. If Fabian's reasoning was right, some of the correlation functions should change their sign as soon as the density of holes reaches a certain value. When Fabian explained his theory to Postdoctoral fellow Daniel Greif, this statement really caught Daniel's attention—he had seen such a sign change in their experimental measurements already! Two hours later, he checked the experimental data and confirmed the existence of a sign change, right around where Fabian had expected it.

Quantum gas microscope snapshots contain much more information beyond correlation functions between two sites, which calls for a new way of studying strongly correlated many-body systems. This motivation meshed perfectly with our desire to experimentally test the geometric string theory. Since this theory describes the quantum system in a superposition state of string configurations, for certain quantities—like the correlations between neighboring sites—we can only see the effect of the string as an average over all possible string positions and arrangements. However, in every snapshot taken with a quantum gas microscope, only one string configuration is realized, suggesting that we may be able to find strings in individual snapshots.

So we set out to find signatures of the strings. The corresponding observables would not be as straightforward as the well-established conventional observables used in the field, such as spin correlators. Graduate students Annabelle Bohrdt and Christie Chiu developed a pattern recognition algorithm to extract string-like patterns from the images taken with the quantum gas microscope. Fairly quickly, we all realized that we would have to gather a substantial amount of data. At this point, Markus Greiner's entire Fermi gas microscope team, which at the time consisted of Daniel, Christie, and graduate students Geoffrey Ji and Muqing Xu, put in a massive effort to take all of the data required for a thorough evaluation of the string pattern-based observables in order to see if they could be used to test different microscopic theories. Once we knew what parameters we needed, the entire dataset was collected in about two months' time. It totaled over 30,000 snapshots, each of a different experimental realization. Fabian made waffles to celebrate.

Indeed, we found evidence for strings in the data. As we added more and more holes to the system, the number of string patterns we found increased proportionally. This was great news, because we expected each hole to cause a new string pattern. Moreover, the comparison to the geometric string theory showed excellent agreement without any fitting parameters.

Looking for string patterns is just one way of extracting more information out of the wealth of data obtained in quantum gas microscopy. There might be other secrets in those snapshots, which we haven't even thought about yet. In recent years, machine learning has developed as a powerful tool in data analysis. We are not yet afraid that our jobs might be taken away by machines, so we were happy to get some help from artificial intelligence: while we gave the machine access to all information, we did not specify which patterns to look for.

We trained a neural network to distinguish between two competing theories, a quantum spin liquid theory and the geometric string theory. Similar to recognizing cats or dogs in photographs, snapshots from each theory are fed into the neural network. The network parameters are then optimized to assign the right label to each snapshot—in this case they are 'spin liquid' or 'geometric strings' instead of 'cat' or 'dog.' After training, snapshots from the experiment are used as an input to the network, which has to label them as one of the two theories. In effect, the neural network decides which theory resembles the experiment more closely, based on a single snapshot at a time.

We found conceptually new ways of analyzing many-body systems using images obtained from quantum gas microscopy. We searched for patterns in quantum gas microscope images and found that they can give information beyond what one can learn from conventional correlation functions.

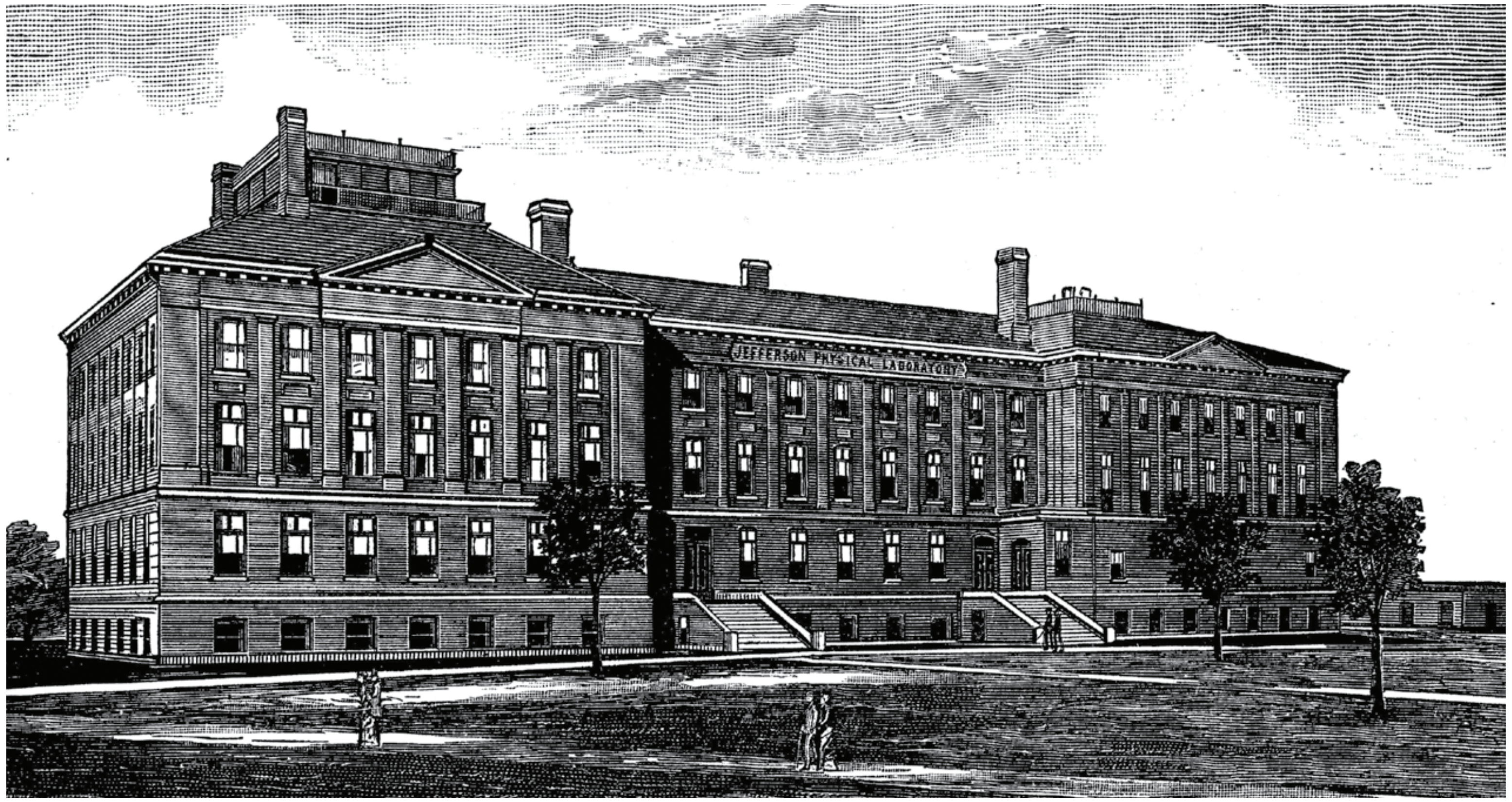
As the result of our work, we have gained a more complete perspective on strongly correlated many-body systems, taking into account the entire richness of properties, rather than relying solely upon straightforward measurements of order parameters and correlation functions. It is similar to Rutherford's scattering experiment—once detailed information is available from experiments, one cannot stick with something as simple as a plum pudding model. Our search for string patterns is just the first step in extracting more information out of quantum gas microscopy data. More complex structures are expected to appear when the temperature is lowered, or in dynamics experiments performed at higher energies.

We have many ideas for our next steps, but currently we are working to measure the dynamics of holes deterministically placed at a given location in an anti-ferromagnetic spin background. Under the microscope, after allowing the hole to propagate for some time, we can freeze out all dynamics and take a snapshot of the system. This allows us to gain new insights on how the hole propagates in a spin background. While this may only be a small step, we are optimistic that, through theory-experiment collaborations and combined efforts across many disciplines, we will solve the puzzle of high-temperature superconductivity.

FOR MORE INFORMATION, CHECK OUT OUR PAPERS:

Christie S. Chiu, Geoffrey Ji, Annabelle Bohrdt, Muqing Xu, Michael Knap, Eugene Demler, Fabian Grusdt, Markus Greiner, and Daniel Greif, "String patterns in the doped Hubbard model," *Science* 365 (2019). https://doi.org/10.1126/science.aav3587.

Annabelle Bohrdt, Christie S. Chiu, Geoffrey Ji, Muqing Xu, Daniel Greif, Markus Greiner, Eugene Demler, Fabian Grusdt, and Michael Knap, "Classifying snapshots of the doped Hubbard model with machine learning," *Nature Physics* (2019). https://doi.org/10.1038/s41567-019-0565-x.



FOCUS

Nuclear Magnetic Resonance: Lyman Laboratory, December 1945

by Paul Horowitz

Seventy five years ago, in the chilly "cosmic-ray shed" that extended from the first floor of Lyman Laboratory, three physicists observed, for the first time, the gentle resonance of protons in a paraffin sample. Thus was born nuclear magnetic resonance (NMR), the basis of the astonishingly successful contemporary tool of medical MRI. The story of NMR is rich with human ingenuity, chance encounters, and good luck.[1] Some of us had the wonderful good fortune to study with two of those, who generously shared their memories; and much of the history has been captured in the oral history archives of the American Institute of Physics[2].

It was December 15, 1945 — exactly four months after Japan's capitulation in the war in the Pacific — and Robert Pound, Edward Purcell, and Henry Torrey had been seeking the elusive resonance since the idea came up in a happenstance lunch while the three were wrapping up their work at the MIT Radiation Lab (the wartime radar project, energized by the British invention of the powerful cavity magnetron). Purcell asked, "Why couldn't one do the Rabi-type of proton resonance in solids?" The resonance frequency in a given magnetic field was known from Rabi's work with molecular beams at Columbia University, but the amount of time for the nuclear spins to equilibrate (what we now call "the spin-lattice relaxation time," T_1) was anyone's guess. Their best guess was a few hours, during which the sample had to sit, undisturbed, in the magnetic field. As Pound described it, "Ed agreed to come in around seven in the morning on Saturday and turn the magnet on and let it cook until we would come in."

They spent the rest of the day (as in the days before) in fruitless pursuit, slowly varying the magnet current through the expected value. But late in the day Pound suggested, in desperation, "why don't we just turn the magnet all the way up?" And as we came down through 80 amperes it went bump. There it was." They had expected it at 73 amperes, and had earlier swept nearly plus and minus 10 percent. They hadn't miscalculated, they simply had not realized that the magnet was close to saturation; as Pound eloquently put it, "we were only off 2% in the calibration, which is pretty good for that kind of system [flip-coil plus galvanometer], but it took 15% more current to get that 2% more field." Amusingly, their estimate of the relaxation was considerably more in error: as Purcell put it, "in the final time when the experiment was successful, I had been over here … it must have been all day, nursing the magnet generator along so as to keep the field on for many hours, that being in our view a possible prerequisite for seeing the resonances. Now, it turned out later that in paraffin the relaxation time is actually 10^{-4} seconds. So I had the magnet on exactly 10^8 times longer than necessary!"

The field moved quickly after that: within a month Felix Bloch[3], William Hansen, and Martin Packard at Stanford University, not knowing of the Harvard work, succeeded in their NMR; and in Cambridge the arrival of Nicolaas Bloembergen advanced the theoretical underpinnings of NMR, most famously with their 34-page 1948 *Phys. Rev.* paper, "Relaxation Effects in Nuclear Magnetic Resonance Absorption" (one of the most-cited articles in physics, ever), familiarly known as "BPP" (Bloembergen, Pound, and Purcell). The "BPP Theory" addressed the effects of molecular motions in the NMR relaxation time and resonance width.

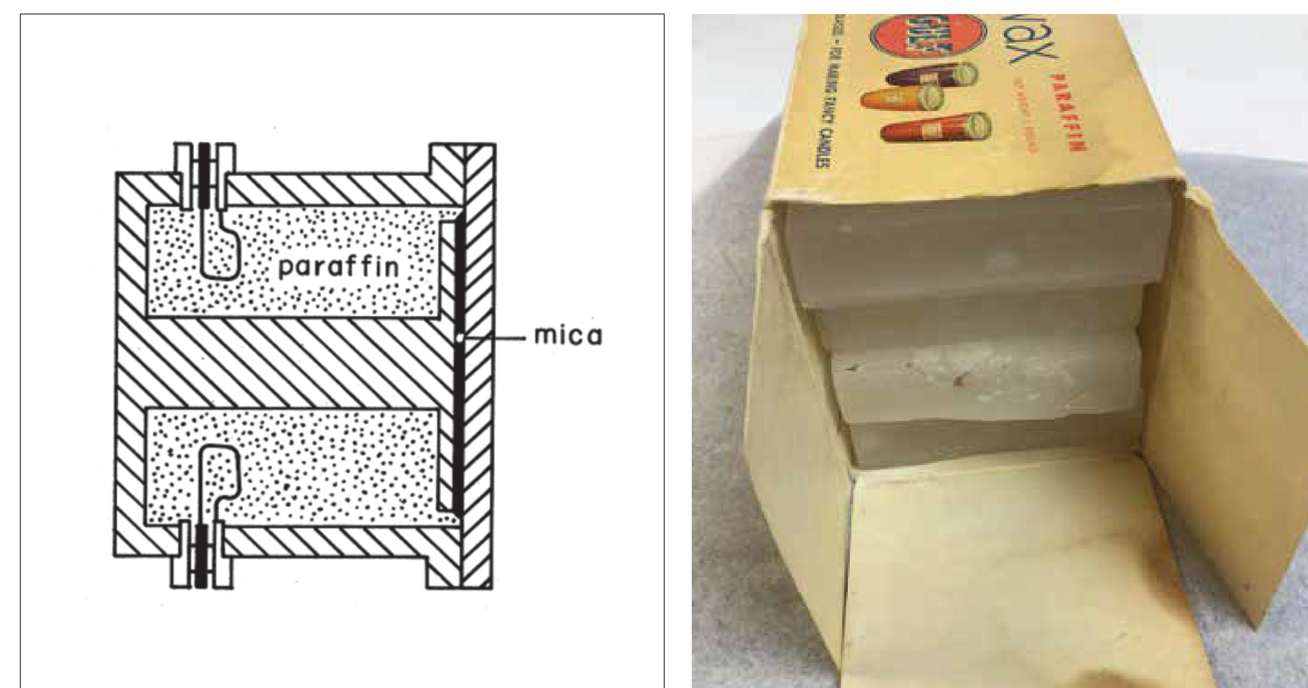


Fig. 1. NMR was first seen in this resonant cavity, filled with paraffin obtained from the First National Store on Purcell's way to work. (leftover wax in original box courtesy of Pound)

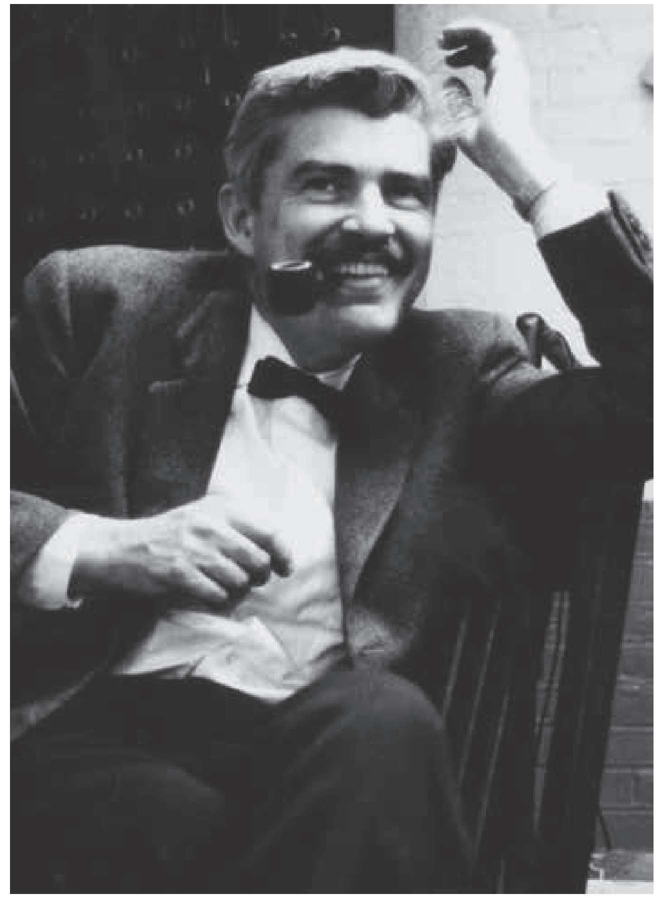



Fig. 2. Purcell (sleeves rolled up) and Pound (with pipe), in their labs, both with their characteristic bowties.

We like to think of the NMR as a Harvard Physics discovery; but it could have been an MIT discovery, Purcell remarked, were it not for the fact that "I tried to borrow a magnet down at MIT and did not succeed. That's why we had to come back and do it here. We would have done it down there if somebody had given us [a magnet]." And MIT might have another claim, because the discovery was made while they were moonlighting from their official employment at MIT (documenting their microwave technology in the legendary 28-volume "Rad Lab Series"[4]). In fact, much of the apparatus was leftover radar gear. Happily, it was Curry Street's cosmic-ray magnet[5] that was available, and the rest is history (as was the elevation of Pound and Purcell to professorships in our department).

NMR matured rapidly — with improved resolution it became a standard tool of analytical chemistry and structural biology, revealing the local molecular environments through "chemical shifts." But perhaps the application with the most impact was the development, beginning in the 1970s, of MRI[6]. This remarkable non-ionizing medical diagnostic tool produces stunning three-dimensional images, enhanced by contrast mechanisms that exploit proton density and differences in relaxation times to reveal subtle details of soft tissue. More than a billion scans have been performed, and it is no exaggeration to say that more than a million lives have been saved by MRI.

Quite apart from the satisfaction that the discoverers must have felt from these practical applications of NMR, the discovery itself was something very special. As Purcell put it in his 1952 Nobel lecture, "I have not yet lost a feeling of wonder, and of delight, that this delicate motion should reside in all the ordinary things around us, revealing itself only to him who looks for it. I remember, in the winter of our first experiments, just seven years ago, looking on snow with new eyes. There the snow lay around my doorstep — great heaps of protons quietly precessing in the Earth's magnetic field. To see the world for a moment as something rich and strange is the private reward of many a discovery."

With Thanks:

The author wishes to thank the Harvard University Archives, the Collection of Historical Scientific Instruments, Gerald Holton, Peter Galison, and Marina Werbeloff for assistance. On a personal note, I am forever grateful for the education I received in the footsteps of Bob Pound and Ed Purcell. Their contribution to human welfare was brought home to me memorably this year, as I succumbed to a bout of severe spinal stenosis (vividly imaged by Figure 3's MRI, which informed a successful surgical intervention). It was an honor to know these fine gentlemen.

References:

1. Oddly, though, not a single photograph of the experiment seems to exist — a stunning contrast with our over-photographed world of today.

2. https://www.aip.org/history-programs/niels-bohr-library/oral-histories. All quotations are from these transcripts unless noted otherwise.

3. Bloch and Purcell, respective leaders of the two groups, shared the 1952 Nobel Prize in Physics. Bloch invited the Harvard group to join in a patent, but Purcell declined, evidently feeling that fundamental discoveries in physics should be openly shared. The Stanford group filed their patent application on December 23, 1946, one day short of a year after the Harvard group's paper had been received at *The Physical Review*.

4. Prefaced with "The tremendous research and development effort that went into the development of radar and related techniques during World War II resulted not only in hundreds of radar sets for military (and some for possible peacetime) use, but also in a great body of information and new techniques in the electronics and high-frequency fields. Because this basic material may be of great value to science and engineering, it seemed most important to publish it as soon as security permitted." It is undisputable that their work with radiofrequency and microwave techniques contributed greatly to their ability to build the necessary NMR apparatus. As Pound relates, "[the choice of paraffin] was automatic for us, and there were two reasons. One is ... that it had all those protons; the other is because we were much involved in microwave spectroscopy, so we knew that paraffin had about the lowest electromagnetic absorption by ordinary dielectric laws, of anything going, you see. Paraffin was an extremely good dielectric, as we call it." Following this "swords into plowshares" thread a bit further, a good case can be made that the wartime radar project spawned the post-war inventions of the transistor, molecular spectroscopy, and the maser/laser; see, for example, Robert Buderi's *The Invention That Changed The World* (Touchstone, 1996) and Peter Galison's *Image and Logic* (Univ. of Chicago, 1997); Chapter 4 of the latter is titled "Laboratory War: Radar Philosophy and the Los Alamos Man," while the former follows the MIT Rad Lab radar project's influence on post-war science and technology.

5. The same magnet used in Street and Stevenson's 1937 confirmation of Anderson and Neddermeyer's observation of the muon (J.C. Street and E.C. Stevenson, "New Evidence for the Existence of a Particle of Mass Intermediate Between the Proton and Electron," *Phys. Rev.*, 52, 9, 1003).

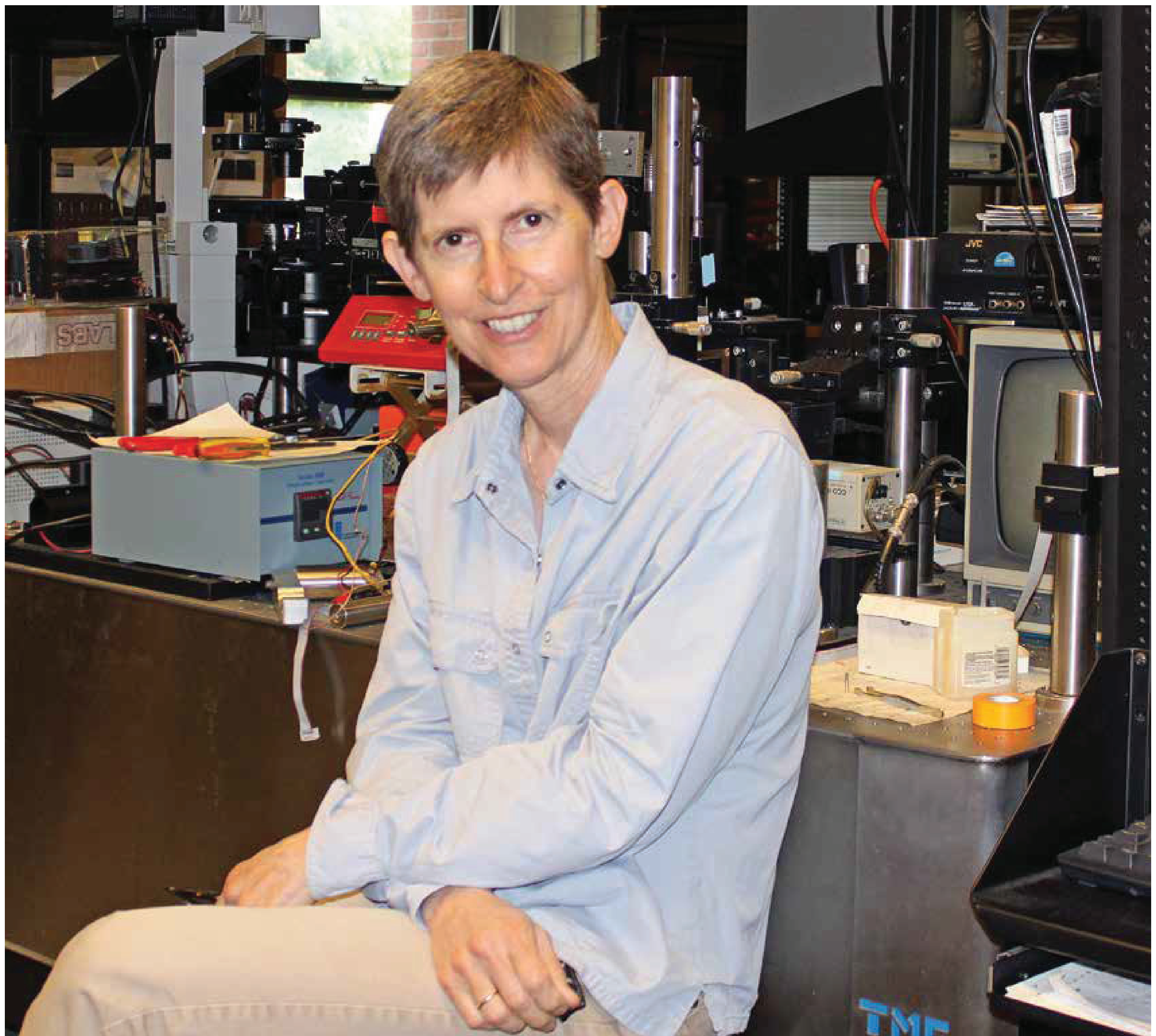
6. Unanticipated even by NMR's inventors: in the Foreword to *Magnetic Resonance Imaging* (Partain et al., Saunders, 1988) Purcell wrote "NMR imaging is so powerful, so general, and at the same time so gentle a diagnostic procedure that it is likely to become part of most people's experience. That seems obvious now, even to an antiquated NMR expert like myself who did not foresee it."

Fig. 3. MRI is good for finding bad things like this in your spine.

Mara Prentiss:

SOLVING PROBLEMS IN BIOLOGY THROUGH PHYSICS AND INGENUITY

by Steve Nadis



Mara Prentiss, the Mallinckrodt Professor of Physics, is not shy about building things, be it new devices, new experimental techniques, or new solutions. Her father was a carpenter, her grandfather a gardener, and as a child growing up in Cleveland, Prentiss was encouraged to work with tools, making use of whatever materials were available to her. When she was a teenager, she built a library in back of the family house, doing all of the carpentry and even digging a ditch more than four-feet deep, as required by local building codes. The passion to design things, which Prentiss believes she inherited from her father, has carried through into her successful and unconventional career in physics.

After receiving a Ph.D. in physics from MIT in 1986, Prentiss took her first job at AT&T Bell Laboratories where she worked under the direction of the future Physics Nobel laureate, Steven Chu. At the time, Chu was developing methods for using laser light to slow down a beam of atoms, which would, among other benefits, give researchers more time for their measurements. "Light carries momentum," Prentiss explains, "so if an atom 'grabs' the light, it gets pushed back and will slow down." Chu's approach was more sophisticated than that, as he'd devised a trap that worked by drawing atoms that interacted with light toward places where the light was brightest—places where the laser beam was, in fact, focused to less than a micron in diameter. The main problem with the trap was that it heated the atoms, which would speed them up, so the light had to be turned off intermittently to let the atoms cool and then turned back on again, off again, and so forth.

At a July 1986 conference in Helsinki, the French physicist Jean Dalibard suggested a different way of confining atoms that wouldn't heat them up, using magnetic fields in place of lasers to push atoms toward the center of the trap. Hence the notion of a "magneto-optical trap" was born. The MIT physicist David Pritchard, who also participated in the Helsinki conference, did some calculations with his then student, Eric Raab, showing that Dalibard's idea could work. Pritchard contacted Chu, whose lab was well equipped to test out a magneto-optical trap. "But Steve was headed to Japan at the time, so it fell to me and Alex Cable, who was a Bell Labs technician at the time, to give it a try," Prentiss says. She and Cable succeeded in making the first-ever magneto-optical trap. "It took a lot to make that happen," she notes, "but after some fussing it worked—quite well, in fact, confining atoms for seconds instead of milliseconds. And that was transforming from the standpoint of scientific research." The paper she coauthored with Cable, Chu, Pritchard, and Raab, "Trapping of Neutral Sodium Atoms with Radiation Pressure," appeared in a 1987 volume of *Physical Review Letters*—one year after Prentiss began a professional career that had clearly gotten off to a fast start.

Prentiss joined Harvard's physics faculty in 1991 and, four years later, became the second woman in the department (after Melissa Franklin) to receive tenure. Initially, she continued her work in "atom lithography," which involves harnessing light to control and manipulate atoms. She and her colleagues have used this approach, for instance, to engrave circuitry in silicon chips to very high precision.

Soon after arriving at Harvard, she explored a new avenue, guiding atoms with magnetic fields in a manner similar to the way fiber optic cables transmit light. These atomic wave guides could have various applications as research tools and perhaps in navigation. Prentiss looked, for instance, into making a kind of gyroscope that could measure rotation. To get an idea of how this might work, imagine a beam of sodium atoms that's shot at a circular-merry-go round. Prentiss devised a beam splitter that would send half the atoms to the left, traveling clockwise around the circular perimeter, and the other half to the right in a counterclockwise path. The beams recombine at the opposite end of the merry-go-round. If the object is stationary, the atoms will meet exactly halfway (180 degrees) around from where they started, but if the object is rotating, the atoms will meet somewhat off-center. The rotation can be assessed by determining the exact location of the rendezvous point or the time delay between the beams' arrivals at the 180-degree point.

Prentiss did not continue this work long enough to build a functioning gyroscope but did demonstrate some key elements: she could take a group of atoms traveling in a pack, change the magnetic field so that they split apart and then change the magnetic field to bring them back together. That was a big advance in itself. She also showed that she could direct atoms down specific paths, as if they were following a fiber, and guide them over substantial distances.

Prentiss might have carried these ideas much further had her career not veered off, sometime in the early-to-mid-1990s, in an entirely different direction—toward problems biological in nature. The transition, she says, happened rather gently as a result of a couple of things coming together. One motivating factor grew from her desire to give undergraduates more research opportunities, but experiments in atomic physics were quite expensive in those days and the instrumentation was delicate and easily broken. That prompted her to make inexpensive but effective "optical tweezers"—devices that use light to trap cell-sized particles and hold them still. She came up with a way to build such a device, cheaply and simply, for about $1000—something students could do themselves—and she then started to consider the kind of measurements that might be made.

Around the same time, she crossed paths with the eminent Harvard chemist George Whitesides. That came about after Prentiss asked a question to a Cornell researcher who told her Whitesides was the person she should be talking to. She and Whitesides began

“The teaching world in general is moving toward more hands-on experiences. At the same time, students are coming here with much less mechanical knowledge than they did 20 years ago, perhaps owing to a shift in culture and all the time spent on screens. We’re trying to address that in the instructional labs and machine shops.”

collaborating around 1995, coauthoring roughly 20 papers over the next two decades. Whitesides was particularly intrigued by the potential for optical tweezers, pointing out that a lot of interesting research in biology was impeded by the fact that biological materials often tend to stick together; perhaps the tweezers could pull them apart. In an early collaboration, the Prentiss and Whitesides groups studied the adhesion of E. coli bacteria to man-made surfaces, using optical tweezers to measure the strength of adhesion.

“George has been a great mentor, and the first project we did together opened up a whole new area for me,” Prentiss notes. Whitesides told her, early on, that “physicists often make incredibly precise measurements of completely uninteresting quantities.” The second bit of advice he passed on to her was this: “Don’t give me an equation for something I already know.”

Sometime around 2000, Prentiss got going on a project initiated by Whitesides concerning urinary tract infections. He wanted to figure out how uropathogenic (E. coli) bacteria find the urinary tract and how the infection progresses. It was generally known that the bacteria look for places with lots of sugar, their preferred food, but beyond that the details were murky. Whitesides realized from his previous work with Prentiss that an experiment involving optical tweezers could clarify the picture.

He procured a strain of bacteria (isolated from patients with acute pyelonephritis, a form of urinary tract infection) from researchers at Massachusetts General Hospital. He and Prentiss then created surfaces with varying concentrations of the sugar that the bacteria attached themselves to. The next step was to pull the bacteria off the surfaces with tweezers while determining the amount of force required to do so. That measurement was of keen interest because the strength of adhesion of microorganisms to biological surfaces often correlates with pathogenicity. Blocking adhesion or weakening it, conversely, could be an effective strategy for limiting the onset of disease.

“We found that the force required to separate the bacteria from the sugar-coated surfaces was quantized,” Prentiss explains. At low sugar concentrations, they could pull off the bacteria with a force of, say, two piconewtons whereas at higher concentrations, exactly twice as much force (four piconewtons) was required. The explanation for this was fairly straightforward: The bacteria have hundreds of feet, each with two “binding sites” that act like grabbers. Each grabber can hold one sugar molecule. If only one grabber out of the pair is able to latch on in places where sugar is sparse, the bacteria comes off almost immediately. In denser sugar regions, both grabbers can latch on, which gives the other legs a chance to latch on as well. In places where the bacteria do stick, people will get infected—a process that optical tweezers helped shed light on.

Prentiss has also forged a long and fruitful partnership with Harvard biologist Nancy Kleckner. “Nancy is a creative person who, like George, tends to think outside of the box. That’s why she’s open to working with physicists and why she brings me problems she hasn’t been able to solve solely with biological methods—a practice that many biologists don’t seem to be comfortable with.”

She and Kleckner looked, for instance, at the motions of chromosomes in cells, which were commonly assumed to be thermally generated. They discovered—as reported with two other colleagues in a 2008 paper for the *Journal of Cell Science*—that the chromosomes were attached to the wall of the cell’s nucleus that was being pulled, in turn, by the protein actin. The chromosomes’ motions, in other words, were not random but were instead the result of proteins moving them.

In another study—published in the *Biophysical Journal* in 2010 (again with two other colleagues)—Prentiss and Kleckner investigated the shape of chromosomes in E. coli bacteria. The prevailing view held that the chromosomes were somewhat formless, lacking a clear-cut geometry, but Prentiss and Kleckner found that they had, in fact, a distinct helical structure. “By bringing physics into biology,” Prentiss says, “I’ve been able to answer some of Nancy’s questions, and that’s been very satisfying for me.”

After getting her start in biology-based problems with Whitesides and Kleckner, Prentiss has continued this line of inquiry with physicists in her own lab where the study of the RecA protein has been a major focus over the past decade. One of RecA’s principal functions is the repair and maintenance of DNA, and Prentiss and her colleagues have gained insight into how those tasks are carried out. Her team has put forth explanations for how RecA quickly searches DNA to find a place where the double strand is broken and how it then inserts itself into that spot, removing the broken portions of genetic material and replacing them with the correct sequences. Understanding this procedure is of critical importance because cancers can arise when RecA malfunctions.

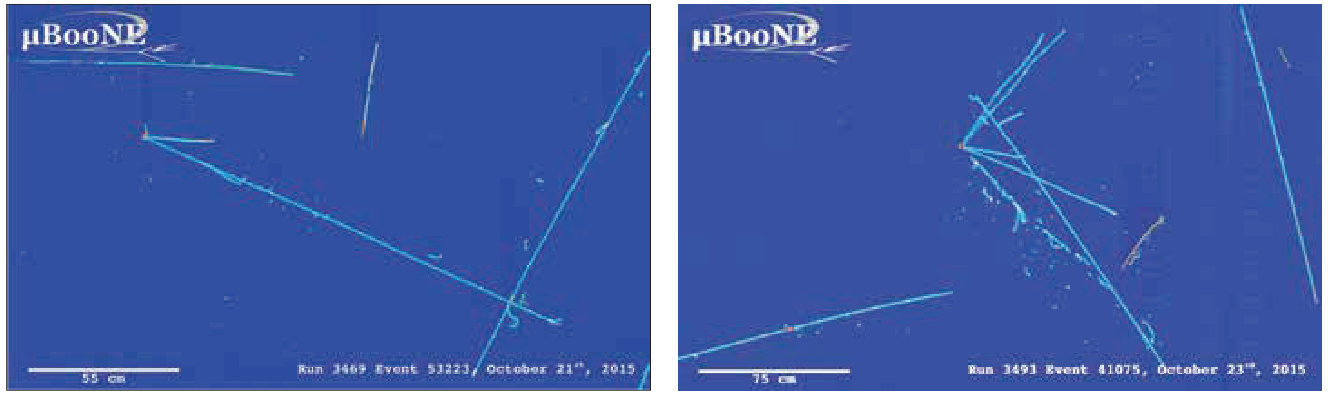
Prentiss has many responsibilities in the department in addition to her main research. Since the fall of 2018, she’s served as the Director of Graduate Studies, working closely with Co-Director Jacob Barandes and Graduate Program Administrator Lisa Cacciabaudo. The program has been growing rapidly, from about 130 Ph.D. students in 2000 to about 240 at present, making physics the largest graduate program within the Faculty of Arts and Sciences division at Harvard. With the increased number of students, Prentiss says, “comes more special cases and challenges. I like helping people, which is why I went into teaching in the first place, and this position gives me even more opportunities to do that.”

In her helping capacity, Prentiss has spent more than a decade overseeing the operation of the department’s machine shops, which have been expertly run by Stan Cotreau since 1993. She’s also headed the Instructional Physics Labs over the past five or so years. “The teaching world in general is moving toward more hands-on experiences,” Prentiss says. “At the same time, students are coming here with much less mechanical knowledge than they did 20 years ago, perhaps owing to a shift in culture and all the time spent on screens. We’re trying to address that in the instructional labs and machine shops.”

Also on the hands-on front, Prentiss has for the past three years taught a freshman seminar, “Energy: Be the Change”—an outgrowth of her 2015 book, *Energy Revolution: The Physics and the Promise of Efficient Technology*. She wrote the book as an antidote to “all the information about energy out there that simply is not true. I wanted to write something that would enable readers to understand where the numbers that are being bandied about come from and then be able to check them. I didn’t want to proselytize about any particular thing; I just wanted people to be better informed.”

In her freshman seminar, students learn the basics of energy sources (renewable and nonrenewable) and conversion technology, how energy can be used efficiently (and inefficiently), as well as the consequences of energy use on climate and the environment. Toward the end of the semester, students are asked to decide what kind of change they’d like to make. In the first year, students recommended that dorm rooms be instrumented so that people can be aware of how much energy they are using. The idea is now being tried out in newly renovated dorms. Students in the course’s second year wanted a discussion of energy to be added to freshman orientation—a suggestion that freshman deans are now contemplating. And in the third year, students created a Facebook page that allows students from all over Harvard to discuss ideas about energy use, locally and globally, as well as presenting their plans for doing something about it.

Prentiss is pleased that students seem to have enjoyed the class so far, appreciating the perspective about energy—and about technology assessment in general—that they’ve gained from it. And for her that’s pretty much what it’s all about. She’s constantly striving to uncover new things—about the physical world, the biological world, and where they interconnect—passing that on to her students, fellow scientists, or anyone else who happens to take an interest. “I love figuring out how things work,” Prentiss says. “That, in itself, gives me great joy. And it’s even better, of course, if I can share some of what I’ve learned with other people.”



HUNTING FOR NEW PHYSICS BY TRACKING ELUSIVE NEUTRINOS

by Roxanne Guenette

The Standard Model of particle physics, developed and perfected over the last half century, provides an outstanding description of all known particles and the way they interact with each other. Despite the tremendous success of that model, there are many open questions that suggest new physics lying beyond the sturdy framework it has established. One such question concerns how our universe has evolved to be dominated by matter when, initially, equal amounts of matter and antimatter should have been created.

Above: Figure 1. Two examples of neutrino interactions in the MicroBooNE liquid argon detector. The different tracks represent different particles emerging from a neutrino interaction or from cosmic rays. The color scale represents the amount of energy deposited by the particles while traveling, going from blue at the lower end of the energy scale to red at the higher end.

The simplest way to produce the current imbalance between matter and antimatter would involve a violation of charge-parity (CP) symmetry, an assumed symmetry holding that matter and antimatter can be substituted for each other in various processes without affecting physical outcomes. A CP violation, on the other hand, means that, in certain cases, matter and antimatter behave differently. Quarks have been shown to violate CP symmetry (by a very small amount), whereas electrons apparently don't violate it at all. It's possible, however, that neutrinos do violate this symmetry, and if that violation is of sufficient magnitude, it could go a long ways toward explaining the matter-antimatter asymmetry.

Neutrinos are the least understood particles of the Standard Model, despite being the most abundant constituent of matter in the universe. The discovery that neutrinos oscillate, or shift forms, between three "flavors" (electron, muon, and tau) represented a paradigm shift, implying that neutrinos have mass—a possibility that was forbidden in the earliest versions of the Standard Model. This discovery posed a significant challenge to theorists, while providing a strong indication that neutrinos are peculiar. Since then, neutrino oscillations have been closely investigated to yield a reasonably good picture of the phenomena. Pursuing higher precision studies of neutrino oscillations could furnish important clues regarding physics beyond the Standard Model.

There are a few properties of neutrinos that make them extremely interesting. First, in our understanding of neutrino oscillations, there are parameters called mixing angles—a measure of the probability of a neutrino shifting from one flavor to another—and obtaining the precise value of one of those angles (theta-13) may tell us how much CP violation can be ascribed to neutrinos. Measuring these parameters with high precision would shed direct light on the matter-antimatter imbalance. Finding a "maximal" violation of CP symmetry would be very intriguing, again pointing to new physics beyond our current grasp.

Several experiments carried out to date have observed anomalous results that could be explained by the presence of a new particle called a sterile neutrino. Such a particle would not interact with regular matter, hence the name "sterile." Discovering a particle that is not part of the Standard Model would clearly constitute a major breakthrough in the field. Furthermore, this new particle—and especially heavier particles related to it—could serve as good candidates for the long sought-after dark matter, the mysterious form of matter making up about 25% of our universe.

Finally, neutrinos are the only particle of the Standard Model that might conceivably be classified as Majorana—all other known particles being of Dirac type. Having a Majorana nature would imply that neutrinos act as their own antiparticles. This prospect, if confirmed, would have tremendous consequences in particle physics, as Majorana neutrinos are an important piece of many theories attempting to explain how neutrinos acquire their mass and how the matter-antimatter asymmetry could arise. These are only a few examples that show ways in which neutrinos could open new avenues in physics.

Guenette's group studies neutrinos in order to unlock some of their secrets. With the MicroBooNE experiment searching for sterile neutrinos, the NEXT experiment searching for Majorana neutrinos, and with the future ambitious Deep Underground Neutrino Experiment (DUNE) designed to study neutrino oscillations with unprecedented sensitivity while also searching for CP violation, the group is attacking the field's big questions from several angles. All of these experiments have one thing in common: they all use state-of-the-art noble element time projection chambers (TPC)—a kind of detector that can reconstruct a particle's three-dimensional trajectory over the passage of time. TPC detectors offer high-resolution imaging as well as excellent methods for calorimetric reconstruction, which means keeping track of the energy going into and coming out of particle interactions—both of which are extremely useful in the study of mysterious neutrinos. (Two images produced from one of these detectors are shown in Figure 1, providing an example of the imaging capabilities.)

Guenette's Group research

Guenette's group employs detectors filled with noble elements like argon and xenon. The detector principle, illustrated in Figure 2, is based on the fact that when charged particles traverse a medium, they ionize the target atoms, leaving a trace of ionized electrons behind. By applying a uniform electric field, these electrons can be diverted to a "readout plane"—analogous to a camera for electrons—in order to produce high-granularity images. These detectors, which measure the number of electrons hitting them, have been refined over the past few decades and are becoming increasingly optimized for neutrino physics.

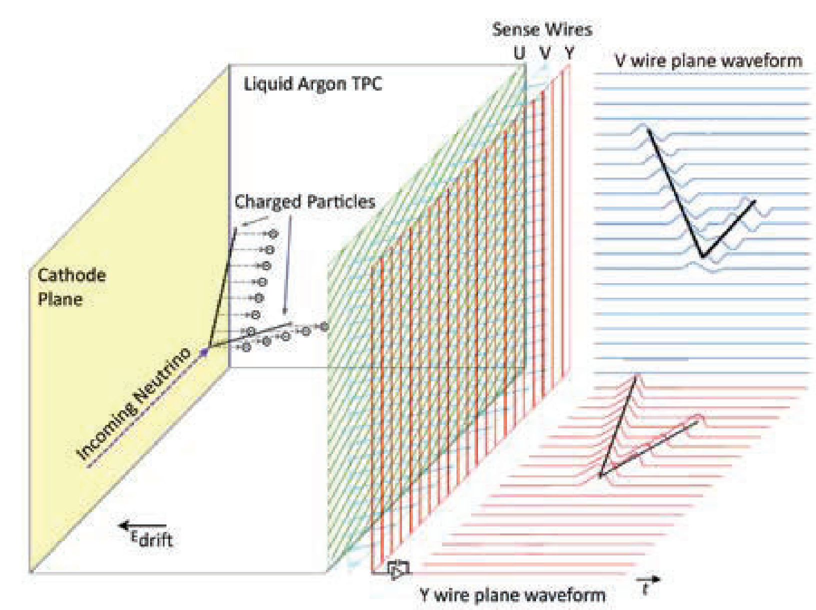


Figure 2. Schematic of the MicroBooNE liquid argon Time Projection Chamber. Ionization electrons produced by the passage of charged particles are drifted to wires planes, where their electrical signals are recorded. These detectors are optimal for neutrino interactions in the GeV regime.

MicroBooNE

The MicroBooNE experiment was proposed for three main reasons. First, to investigate a puzzling anomaly observed by the previous Liquid Scintillator Neutrino Detector (LSND) and MiniBooNE experiments, which both found curious excesses above predicted values in the number of neutrinos of a certain flavor. These excesses were not significant enough to be considered a discovery, but they intrigued the scientific community nevertheless. The most exciting hypothesis put forth to explain these puzzling excesses was the presence of a new exotic particle, the sterile neutrino, which would not interact with regular matter but could still be observed via neutrino oscillations. In this case, the beam of neutrinos would mostly produce muon neutrinos, which would eventually transform into the other two flavors. However, if sterile neutrinos exist, it's possible that muon neutrinos will transform into sterile neutrinos, which in turn will transform into electron neutrinos, producing an excess of electron neutrinos in the detectors well above expected levels. If such an excess were confirmed, it would be the first discovery of physics beyond the Standard Model, as sterile neutrinos are not incorporated in that model. And even if MicroBooNE falls short of that discovery, the experiment is still advancing our understanding of how neutrino interactions work.

In recent years, it has become apparent that neutrino interactions with heavy nuclei targets (required to increase the neutrino interaction rates) are far more complex than previously thought. Current theoretical nuclear models cannot successfully describe the experimental data, especially as the precision of that data has steadily increased. However, MicroBooNE's high-resolution detector could shed light on this issue due to its exquisite capabilities for imaging neutrino interactions. Yet another goal of MicroBooNE has been to demonstrate that it is possible to construct complex detectors on such a large scale and operate them successfully. Since the detectors needed to address the questions currently facing our field will need to be about 450 times bigger than MicroBooNE's detector, it is essential that we test the viability of these ambitious devices.

Since first joining the MicroBooNE project in late 2010, Guenette led the design and construction of the experiment's time projection chamber. The 170-ton MicroBooNE detector was constructed, assembled, and commissioned, taking its first neutrino data in the Booster Neutrino Beam at Fermilab in October 2015. After working on understanding the new detector, Guenette and her graduate student, Marco Del Tutto, focused on studying neutrino interactions with an argon target. They have obtained the first "double-differential" measurements of this sort in the low-GeV range, determining both the energy and angle of all the particles involved in this interaction. This work, comprising the first high-impact physics result from the MicroBooNE collaboration, has been described in a paper just submitted to *Physical Review Letters*.

More recently, Guenette's team has been focusing on MicroBooNE's primary mission, which is to continue the search for an excess of neutron events. Drawing at first upon a small data set, they established the soundness of their analytic approach and presented their preliminary results in the summer of 2018. The team members hope to present the results of their analysis of the full data set by the end of 2019.

DUNE

Guenette and a few members of her group are also heavily involved in the design of the most ambitious neutrino experiment ever attempted, DUNE, which is currently in the prototype stage. This long-baseline experiment, shown in Figure 3, will detect neutrinos from the world's most powerful neutrino beam to study the change of flavor, or oscillations, during the 1300-kilometer journey between the source and the detectors. Four very large liquid argon detectors (10 kilotons of argon each), located 1.4 kilometers underground, will observe neutrinos with unprecedented sensitivity. In addition to studying neutrino oscillations to search for CP violation, DUNE will be ready and waiting in the event of a rare galactic supernova explosion, where thousands of neutrinos could be observed, potentially shedding light on poorly understood supernova mechanisms. DUNE will also be searching for signs of proton decay, a clear signature of many Grand Unified Theories. After having significantly contributed to the physics rationale for the project, Guenette's Group is now in charge of testing the DUNE detectors to ensure that they live up to their design specifications and perform as expected.

NEXT

The last part of Guenette's research is dedicated to searching for neutrinoless double beta decays—a kind of radioactive decay in which two neutrons are transformed into two protons, or two protons into two neutrons, and only electrons (but no neutrinos) are emitted. Observing this peculiar decay process, which would occur without the release of neutrinos, is currently the only known experimental strategy that could reveal the true nature of neutrinos. It could tell us, specifically, whether neutrinos are "Dirac particles," which are

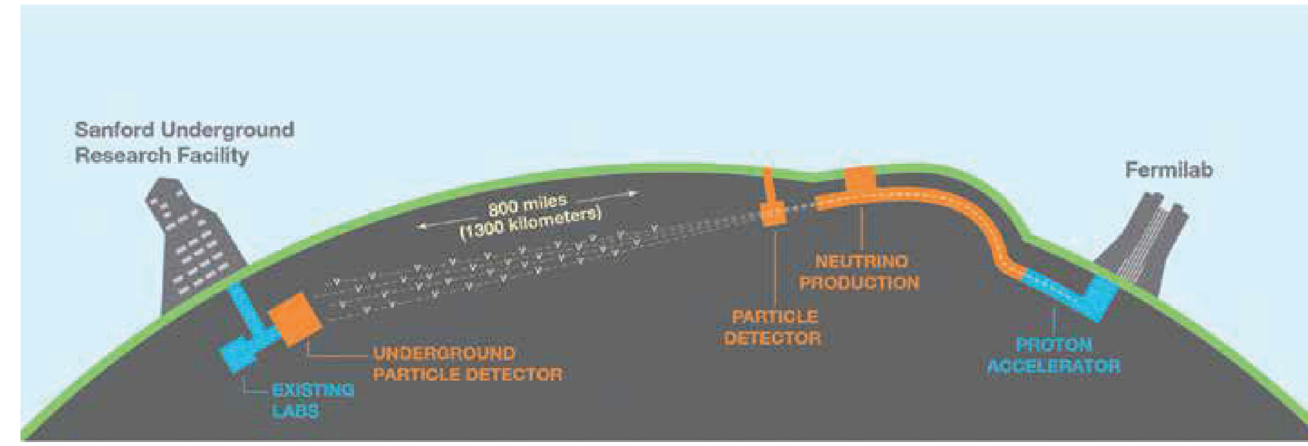


Figure 3: Schematic of the DUNE experiment. A powerful neutrino beam at Fermilab in Illinois will fire neutrinos to the SURF laboratory in the Homestake mine in South Dakota, 1300 kilometers away, where four 10-kiloton liquid argon detectors will record neutrino interactions. By studying the change in neutrino flavor from the beam to the detectors, DUNE will be able to advance the search for CP violation.

different from their antiparticles, or Majorana particles, which are their own antiparticles. Unambiguous evidence of neutrinoless beta decay would essentially constitute proof of the existence of Majorana neutrinos.

Using a different version of a noble element time projection chamber, the Neutrino Experiment with a Xenon TPC (NEXT) collaboration is hunting for Majorana neutrinos from double beta decays of xenon nuclei. The high-pressure gas time projection chamber offers the energy resolution needed to identify the sought-after decay, as well as a unique and powerful ability to determine the "topology" or shape of all events, which can clearly identify the signature of neutrinoless double beta decay. Based on recent results from the NEXT collaboration, this technology appears to be very promising and is being proposed for a next generation ton-scale detector that would be bigger than any used in double beta decay searches before.

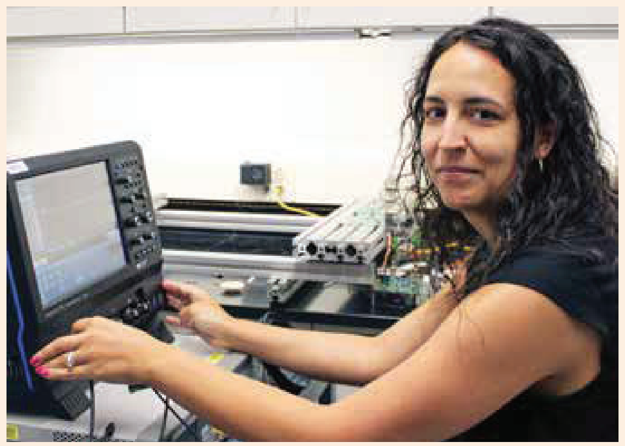
Guenette's group is working on two aspects of the NEXT experiment. The first consists of analyzing data from their already running prototype, NEXT-White. The second task they're pursuing involves the development of new detector technology with enhanced performance—namely better background control, energy resolution, and scalability. Given that several limitations were identified in the prototype design, it is essential to develop new technical solutions before proceeding to build a ton-scale detector. Guenette's group is planning to develop a new readout plane for detecting charged particles. This device will be made only of low-radioactivity photon detectors that can still provide the excellent energy resolution required while offering the same imaging capabilities to efficiently screen out background signals. This research and development project, which is aimed at significantly improving detector performances, could offer the perfect solution for the next-generation detector.

Summary and conclusions

Understanding neutrinos is, without a doubt, a high priority for the scientific community, and it's surely one of the top priorities in the nuclear and particle physics program of the United States. By investigating the different properties of neutrinos, Guenette's group is exploring uncharted territories in particle physics, and any of these research avenues could potentially lead to transformative discoveries. By pushing ahead with state-of-the-art detection techniques, this group is working hard to extract as much information as possible from these ubiquitous and elusive particles that appear to harbor many of nature's most important and closely held secrets.

Roxanne Guenette: A Short Jaunt for Neutrinos, a Giant Leap for Science?

by Steve Nadis



Roxanne Guenette

It's a long journey from the hardscrabble Quebecois town of Mont-Saint-Michel to Harvard University—about 460 miles by car though much farther in terms of the cultural differences.

Assistant Professor of Physics Roxanne Guenette grew up in that remote rural outpost, where winters are harsh and few thoughts are expended on something as ethereal as higher education. Her father is a carpenter, and her three brothers followed closely in his footsteps. No one in Guenette's extended family has gone to college except for an aunt who worked her way through community college while helping her mother take care of eight younger siblings.

A main childhood outlet for Guenette and her brothers was the quarter-mile-long racetrack her father created in a field near their home. When she was 12 and the boys even younger, they started driving beat-up cars around the track. Bigger races were sometimes held before hundreds of spectators, and Guenette worked at these events in what constituted her first official job.

Yet she had more ambitious plans, resolving in high school to study science in college and choosing the University of Montreal simply because she wouldn't have to speak English there. Although she received some scholarship money, she also got key financial assistance from a generous aunt, which enabled Guenette to realize her academic dreams.

One thing rural Quebec had afforded her was spectacular, star-filled skies, along with the occasional meteor shower and aurora—and Guenette was able to pursue her interest in astronomy as an undergraduate. In 2010, she earned a Ph.D. in physics from McGill, where she focused on gamma ray astronomy. Later that year, Guenette began a postdoc at Yale where she was introduced to neutrinos—"the least understood particles among those discovered so far, which don't fit well into the Standard Model," she says. "We know the mass of the Higgs boson, but we still don't know the masses of neutrinos."

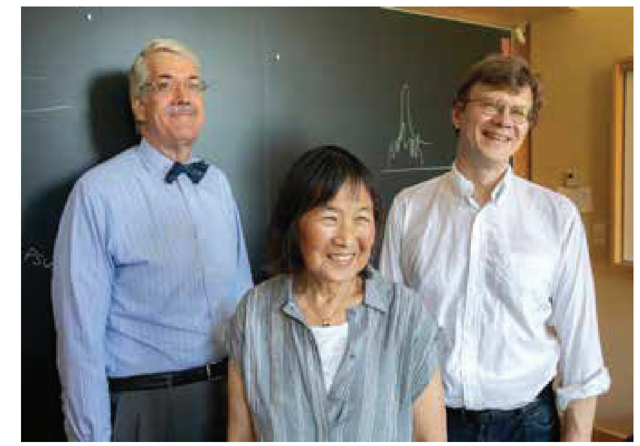
Guenette is doing her part to fill those gaps in understanding. Since joining Harvard's faculty in 2017 (after a four-year Oxford fellowship), she's participated in an experiment at Fermilab in which neutrino beams are being sent 470 meters to the MicroBooNE detector. Two other detectors will soon be installed, increasing the sensitivity of the experiment and raising the chances of discovering "sterile neutrinos"—hypothetical particles with "right-handed" spin which, if observed, would provide a window into phenomena beyond the Standard Model.

Guenette also has an important role in the Deep Underground Neutrino Experiment (DUNE), a $1.5-billion endeavor involving more than 1,000 scientists from more than 30 countries. The experiment may resolve the longstanding question of why the universe is dominated by matter as opposed to antimatter, while also enabling physicists to determine the mass "hierarchy" or ranking of the three known neutrino types (electron, muon, and tau). In pursuit of these and other goals, researchers will send neutrinos streaming at close to lightspeed on an 800-mile (1300-kilometer) trajectory from Fermilab (outside Chicago) to an underground detector in South Dakota—a significant step up in scale, expense, and velocity from the unpaved racetrack of Guenette's youth.

Of course, Guenette would not be part of this grand adventure had she not been motivated to get an education, with the help of a kind aunt. Appreciative of that fact, she's now working with first-generation student organizations, reaching out to people from low-income rural areas—just like the one she calls home.

Harvard Quantum Initiative in Science and Engineering (HQI)

by Clare Ploucha



Co-directors of the Quantum Science and Engineering Initiative John Doyle, Evelyn Hu, and Mikhail Lukin. Photo by Kris Snibbe/Harvard Staff Photographer

The quantum world of very small things has only recently been amenable to full control: this has led to an explosion in field-opening scientific research and a host of potential applications, ranging from new approaches to computation and communication, to more rapid drug discovery, to new sensors with unprecedented precision and resolution. The Harvard Quantum Initiative in Science and Engineering (HQI) was launched in November 2018 as part of Harvard's commitment to expanding research and education in this cutting-edge field at the interface of multiple science and engineering disciplines.

The new initiative, jointly funded by the Harvard Faculty of Arts and Sciences (FAS), the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS), and the Office of the Provost, seeks to build on Harvard's existing strength in quantum science and engineering (QSE) and create an environment where the emerging discipline can flourish. HQI is co-directed by John Doyle, Henry B. Silsbee Professor of Physics (FAS); Evelyn Hu, Tarr-Coyne Professor of Applied Physics and of Electrical Engineering (SEAS); and Mikhail Lukin, George Vasmer Leverett Professor of Physics (FAS).

Its strategic direction and programming priorities are shaped by an Executive Committee of faculty in Physics, Chemistry, Applied Physics, Electrical Engineering, and Computer Science.

HQI is foremost a community of researchers, drawn from a wide array of disciplines and subfields, with an intense interest in advancing the science and engineering of quantum systems and their applications. Its mission is to help scientists and engineers explore new ways to transform quantum theory into useful systems and devices. HQI has grown out of Harvard's extraordinary scientific community and builds on a rich legacy of research conducted here that was pivotal in revealing the laws of physics that govern the behavior of atoms and molecules. Today, HQI brings together scientists and engineers across diverse sectors to leverage quantum effects such as superposition and entanglement in ways that will profoundly impact how information is acquired, stored, sent, and processed.

HQI's priorities include the recruitment and development of faculty focused on both the science and engineering aspects of quantum systems, the development of an innovative education program and interdisciplinary research program, and the formation of a "quantum ecosystem," centered at Harvard, that will bring together scientists and engineers in quantum information science, nanotechnology, electrical and mechanical engineering, computation and mathematics, and will link universities, industry, and government labs. Current programs include the HQI Prize Postdoctoral Fellowship, that welcomed its first class of fellows in Fall 2019; the weekly Joint Quantum Seminar series, co-sponsored by HQI, the Max Plank-Harvard Research Center for Quantum Optics (MPHQ), and the Institute for Theoretical Atomic, Molecular, and Optical Physics (ITAMP), which features speakers whose work is of particular interest to theoretical and experimental physics, applied physics, and engineering groups working in quantum-related research; and a seed funding program to support pioneering QSE research at Harvard. To stay abreast of HQI's activities, please visit www.quantum.harvard.edu.

Fostering Community In The Pursuit Of A Common Goal — Physics

Above: Women+ of Color Project workshop, held at Harvard on October 3-5, 2019.

by Steve Nadis

Physics at Harvard is a pretty big enterprise, involving well over 400 students (graduate and undergraduate), nearly 300 postdoctoral fellows and other research scholars, more than 60 faculty, and about 35 staff members.

It's safe to assume that everything works better—in terms of research, scientific advances, learning, and the communication of knowledge—when people are getting along with one another and are reasonably content. Achieving that is, of course, a tall order, but the department is trying in a number of ways—some lighthearted in nature, like the annual fall pumpkin drop (a 38-foot plunge from an open window of Jefferson 450), and others of significantly greater gravity (though still subject to the same 9.8 meters-per-second-squared gravitational acceleration). Here's a brief look at some of the initiatives underway aimed at building and strengthening a sense of community, starting with the weightiest and proceeding to outings that are designed mainly for fun while still serving important purposes.

Increasing the diversity of students, researchers, faculty, and staff, while at the same time promoting the academic and professional advancement of all parties concerned, is an essential though formidable challenge—not only for the Harvard Physics Department but for most physics departments throughout the country. National statistics show that underrepresented minorities (including African Americans, Hispanic Americans, and Native Americans) collectively earned only about 13 percent of all Bachelor degrees granted in physics in 2017 and about 8 percent of the Ph.D. degrees.

Harvard is hoping to boost those numbers within the Physics Department, as well as to enhance the culture and overall climate, through an Equity and Inclusion (E&I) initiative started in early 2018 that's charged with augmenting the department's diversity and "cultivating a more equitable and inclusive environment for all community members." The E&I Committee is composed of three subcommittees: Recruitment and Access, headed by third-year graduate student LaNell Williams; Retention and Success, headed by third-year graduate student Cari Cesarotti; and Assessment and Tracking, headed by Donner Professor of Science John Huth.

At the moment, says Williams, "Harvard Physics, like most predominantly white institutions, doesn't fare well in terms of the number of underrepresented minorities." As of this writing, there are just five Black/African American graduate students making up just 2 percent of the department total, along with a comparable number of non-white Hispanic students—a stark illustration in itself that much more needs to be done. "It's not simply a matter of increasing the number of minority students," Williams affirms. "We also have to ensure the wellbeing of those students once they get here."

By establishing the E&I program, Harvard has acknowledged the importance of this issue, which, she notes, "is a step that many departments across the country have not yet taken. And we have started to have conversations. But conversations alone will not be enough." While there are people within the department who truly care about improving diversity and equity, Williams adds, "much of the acknowledgement and commitment needs to come from the people most able to make the needed changes—people in positions of privilege and power."

As the leader of the retention subcommittee, Cesarotti has to grapple with issues like the following: "Just because someone has been accepted into this school doesn't mean the atmosphere and environment is presently set up in a way that affords them the best chance to succeed." Therefore, she says, "it's crucial to maintain an environment where everyone feels welcome and supported."

That won't happen overnight and therefore has to be regarded as more of a long-term goal. Part of the E&I committee's focus in the short run has been to draft a yet-to-be-released code of conduct that spells out the kind of behaviors that are expected within the department and those that won't be tolerated, while at the same time pushing for the values and actions that, as Cesarotti puts it, "help create an environment where people can thrive academically and personally." Data and ideas from a "climate survey" carried out by the Physics Graduate Student Council (PGSC) are being incorporated into the code of conduct.

The committee hasn't yet figured out the best way of getting the community at large to embrace their code when it's ready for release, nor have they worked out the details of how it's going to be enforced. "There needs to be some way we can constructively improve the environment beyond just filing complaints," Cesarotti acknowledges. "Because it's clear that progress won't be made by telling everyone they're wrong."

Enforcement can be tricky, Huth agrees, because going about it in the wrong way could create a backlash that's counterproductive. "Lecturing people isn't always the most effective strategy. The trick is to make the roll-out of the code of conduct less of a lecture and more of an awareness-raising experience." The code has to be introduced in such a way, he adds, "that it gives people a desire to buy in rather than turning them away."

What needs to happen for principles of equity and inclusion to gain widespread support, Cesarotti adds, "is for people to come to understand that there is merit in diversity, merit in having different ways of thinking—recognizing that everyone doesn't have to fit the same template of what has traditionally been considered successful."

It's going to take time to transform the department in this way, which can be frustrating on one level, admits Huth. "The upside of the slow pace is that it could ultimately lead to stronger acceptance among the faculty and everyone else in the department."

Being physicists, Huth and his peers don't necessarily have the training needed to deal with complex social issues. Consequently, he and other members of the E&I committee had been pushing to get someone with expertise in this area to help out, just as Harvard's School of Engineering and Applied Sciences had hired a Director of Diversity, Inclusion, and Belonging in 2017. The Physics Department —with backing from the Dean, as well as budgetary approval—has just followed suit, hiring Benita Wolff to serve as its first-ever Equity & Inclusion Administrative Fellow. Wolff—who'd previously been the Director of Diversity and Inclusion at the University of Nevada, Las Vegas, School of Medicine—started at Harvard in October 2019.

"What needs to happen for principles of Equity and Inclusion to gain widespread support, Cesarotti adds, "is for people to come to understand that there is merit in diversity, merit in having different ways of thinking—recognizing that everyone doesn't have to fit the same template of what has traditionally been considered successful."

Participants of the Retreat for Women in Physics and Astronomy at Harvard, May 2019

Huth is not alone in welcoming the news. "There's hope in the long run," he says, "provided we keep working on these issues, steadfastly and diligently, over the years."

In the meantime, there are a variety of parallel efforts going on in the department. Cesarotti, for example, is a member of the Women in Physics (WIP) group, which holds monthly dinners and runs occasional book group discussions. In the spring, as part of Harvard's academic fair known as Advising Fortnight, graduate students led interested undergraduates on physics lab tours and discussions of theoretical research. After going to physics conferences in which more than 90 percent of the participants are male, Cesarotti really looks forward to the WIP dinners. "It's nice to go into a room where everyone is a woman and a physicist," she says, "and where you can always find a sympathetic and empathetic ear."

In May 2019, 30 female graduate students and postdocs from the Harvard physics, applied physics, and astronomy departments spent three days on a professional development retreat in Cape Cod during which they honed their writing, negotiation, and communication skills. The retreat was sponsored by the Heising-Simons Foundation (HSF) and organized by Professor Jenny Hoffman, who serves on HSF's Physics and Astronomy Leadership Council.

Events like this and the foregoing can clearly offer benefits as well as boost spirits among participants. And there certainly are things to cheer about. Admittance numbers have gone up in the department so that women now make up roughly 40 percent of the graduate student body, according to Cesarotti. Nevertheless, she and others still recognize that the inclusion of women in physics—at Harvard and beyond—is at different stages for Asian and white women than it is for non-white Hispanic and black women. Therefore, Cesarotti points out, increasing the representation of women in the department is not a uniform measure that can, in itself, address all long held disparities at once.

On a separate front, Williams has cofounded (with Lavontria Miché Aaron of Johns Hopkins) the Women+ of Color Project (WoCP) aimed at a counteracting the current imbalance whereby fewer than 100 black women have received Ph.D. degrees in physics at any American university in history to date, as compared to 22,000 white men who've received the same degrees. As a first step, the WoCP held a three-day workshop (October 3-5, 2019) at the Harvard Physics Department aimed at providing help for underrepresented (black, native American/indigenous, and Latinx) women with "applying to graduate school [in physics], surviving graduate school, maintaining research productivity, and growing [their] academic careers." With support from the Heising-Simons Foundation, the program provided free travel, lodging, and meals to the 20 students accepted to the October event out of 150 applicants. Williams is now trying to help other universities hold similar workshops to benefit underrepresented women in physics and redress the aforementioned Ph.D. imbalance.

Earlier this year (in February 2019), Williams and Delilah Gates, a fifth-year graduate student, ran a Black History Month movie series. "We did this informally in 2018, and since people liked it so much, we brought it back this year with funding from the Physics Graduate Student Council," says Gates, who picked this year's movies—Get Out, BlacKkKlansman, The Tuskegee Airmen, and Black Panther—and arranged for the food. Things went well enough that she plans to organize a film series next year too.

The movies, which are open to and attended by students of all racial and ethnic backgrounds, are followed by a discussion. "There's often a feeling people have that if you're going to talk about race, they might worry that they don't know enough to attend and participate," Gates says. "But the movies provide a good jumping-off point, allowing people to see how the struggles one group has faced might be similar to struggles their own group has gone through. It makes you appreciate how connected we all are." (In April 2019, a physics graduate student also arranged for a film showing as part of a broader Asian Pacific Islander Heritage Month celebration at Harvard. And in June, an LGBT group in the Physics and Applied Physics Departments screened the movie Pride in addition to hosting a separate Pride Week tea event.)

Gates is president of the PGSC for the 2019-2020 year, and the group sponsors less topical agenda items such as the Friday social hours with beer and pizza, as well as the occasional ice cream party. These events provide regular opportunities for graduate students to talk to each other about physics and hopefully about topics that are unrelated to their chosen field.

Another thing the department does to build community is to put all first-year graduate student offices together in the so-called G1 area. "Having the offices together is a wonderful idea," Gates says. "People in my cohort got to know each other early on and many of us have become close. Some of us have ended up living together in off-campus houses, and a few of my classmates have played Dungeons and Dragons together for four years straight. We also come to learn about broader areas of physics than if we only interacted with students in our research subgroups."

Apart from these social gatherings, the PGSC carries out the aforementioned climate survey and a mental health survey that started in 2018. Seventy-six percent of the students responded to the latter survey, according to third-year graduate student Zoe Zhu who is overseeing this effort with another graduate student Jonathan Haefner. "We want to increase awareness of mental health issues among graduate students and provide a channel for people experiencing problems," says Zhu. "Resources exist and all they need to do is ask for help."

The survey has shown, for instance, that depression among physics graduate students is not better or worse than in other departments, though women in physics tend to be much lonelier than men. The survey also revealed that most students are not exercising enough, so the plan is to introduce team sports within the department both to forge new ties within the community and to improve physical and mental well-being. There's also a plan to introduce graduate-only seminars soon, possibly as early as this fall, to build confidence among inexperienced presenters and make students more comfortable speaking up in group settings.

Meanwhile, there are journal clubs in various fields of physics where graduate students get to introduce papers written by others in the field. "It's good practice for the presenters and also for audience members who get to learn about new research," says Zeyu Hao, a third-year graduate student who regularly attends the weekly sessions of the condensed matter journal club. The high-energy theory journal club meets once a week too. "It's a non-threatening environment," comments fifth-year graduate student Scott Collier. "One of the best parts about being at Harvard is having the chance to interact with so many excellent students. We really learn a lot from each other."

There are some events intended for the entire department—undergraduates, graduate students, postdocs, fellows, faculty, and staff—that hundreds of people typically attend, including the annual physics barbeque held in September and the winter party held in December. Everyone is also welcome for the teatimes that precede the weekly physics colloquia.

The faculty typically hold meetings every Monday, eating lunch together beforehand. About nine times a year, undergraduates and graduate students join in during the lunch hour, which allows them to talk with professors in a casual setting. Director of Administration Anne Trubia also meets with graduate students on a regular basis for lunch at the Harvard Faculty Club—in this way reaching out to students who might not otherwise have much occasion to come to the department's staff offices. In a recently introduced program, a professor will periodically meet with the staff to give informal talks on the physics topics they specialize in. "The response to the first two 'Let's Talk Physics' events has been really enthusiastic," says Mary McCarthy, associate director of administration. "These introductory physics lectures foster an inclusive vibe and support a deeper understanding of the research going on around us."

Faculty and staff also get together in annual gatherings organized by Professor Cumrun Vafa, who especially enjoys meeting the families of his colleagues and coworkers—something that's not possible in the course of a normal business day. "There's always great food and fun games," says Jolanta Davis, Administrator to the Department Chair. "Events like this are good for the department and also good for the families."

The staff holds some events on its own, such as Fruitful Thursdays—weekly occasions for healthful snacks and a welcome break. One popular way of boosting morale has been through the adoption of alternative work schedules. The staff also engages in a Yankee gift swap every December, a Valentine's day breakfast, and team-building summer outings that have included a scavenger hunt at the Museum of Fine Arts and a trip to "Escape the Room" in downtown Boston, where groups of staff members found themselves locked up in a room. They had to join forces and gather clues in order to find a way out so they could escape confinement—a hilarious afternoon of problem solving and team building.

Outings of this sort—and game nights, movie nights, pizza nights, bingo nights, pottery-painting junkets, and the like—"absolutely serve a bigger purpose than just fun," says Hannah Belcher, an assistant to Professors Philip Kim and Amir Yacoby who heads the staff social committee. "Work can be busy and sometimes stressful. There's a lot of value in getting to know people outside the day-to-day professional setting. Events like this help build respect for colleagues, which in turn helps the work. The fact that we regularly have events like this shows that the department cares about how we feel and tries to create an atmosphere that allows us to strengthen these important relationships with our colleagues."

While there is still a need for greater connectivity and inclusion, the Department is demonstrating a strong commitment to making it a more inviting, inclusive, and supportive place for all people, which should, in turn, make it a better place both for learning and doing physics.

Academic Programs

David Morin and Jacob Barandes

In recognition of their outstanding contributions and generous dedication to our undergraduate concentrators and graduate students, Dr. David Morin and Dr. Jacob Barandes have been named as Co-Directors of Undergraduate and Graduate Studies, respectively. In May 2019, David was also promoted to the rank of Senior Lecturer.

The two Co-Directors both graduated from the Harvard Physics program in high-energy theory: David defended his Ph.D. in 1996 (advisor: Howard Georgi), Jacob in 2011 (advisor: Frederick Denef). The pull of Harvard Physics remained so strong on both that they stayed after graduation and now devote their attention to teaching physics classes, running our department's academic programs, and engaging in scholarly pursuits.

David manages the undergraduate program in the Physics and Chem/Phys concentrations and teaches undergraduate courses (most recently, 15A: Introductory Mechanics and Relativity, and 125: Widely Applied Physics). He has channeled his formidable expertise as an educator and his deep knowledge of the subject into several very popular physics textbooks, including *Introduction to Classical Mechanics*. He also co-authored the 3rd edition of Ed Purcell's classic *Electricity and Magnetism* and, most recently, published a book of mathematical puzzles, *The Green-Eyed Dragons and Other Mathematical Monsters*.

Jacob oversees the Department of Physics graduate program and admissions process, and considers it one of his most important duties to provide empathetic guidance to students working through various challenges of graduate school. As the Director Graduate Studies for the FAS Science, he works across the graduate programs that make up Harvard's Division of Science on admissions, best practices, and finances.

Jacob also teaches graduate classes: Physics 232: Advanced Classical Electromagnetism; 210: General Theory of Relativity; and 302A: Teaching and Communicating Physics, a required course that offers new graduate students practical advice and hands-on experience in becoming teachers. In addition, as of Fall 2019, Jacob's innovative course Physics 19: Introduction to Theoretical Physics (previously Physics S-10 and Physics 101), has been made part of the freshman sequence for aspiring undergraduate physics concentrators. This introductory course covers a wide set of first-principles and foundational topics for theoretical physics, and it is intended to give a broad preview of more advanced physics courses. Jacob is currently finishing a book based on this course and also working on papers exploring several topics at the nexus of physics and philosophy.

David and Jacob have been honored with Prizes for Excellence in Teaching by the undergraduate members of Alpha Iota, the Harvard College chapter of the Phi Beta Kappa Society, and both feature frequently on the list of Derek Bok Center's Excellence in Teaching awardees. "Best professor ever" is a persistent refrain in their course evaluations.

Congratulations, David (left) and Jacob!

PROGRAMS

Undergraduate Program

Above: Harvard College Physics & Chem/Phys Class of 2019

NEW CONCENTRATORS

The Physics Department welcomed a new group of 56 sophomores who signed up for the Physics and Chem/Phys concentrations, many of them pursuing joint concentrations or secondaries in other fields. These fields include computer science, philosophy, astrophysics, mathematics, earth and planetary sciences, comparative study of religion, engineering, and statistics.

CAREER PATHS

This past year's graduating class consisted of 47 Physics and Chem/Phys concentrators. Eighteen of these students moved on to graduate school. They are now attending 13 different institutions (MIT leads the way with four students) to study physics, chemistry, astronomy, mathematics, engineering, and computer science. Others are attending medical school and law school, one student is performing as an opera singer, and another is training with the US men's national rowing team. Still others have entered the workforce in software, consulting, data science, finance, and filmmaking.

PRIZES & AWARDS

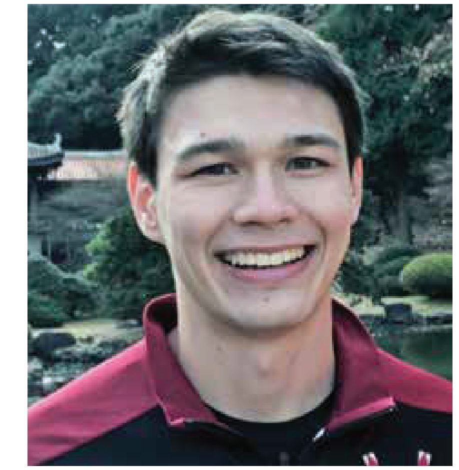
Vaibhav Mohanty won a Marshall Scholarship and is studying theoretical physics at Oxford (followed by the Harvard/MIT M.D.-Ph.D. program). Rodrigo Cordova was awarded a Gates Cambridge Scholarship and is pursuing archaeology at Cambridge (followed by grad school in astronomy at Princeton). Elba Alonso Monsalve won a Harvard-Cambridge Scholarship and is studying mathematics at Cambridge (followed by grad school in physics at MIT). Three students were awarded National Science Foundation Graduate Research Fellowships: Madeline Bernstein, Cameron Krulewski, and Eunice Lee. Brian Marinelli was the recipient of the Physics Department's Sanderson Award, given to the graduating Physics concentrator with the highest grade average in concentration courses.

STUDENTS' RESEARCH

This past summer, roughly 40 Physics and Chem/Phys concentrators engaged in full-time research on campus. Each year, this research is made possible by generous funding from a number of sources: the Program for Research in Science and Engineering (PRISE), the Harvard College Research Program (HCRP), the Haase Family Fund, the Stephen Brook Fels Fund, the Herchel Smith Fellowship, and individual lab funds.

FUN STUFF

The Society of Physics Students (SPS) was active again last year with many events, including the ever-popular pumpkin drop and Visitas liquid nitrogen ice cream party. Numerous social events were held in the Undergraduate Study (Jefferson 251), ranging from a welcome event for first-year students to a dinner following the senior picture. Carol Davis, the Undergraduate Student Coordinator, maintains the Study as an inviting space for concentrators to gather, which often entails stocking it with treats. On the more academic side, the SPS helped organize the annual Harvard-MIT SPS Research Conference and held a panel on grad schools hosted by graduating seniors. In recognition of its efforts, Harvard's SPS chapter was presented with an Outstanding Chapter award by the National SPS Council.



Samuel Detmer

STUDENT PROFILE

Samuel Detmer '20 enjoys studying the application of chemistry and physics to a wide variety of research topics. He has been studying the quasi-one-dimensional surface of lithium purple bronze (LPB) since the start of his junior year in the lab of Professor Jennifer Hoffman. LPB is unique because of its anisotropic electrical conductivity and unusual behavior as a one-dimensional superconductor. After presenting his research at the March meeting of the American Physical Society, Samuel is now writing a paper on the discovery that chains of atoms on the surface of LPB tend to resonate, or "turn on," at various energies. These resonances may indicate the presence of fermionic particles trapped within the chains of atoms, thus providing insight into causes for LPB's unusual transition to superconductivity at low temperature.

As a sophomore, Samuel worked with Professor Gerald Gabrielse on the ATRAP project at CERN. ATRAP combines antimatter protons with positrons to form the antimatter equivalent of hydrogen atoms. The energy levels of these antimatter atoms are then measured through laser spectroscopy and compared with those of normal hydrogen atoms. The comparison is a precise test of CPT invariance, a symmetry that is foundational to the Standard Model but also suspect because of the matter-antimatter imbalance in the universe. With support from the Harvard College Research Program, Samuel worked to design a new quench detection system for the superconducting magnets used to trap antimatter atoms in the ATRAP experiment. After working in laboratories at Harvard and Northwestern to design and test his device, he finished the equipment at CERN.

This past summer, Samuel conducted research at Cambridge University in England through the Harvard-Cambridge Summer Fellowship. Working in the lab of Professor Michele Vendruscolo at the Centre for Misfolding Diseases, his projects focused on two aspects of Alzheimer's disease: first, quantification of the toxic amyloid-beta species that cause Alzheimer's in an *in vivo* model, in order to gauge the efficacy of various candidate drugs; second, better characterization of the tau oligomers that occur inside the neurons of patients with Alzheimer's.

Samuel is currently pursuing a master's in Physics and a bachelor's degree in Chemistry and Physics through the advanced standing program at Harvard. In addition to his interests in the sciences, Samuel also walked onto the lightweight crew team and rowed as a freshman and sophomore. In his junior year he transferred to heavyweight crew and currently rows on the heavyweight team. Samuel is also writing a research paper on the use of numbers in ancient literary texts under the supervision of Dr. Richard Saley in the Harvard Near Eastern Languages and Civilizations Department. He participates in a number of faith-based groups on campus and seeks to promote dialogue between different religious organizations. Motivated by his experiences in undergraduate research, Samuel plans to enter a Ph.D. program and continue research after graduating from Harvard.

PROGRAMS

Graduate Program

THE PH.D. CLASS ENTERING IN 2019

The incoming students entering the Physics Ph.D. program in Fall 2019 hail from a remarkable set of places, including the American states of Arizona, California, Colorado, Connecticut, Illinois, Iowa, Maryland, Minnesota, New Jersey, New York, Pennsylvania, and Texas, and the countries of Australia, Canada, China, Croatia, Denmark, Germany, India, Iran, Israel, Mexico, Spain, South Korea, Switzerland, and Taiwan.

THE PHYSICS GRADUATE STUDENT COUNCIL

Created by our Physics Ph.D. students in the spring of 2009, the Physics Graduate Student Council is an important part of the Physics Department. The council provides a forum for graduate students to propose new initiatives and discuss issues of common concern. It organizes social events like the popular biweekly Friday afternoon social hour and monthly movie nights. The council also administers annual surveys to graduate students on advising and the school's overall climate. The council's new president this year is Delilah Gates, and its other members (in alphabetical order) are Jonathan Haefner, Ian Kivlichan, Nathaniel Leitao, Cole Meisenhelder, Noah Miller, Aditya Parikh, Ana Maria Raclariu, Yanting Teng, and Zoe (Ziyan) Zhu.

This year the council organized a number of programs and events. These included the council's buddy program, which kicked off with an opening dinner and matched 40 Ph.D. students with more senior mentors in the graduate program. The council also organized an outing to Coolidge Corner Theatre to see a special 50th anniversary showing of 2001: A Space Odyssey (Paul Dirac's favorite film), put together a Pi Day celebration on March 14 (many pies were eaten), orchestrated a game night for newly admitted physics Ph.D. students

during the department's annual open house, and held a watch party for one of the USA World Cup games (in collaboration with the department's Women in Physics group).

PANEL EVENTS

As part of our physics program's efforts to inform students about opportunities to apply for outside funding, the department organized a panel discussion on October 4 covering issues related to external fellowships. Moderated by the Prof. John Huth and the Co-Director of Graduate Studies, Dr. Jacob Barandes, the panel included (in alphabetical order) Ph.D. students Iris Cong, Will Conway, Nat Tantivasadakarn, and Elana Urbach, who shared their experiences and answered questions from the first- and second-year Ph.D. students in attendance.

On November 14, the Physics Graduate Student Council held a panel event on internship opportunities for graduate students. On the panel were four of our current physics Ph.D. students: Ishita Dasgupta, who talked about her work on artificial intelligence at DeepMind; Ruffin Evans, who discussed his internship working on self-driving cars at Waymo; Ian Kivlichan, who shared his experiences working in quantum computing at the Google Quantum AI Lab and Microsoft Research; and Grey Wilburn, who spoke about his internship working in baseball research and development for the Tampa Bay Rays.

On March 29, the department hosted a panel for graduate students on applying for post-doctoral fellowship positions. On the panel were post-doctoral fellows representing a variety of research groups in the physics department in areas ranging from quantum gravity and astrophysics to condensed matter and particle physics.

PHOTO BY TONY RINALDO

Goldhaber Prize

The Maurice and Gertrude Goldhaber Prize fund was established in honor of two great physicists: Dr. Maurice Goldhaber, who was an experimental nuclear physicist and one of the pioneers of modern physics, and his wife Dr. Gertrude Scharff Goldhaber, a physicist who contributed to scientists' understanding of nuclear fission and the structure of atomic nuclei.

Georges Obied

2019 GOLDHABER PRIZE WINNER

Before joining the Harvard Physics Ph.D. program, Georges Obied was an international student from Syria at Johns Hopkins University, where he received his B.S. and M.A. in physics and mathematics. Now, as a fourth-year graduate student, Georges is interested in questions about fundamental physics that can be answered by cosmological observations.

His work, under the supervision of Prof. Cumrun Vafa, focuses on differentiating low-energy effective field theories that admit an ultraviolet completion within a quantum-gravity framework from those that don't. The latter set is called "the Swampland" (a term coined by Prof. Vafa in 2006). In particular, Georges explores Swampland criteria that have cosmological implications for the past, present, and future universe.

In addition to his Swampland research, Georges has also worked on using Cosmic Microwave Background data to study deviations from the simplest inflation and reionization paradigms in a model-independent way with Prof. Cora Dvorkin.

Outside of physics, Georges enjoys playing squash with friends and rowing on the Harvard Dudley team.

Ann Wang

2019 GOLDHABER PRIZE WINNER

Ann Wang entered college thinking that she was going to go into medicine and major in bioengineering, but she switched to physics after a freshman electromagnetism course. Her interest in experimental high-energy physics grew after conducting research with Prof. Maria Spiropulu in the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC). Ann graduated with a B.S. in physics from Caltech in 2015.

After beginning her graduate studies at Harvard, Ann joined the ATLAS experiment, one of the four other experiments on the LHC ring. Advised by Prof. Melissa Franklin, the majority of Ann's Ph.D. work has involved upgrading the muon detectors for future LHC collisions. She has recently joined an effort to search for long-lived particles that deposit a large ionization energy in the inner tracker of ATLAS.

*Includes awards from 2017–2018

Stephen Carr

2019 GOLDHABER PRIZE WINNER

Stephen Carr studied undergraduate physics and mathematics at Columbia University, while also exploring experimental atomic, molecular, and optical physics and condensed-matter research. In his last year, he worked on numerical PDEs and Density Functional Theory, and continued those interests at Harvard by joining Prof. Efthimios Kaxiras' research group.

During Stephen's first years in the Ph.D. program, he collaborated closely with visiting mathematicians to study electronic structure in twisted 2D materials, or "twistronics." These systems are challenging to model because their characteristic size is orders of magnitude larger than any of the constituent crystals. But the mix of exciting physics and computational challenge was a good fit.

Stephen continues to work with members of the Kaxiras group on multiscale mechanical and electronic models. Of recent focus are superconducting twisted-bilayer-graphene devices. Careful comparison with experimental collaborators has shown good agreement, but there are still plenty of unanswered questions.

Harry Levine

2019 GOLDHABER PRIZE WINNER

Harry Levine received his undergraduate degree in physics and mathematics from Stanford University. He did undergraduate research in the Schleier-Smith lab, working on laser physics and two-photon absorption in atomic vapors.

At Harvard, Harry joined the Lukin group in 2015 and worked within a team to develop a platform for quantum information science based on arrays of individual neutral atoms in optical tweezers. With this team, he developed new techniques for coherent control of the atomic system, enabling the experimental study of a widely tunable model of quantum magnetism. More recently, the team demonstrated new approaches to engineer entanglement within the system and showed the creation of a 20-atom "Schrödinger cat" state, which is the largest fully entangled quantum system to date. Harry hopes to continue experiments with this platform, focusing on applications in quantum information processing and in particular on using this quantum system to solve real-world optimization problems.

GSAS Merit Fellowship

The Merit Fellowship is awarded by GSAS to Ph.D students based on the quality of their academic work and research. To be eligible, students must be in their fourth year or earlier and have passed their qualifying exams. Students must be nominated by their home departments, and the Physics Department typically nominates one or two Ph.D students for the award each year. Students who win the award receive partial or complete stipend support from GSAS for one semester.

Hofie Hannesdottir

2019 GSAS MERIT FELLOWSHIP WINNER

Hofie Hannesdottir completed her B.S. in physics at the University of Iceland in Reykjavik. She spent her senior year at the University of California, Santa Barbara, as an exchange student. At Harvard, Hofie joined Prof. Matthew Schwartz's research group and is currently a fourth year Ph.D. candidate working in high-energy particle theory.

Hofie is interested in understanding the fundamental laws of nature that govern how particles interact. In particular, she is trying to figure out a consistent way to define particles in quantum field theory (QFT). To approach these questions, she studies infrared (IR) divergences, which arise in QFT calculations as infinite probabilities for certain processes to occur. These infinite probabilities are unphysical since measurements are always finite and probabilities are at most 100%. IR divergences are believed to be a result of an inaccurate description of particles in QFT.

To see the problem, consider the electron. It seems to be a particle, but wherever it goes, it drags around an electromagnetic field with it. This field is made up of other particles, called photons. So what part is the electron and what part is the photon? If one tries to strip off all the photons from the electron, the resulting theory is pathological. Instead, Hofie is using insights into the universality of long-distance interactions among charged particles to derive a practical method to isolate the electrons from their photon cloud. Doing so could lead not just to a solid foundation for quantum field theory, but also to more precise predictions that can be compared to data from the Large Hadron Collider.

Trond Andersen

2019 GSAS MERIT FELLOWSHIP WINNER

Trond grew up in Norway and represented the Norwegian team at the International Physics Olympiad (IPhO) in Bangkok in 2011. A year later, he began his undergraduate degree at MIT, doing research on two-dimensional materials in Pablo Jarillo-Herrero's group. In particular, Trond studied graphene optoelectronics, phonon-polaritons in hexagonal boron nitride, and vibrational modes in transition metal dichalcogenides. For this work, presented in six publications, Trond received the Joel M. Orloff award for best undergraduate research, and was MIT's nominee for the APS LeRoy Apker award.

Now Trond is a fourth-year graduate student in the Lukin group, using atomic-scale defects in diamonds to locally probe current fluctuations in graphene devices. With this new technique, his group recently discovered an instability in biased graphene that occurs when the electronic drift velocity exceeds the speed of sound. The effective electronic population inversion causes high rates of stimulated phonon emission, known as Cerenkov amplification. This work was recently published in *Science* magazine.

Graduate Student Awards and Fellowships*

Frederick Sheldon Traveling Fellowship
Ann Wang

Harvey Fellowship
Daniel Ang

Hertz Foundation Fellowship
Alex Atanasov
Dolev Bluvstein

IBM Fellowship
Charlotte Boettcher

NDSEG Fellowship
Alex Atanasov
Madelyn Cain
Michelle Chalupnik
Brandon Grinkemeyer
Patrick Ledwith
Nathaniel Vilas

Neekeyfar Award for Graduate Study
Alek Bedroya

NSF Graduate Research Fellowship Program
Alex Atanasov
Oscar Araiza Bravo
Dolev Bluvstein
Cari Cesarotti
Taylor Contreras
Spencer Doyle
Patrick Forrester
Lev Kendrick
Saranesh Prembabu
Kenneth Wan

Paul & Daisy Soros Fellowship for New Americans
Grace Pan
Grace Zhang

Physics World Science-Communication Award
Liujun Zou

Certificate of Distinction in Teaching: Fall 2018
Yu-Ting Chen
Barak Gabai
Julia Gonski
Hofie Hannesdottir
Alex Keesling
James Mitchell
Sruthi Narayanan
Monica Pate
Abigail Plummer
Rhine Samajdar
Elliot Schneider
Tatiana Webb
Jeremy Yodh
Liujun Zou

*Includes awards from 2018–2019.

Recent Graduates

Jesse Amato-Grill
Thesis: A Fast ^{7}Li-Based Quantum Simulator
Advisor: Markus Greiner

Victor Buza
Thesis: Constraining Primordial Gravitational Waves Using Present and Future CMB Experiments
Advisor: John Kovac

Andrew Chael
Thesis: Simulating and Imaging Supermassive Black Hole Accretion Flows
Advisor: Cora Dvorkin

Christie Chiu
Thesis: Quantum Simulation of The Hubbard Model
Advisor: Markus Greiner

Karri DiPetrillo
Thesis: Search for long-lived, massive particles in events with a displaced vertex and a displaced muon using sqrt{s} = 13 TeV pp-collisions with the ATLAS detector
Advisor: Melissa Franklin

Shiang Fang
Thesis: Multi-scale Theoretical Modeling of Twisted van der Waals Bilayers
Advisor: Efthimios Kaxiras

Ping Gao
Thesis: Traversable Wormholes and Regenesis
Advisor: Daniel Jafferis

Julia Gonski
Thesis: Probing Natural Supersymmetry With Initial State Radiation: The Search For Stops and Higgsinos at ATLAS
Advisor: Masahiro Morii

Shannon Harvey
Thesis: Developing Singlet-Triplet Qubits in Gallium Arsenide as a Platform for Quantum Computing
Advisor: Amir Yacoby

Jinwoo (Monica) Kang
Thesis: Two Views on Gravity: F-theory and Holography
Advisor: Daniel Jafferis

Jae Hyeon Lee
Thesis: Prediction and Inference Methods for Modern Astronomical Surveys
Advisor: Douglas Finkbeiner

Patrick Jefferson
Thesis: Geometric Deconstruction of Supersymmetric Quantum Field Theories
Advisor: Cumrun Vafa

Continued on next page

Recent Graduates continued

Andrei Levin
Thesis: Single-Electron Probes of Two-Dimensional Materials
Advisor: Amir Yacoby

Lee Liu
Thesis: Building Single Molecules – Reactions, Collisions, and Spectroscopy of Two Atoms
Advisor: Kang-Kuen Ni

Xiaomeng Liu
Thesis: Correlated electron states in coupled graphene double-layer heterostructures
Advisor: Philip Kim

Alexander Lukin
Thesis: Entanglement Dynamics in One Dimension — From Quantum Thermalization to Many-Body Localization
Advisor: Markus Greiner

Mason Marshall
Thesis: New Apparatus and Methods for the Measurement of the Proton and Antiproton Magnetic Moments
Advisor: Gerald Gabrielse

Baurzhan Mukhametzhanov
Thesis: Bootstrapping High-Energy States in Conformal Field Theories
Advisor: Daniel Jafferis

Cristian Panda
Thesis: Order of Magnitude Improved Limit on the Electric Dipole Moment of the Electron
Advisor: Gerald Gabrielse

Sabrina Pasterski
Thesis: Implications of Superrotations
Advisor: Andrew Strominger

Monica Pate
Thesis: Aspects of Symmetry in the Infrared
Advisor: Andrew Strominger

Aavishkar Patel
Thesis: Transport, Criticality, and Chaos in Fermionic Quantum Matter at Nonzero Density
Advisor: Subir Sachdev

Gregory Phelps
Thesis: A dipolar Quantum Gas Microscope
Advisor: Markus Greiner

Matthew Rispoli
Thesis: Microscopy of Correlations at a Non-Equilibrium Phase Transition
Advisor: Markus Greiner

Jennifer Roloff
Thesis: Exploring the Standard Model and Beyond with Jets from Proton-Proton Collisions at $\sqrt{s}$=13 TeV with the ATLAS Experiment
Advisor: John Huth

Arthur Safira
Thesis: NV Magnetic Noise Sensing and Quantum Information Processing, and Levitating Micromagnets over Type-II Superconductors
Advisor: Mikhail Lukin

Yichen (Lily) Shi
Thesis: Analytical Steps Towards the Observation of High-Spin Black Holes
Advisor: Andrew Strominger

Oleksandr Shtyk
Thesis: Designing Singularities in Electronic Dispersions
Advisor: Eugene Demler

Tatiana Webb
Thesis: The Nanoscale Structure of Charge Order in Cuprate Superconductor Bi2201
Advisor: Jenny Hoffman

Mobolaji Williams
Thesis: Biomolecules, Combinatorics, and Statistical Physics
Advisor: Vinny Manoharan

Zhaoxi (Charles) Xiong
Thesis: Classification and Construction of Topological Phases of Quantum Matter
Advisor: Ashvin Vishwanath

Liujun Zou
Thesis: An Odyssey in Modern Quantum Many-Body Physics
Advisor: Subir Sachdev

PROGRAMS

Research Scholars

by Bonnie Currier, Research Scholar Coordinator

During the 2018-2019 academic year, we continued our research scholar development series by offering a variety of panel discussions. This series rotates every two to three years, and we welcome new panel recommendations from our research scholars.

A panel on "Patents and Intellectual Property" was held on October 12, 2018. This panel was composed of faculty from inside and outside the Physics Department, along with representatives from Harvard's Office of Technology Development.

Two panels on "Getting a Junior Faculty" position were held this year. The first panel, which took place on November 16, 2018, was composed of former postdocs and graduate students who currently hold junior faculty appointments at Harvard and other institutions, so that attendees could hear from people who may have been, quite recently, in a similar position as their own. The second panel, which took place on November 29, 2018, was composed of senior faculty, inside and outside of Harvard, to provide viewpoints from people at more advanced stages in their careers. This panel, like the previous one, was moderated by members of the Harvard Physics Research Scholar Advisory Committee.

We offered a panel on March 29, 2019, as we have in previous years, on "How to Get a PostDoc." This panel was composed of current postdocs and graduating students who had just obtained postdoctoral positions, and the discussion was moderated by current graduate students.

The 7th Annual Harvard Physics Department Research Scholar Retreat took place on September 11, 2019, at the Red Lion Inn in Cohasset, Mass. Our invited plenary speaker was the physicist and inventor (and holder of 47 patents) Richard Garwin, an IBM Fellow Emeritus at the IBM Thomas J. Watson Research Center. Garwin, who earned his Ph.D. at the age of 21 under the supervision of Enrico Fermi, later collaborated with Edward Teller on the design of the hydrogen bomb, and served on the JASON Defense Advisory Group since 1966. Having been among the very first researchers (working in concert with Leon Lederman) to observe parity violation during particle decay, Garwin had many interesting stories to tell.

Research Scholar Advisory Committee, composed of scholars who have current appointments with Harvard Physics faculty, helps organize the Annual Retreats. The Committee members also advise the Research Scholar Coordinator, moderate and serve on panels, and peer-mentor new scholars. The faculty advisor to the Committee is Professor Cumrun Vafa.

We invite you to connect with graduate students and former research scholars of the Department by agreeing to be listed on our confidential list of physics alumni administered by Bonnie Currier, Research Scholar Coordinator (bcurrier@fas.harvard. edu).

Alumni Notes

1948

Frank R. Tangherlini (S.B.) : Although I retired in 1994, in 2018 I published two papers in the *Journal of Modern Physics*, and a letter in Physics Today about the problem of the electron's mass. My main research has been in Cosmology, and secondarily in SR & GR. Since 2015, I have been publishing on a possible alternative to the accelerating universe. This led to the second 2018 paper that gives a possible solution to the long-standing Hubble constant disagreement. It was followed up by a contributed talk at the 2019 April APS meeting in Denver. In 2018 I attended my 70th Harvard Class Reunion.

1954

John McLeod (A.B.): I earned a Ph.D. in experimental nuclear physics at Princeton University and did my duty to the nation for 35 years at the Los Alamos National Laboratory working on various projects which we could not afford not to try, such as a nuclear rocket engine and microscopic hydrogen bombs driven by lasers that could be harnessed to produce power. None of these actually worked, at least not yet. I am now retired for 24 years and enjoying the climate at high altitude in New Mexico. I try to keep up with current research and am particularly concerned about global warming.

1957

Lawrence P. Horwitz (Ph.D.): I published a book, *Relativistic Many Body Theory and Statistical Mechanics*, Lawrence P. Horwitz and Rafael I. Arshansky, IOP Concise Book, Morgan and Claypool, Bristol (2018), a succession to my book Relativistic Quantum Mechaniocs, Lawrence P. Horwitz, Fundamental Theories of Physics 180, Springer, 2015. Now 6 great grandchildren…so far.

1958

Edwin Taylor (Ph.D.) has revised and updated the book he had originally published with John Archibald Wheeler: *Exploring Black Holes: Introduction to General Relativity* (Addison Wesley Longman, 2000). The new edition, co-written with Edmund Bertschinger, is available for download online at http://www.eftaylor.com/exploringblackholes.

1963

Michael H. Goldhaber (A.B.): The April 29, 2019 New Yorker, page 72 says this about me: "More than 20 years ago, the writer Michael Goldhaber observed, in Wired, that the Internet drowns its users in information while constantly increasing information production; this makes attention a scarce and desirable resource—the 'natural economy of cyberspace.' Goldhaber speculated that, when the 'attention economy' had matured nearly everyone would have her own Web site, and he warned readers that 'increasing demand for our limited attention will keep us from reflecting, or thinking deeply (let alone enjoying leisure).' In other words, he roughly outlined the social-media age."

I had begun formulating ideas about the attention economy, and coined the term, some fifteen years earlier. For more, see my article in First Monday, and my other articles there. Though not physics, I believe the intellectual basis of my work in this area stemmed in large measure from my physics training.

1965

Louis J. Lanzerotti (Ph.D.): Over the decades I have done many things, including being elected to the NAE (1988), serving on the National Science Board and receiving the NAE Bueche Award.

1966

Stephen G Bown (A.M.): After Harvard, I went on to medical school (Cambridge UK), specialized in gastroenterology and later set up the National Medical Laser Centre in University College London (UCL), a translational research group for the scientific and clinical development of techniques using light, particularly lasers, for the detection, diagnosis and treatment of human disease. We pioneered a range of endoscopic and image guided laser techniques, particularly Photodynamic Therapy (PDT), for various pre-malignant, malignant and non-malignant conditions from basic biology to routine clinical practice, many in collaboration with Harvard Medical School (Wellman Laboratories of Photobiology).

Barry Simon (A.B.): I was elected to the National Academy of Sciences in Mathematics in April, 2019.

1967

Kevin Cahill (Ph.D.; Thesis advisor: Glauber): Cambridge University Press will publish the second edition of my book *Physical Mathematics* late this summer. The book is meant for precocious undergraduates, graduate students, and working physicists.

Andy Zucker (A.B.): A colleague, Penny Noyce, and I recently tested and published "Resisting Scientific Misinformation," a free one-week unit for science students in grades 6-12 (https://bit. ly/2GXMfQy). After reading peer-reviewed psychology research demonstrating that people can be "inoculated" against misinformation to some degree, and knowing how serious the problem of misinformation is (e.g., "climate change is a hoax;" "vaccines cause autism"), we realized that these studies could be applied to improve students' understanding of science. The unit includes a variety of engaging activities, as well as four short videos for which PBS NOVA staff at WGBH provided assistance.

1968

Frederick Cooper (Ph.D., Thesis Advisor: Sheldon L. Glashow): This past year I have won a Lifetime Achievement award from Marquis Who's Who. I have given talks on the Use of Collective Coordinates to study solitary waves and their stability at the University of Texas, Arlington and at the University of Delhi, and was asked to write a book on Soliton Dynamics by World Scientific. I have also published several papers on Exact solutions to the Nonlinear Schrödinger equation and Nonlinear Dirac equation in different external complex potentials. I have been a visiting Scientist at Harvard and Boston University and I am on the external Faculty of the Santa Fe Institute. I also am a Guest Scientist at Los Alamos National Labs. I also travel around the world giving workshops on Meditation in the Tibetan Buddhist tradition.

1969

Carl M. Bender (Ph.D., advisors: Coleman and Wu): I received the Dannie Heineman Prize in Mathematical Physics (awarded annually jointly by the APS and the AIP) in 2017. I was awarded in 2019 a research award from the von Humboldt Foundation.

1970

Ashok Khosla (Ph.D.) recently stepped down after serving for ten years as the founding Co-Chair of the United Nations' International Resource Panel. He was awarded an honorary Doctor of Laws by Simon Fraser University of British Columbia and the UNEP Science-Policy Lifetime Award for his services to the environment.

1975

Peter B. Kramer (Ph.D.) Peter left Harvard for a Post Doc in Rai Weiss' lab at MIT developing the first prototype LIGO detector over 40 years ago. He left LIGO and Physics after a few years for a career in biopharmaceuticals. Now in retirement, Peter started writing iPhone apps to relive old adventures. Go Game Connect let him once again spend an afternoon playing Go with his fellow graduate student Stephen Lundeen after 44 years even though they are 2000 miles apart. His latest, Gravitational Wave Events, takes the LIGO Open Public Alerts and broadcasts each new gravitational wave event to anyone with an iPhone. Who said you could never go back?

Daniel Prober (Ph.D., Advisors: M. Beasley and M. Tinkham) has been on the Yale faculty, Dept. of Applied Physics since 1975. He continues at Yale and recently received two awards - 2018 Recipient of the IEEE Award for Continuing and Significant Contributions in the Field of Applied Superconductivity (awarded biannually) and the 2019 YSEA Award for Advancement of Basic and Applied Science. (YSEA is the Yale Science and Engineering (Alumni) Association)

1976

Alan J Cohen (Ph.D.): Alan recently joined Belmont Technology - an AI startup - in Houston, as Executive Advisor - Industry Solutions.

1977

David Schreiber (A.B.): In February 2019, I retired from AT&T after 34 years of employment. My positions at AT&T included systems engineer, supervisor, and data scientist.

1978

Kelly Chance (Ph.D.) is Principal Investigator on the NASA-funded Tropospheric Emissions: Monitoring of Pollution satellite spectrometer (TEMPO; tempo.si.edu), which has been delivered and is in storage awaiting launch. Upon launch to geostationary orbit, TEMPO will measure North American air pollution hourly in the daytime, at 10 square kilometer ground resolution, from Mexico City and Cuba to the Canadian tar sands, and from the Atlantic to the Pacific. In addition, he has published *Spectroscopy and Radiative Transfer of Planetary Atmospheres*, with Prof. Randall Martin (Ph.D., Engineering Sciences, Harvard University, 2002), Oxford University Press, ISBN-13: 978- 0199662104, 2017.

1983

James A. Glazier (A.B.): After 25 years as a physics professor in Indiana, during which my research focus has become progressively more biomedical, applied and computational, I have joined Indiana University's new Department of Intelligent Systems Engineering (our first Engineering program!) to build a program in bioengineering. I continue my work developing the open-source software framework for multiscale biological modeling (CompuCell3D) and in developing models of specific developmental biology and disease states using that framework.

1985

Lishan Aklog (A.B.): After graduating in 1985, my trajectory deviated from Physics to Medicine, specifically Cardiac Surgery (HMS '89, Harvard residency and research fellowships, specialized valve surgery training in Europe and faculty appointments at Harvard, Mount Sinai and Arizona). Ten years ago a passion for innovation drove a transition to entrepreneurship (multiple patented products and five companies). I currently serve as Chairman & CEO of PAVmed Inc (Nasdaq:PAVM), which I co-founded in 2014.

Although Prof Georgi's Physics 55 and Fermilab summers with the late Leon Lederman are distant cherished memories, I remain a physicist at heart. My passion for Physics has recently been rekindled. I am teaching myself General Relativity. Taylor & Wheeler c. 1981, group theory, tensors and Hartle have been a joyful slog.

I am a husband and father of two including a sophomore at Harvard (sadly not Physics) through whom I am vicariously reliving my undergrad years.

1987

Larry Baum (A.B. Chem/Phys): I've done biomedical research since graduating and now study genetics and mechanisms of brain diseases like Alzheimer's disease and depression as a research officer at the University of Hong Kong. For scientific fun, I compile a free weekly science humor list which I welcome you all to enjoy at tinyletter.com/top5science.

1997

Deborah R. Coen (A.B.): Thank you for asking for announcements for your alumni newsletter. I'd like to share the news of the publication of my latest book, *Climate in Motion: Science, Empire, and the Problem of Scale* (Univ. Chicago Press, 2018).

David Zeltser (A.B.): I love being a children's books author. My first novel, *Lug: Dawn of the Ice Age*, was published by Egmont for ages 8-11. It satirized mankind's response to climate change and Al Gore called it "a great combination of humor and powerful insight." One of my recent picture books, *The Universe Ate My Homework*, was published by Lerner Books for ages 4-7. NPR science journalist and Radiolab host Robert Krulwich wrote about the book: "Don't try this at home, just bring it home. The Universe Ate My Homework is totally safe (and delightful) to read." I can be reached at davidzeltser.com.

1993

Talal A. Debs (A.B.): My main update with respect to physics is that I published a book on Group Theory and Scientific Representation which has been getting good reviews since it was published (now over 10 years ago – hard to believe). I would be interested to hear what my old Harvard classmates think of it; the book is *Objectivity, Invariance and Convention: Symmetries in Physical Science* (Co-authored with Michael Redhead, HUP, 2007)

1998

Alix Guerrier (A.B.): In November 2018, Alix started a new role as the CEO of GlobalGiving, the largest global crowdfunding community connecting nonprofits, donors, and companies in over 170 countries. He was previously President and Chief Product Officer at LearnZillion, the education technology company he co-founded (he is now a board member). GlobalGiving's model addresses a wide range of themes, including over 2,300 projects focused on science education. He hopes that some members of the next generation of physicists around the world are among the beneficiaries of these projects.

1999

Sarah Demers (A.B.): I'm currently the Horace D. Taft Associate Professor of Physics at Yale, and my news is that I've co-written the book *Physics and Dance* with Yale professor Emily Coates, which came out this past January. (https://yalebooks.yale.edu/book/9780300195835/physics-and-dance) Emily and I co-teach a course on physics and dance at Yale, and have had a tremendous amount of fun in our collaboration.

2001

Jacob E. Grose (A.B.): While I did not manage a career in physics, I am managing to stay physics adjacent. On behalf of BASF Venture Capital, I invested recently in the Harvard quantum computing startup, Zapata Computing, which is part of The Engine accelerator in Cambridge. If anyone reading is an expert in quantum algorithm development or is just interested in learning more, please feel free to reach out to me on LinkedIn.

2004

Benjamin E Lauderdale (A.B.): I am leaving the LSE at the end of 2018. From January 2019 I will be a Professor in the Department of Political Science at University College London.

2006

Brenden Millstein (A.B.): is now wonderfully happily married to Amanda Millstein, a pediatrician from Stanford, and they have a 3 year old boy named Cameron and a 1 year old girl named Alex who keep them plenty busy. To add to the chaos of a toddler and a baby Brenden cofounded Carbon Lighthouse, a clean energy company, with physics lab partner Raphael Rosen (also '06). Study mate Francisco Isenberg (Engineering, '06) runs Software and Data Science for the company. We are always hiring so if you want to use math to stop climate change check out our careers page, and to date we've eliminated the emissions of 8 power plants. 49,992 left to stop climate change.

2007

Alexander D. Wissner-Gross (Ph.D.) was pleased to announce that his artificial intelligence software company, Gemedy, was part of a team that was awarded a $28 billion, 9-year research and development contract by the U.S. Department of Defense. To learn more, visit https://www.alexwg.org.

2010

Noah Bruegmann (A.B., Chem/Phys): I've started organizing monthly meetings for data professionals in the San Francisco area. Data Scientists, Data Engineers and Analysts talk informally about a range of data-related topics. The group includes Isaac Shivvers (also Physics 2010) and some non-Physics Harvard graduates. Please get in touch if you'd like to join.

2011

Lester Kim (A.B.): I went to Burning Man for the first time. I had a blast and recommend going there at some point. People think about the partying, drugs, and polyamory, but there is much more to the experience: beauty, art, music, technology, bonding, survival, identity. Afterwards, I went on a yoga retreat in the mountains of Portugal where I met my current romantic partner. I also traveled to Madrid where I learned about handstand technique from local circus performers. I left my data scientist position at a VR startup to be a machine learning engineer at Blue Apron.

Josh Goldman (Ph.D.) founded KoBold Metals, which is exploring for mineral deposits containing cobalt and nickel, which are critical for making high-performing lithium-ion batteries for electric vehicles. KoBold is aggregating large datasets and using a combination of basic science and machine learning to identify properties that are highly prospective for discovering new ore deposits, and then acquiring and exploring their portfolio of properties. Fellow physics alumna Elizabeth Main Ph.D '11 recently joined to lead KoBold's technology program. KoBold is backed by Breakthrough Energy Ventures and Andreessen Horowitz. Our company was also featured in a recent article in Bloomberg.

2013

Tony Pan (Ph.D., CEO at Modern Electron): I was recognized by the Puget Sound Business Journal with the "40 under 40" award for my company's work in energy.

Christian Yoo (A.B.): 2019 has been an incredible year. I have had the honor and privilege of completing five and a half years of service in the US Navy as a Surface Warfare Officer and Nuclear Engineering Officer. I am excited to matriculate into MIT's Ph.D program in Nuclear Engineering, where I will conduct research in the area of plasma physics and nuclear fusion as a sustainable and carbon-free source of energy. And I am incredibly happy and lucky to have recently married my best friend, Sharon Teng, a fellow graduate of Harvard's Class of 2013.

Celebrating a Phenomenal Department

by Mary McCarthy

One of the best things about working in the Department of Physics is being surrounded by world-class physicists who are forever pushing the limits of discovery in the physical world. This proximity can also pose a challenge, however: How can the administration keep pace with brilliant scholars whose research contributions lie in a domain that few can fathom?

Fortunately, the staff in the Department of Physics is singular in its dedication, focus, and effectiveness – so we're able to keep pace just fine. In a 2012 staff retreat, a resounding message came through: it was high time for the staff to be celebrated for their accomplishments. A group of administrators then partnered with the faculty in developing the *Physics Phenom* Reward and Recognition Program. Once a year, the entire department – including faculty, students at every level, and staff – are invited to nominate members of the staff for this esteemed status. After nominations are gathered, the faculty and staff are invited to cast a vote for the staff member who has best met the criteria of having delivered "meaningful and special contributions 'above and beyond' standard job responsibilities… persons who demonstrate concrete achievement and contributions to the department in areas that may include: collegiality, innovation, mentorship, professionalism, special projects, and teamwork." Since its inception, eight staff members have won the award.

One of the first named Phenoms was Barbara Drauschke, now a 40-plus-year seasoned veteran of the Department, who claimed that winning the award "made me feel that my efforts are noticed and appreciated by my peers and the department. I have nominated people, motivated by the way it made me feel about my work in the department, and a want for them to be acknowledged as well."

Our most recent season yielded 58 nominations for 21 staff members — the highest participation yet. And the voting rolls demonstrated tremendous enthusiasm for the program. The full transcript of nomination statements are posted online for all to see, with one past winner, Adam Ackerman, noting, "sharing the nomination text is a great way to show how many colleagues are valued even though only one "wins" each year."

Anne Trubia (left) presents Lisa Cacciabaudo with the 2019 Physics Phenom Award. Lisa expressed her appreciation this way: "When I read through the nominations I had received for the Physics Phenom award and shared what students and colleagues had written about me with my wife Jen, we both started crying! She knows better than anyone how deeply I care about our students and their well-being. And the fact that so many people took the time and energy out of their busy lives to nominate me and to say such nice things really means the world to me!"

Another past winner, Hannah Belcher, a faculty assistant for Professors Yacoby and Kim and their labs, shared this comment: "Receiving the Physics Phenom award was incredibly meaningful to me. I care deeply about the Physics Department as a whole – my colleagues and the faculty, students, and researchers I support. Knowing that the work that I do is meaningful enough for them to reach out and submit a nomination was immensely validating. Receiving the award was an incredible honor and made me want to continue to offer the best support that I can."

This year's Phenom, Lisa Cacciabaudo, the Graduate Program Administrator, reflected: "I think it's really important to have a staff recognition program like this. It is all too easy to get caught up in our day-to-day work in this environment, and this program gives us a chance to think about our colleagues and to recognize their contributions and their value to the department in a meaningful way."

"The Physics Phenom program will continue to play an important role in recognizing staff achievement," says Anne Trubia, Director of Administration. "We have enjoyed administering it and are always on the lookout for new and effective ways to support the staff. Alumni are welcome to offer suggestions to the program at phenom@physics.harvard.edu.

Previous Winners

2019: Lisa Cacciabaudo
2018: Hannah Belcher and Marina Werbeloff
2016: Adam Ackerman
2015: Carol Davis
2014: Barbara Drauschke and Nils Sorensen
2013: Bonnie Currier

Letters from Our Readers

Continued from page 2

Thank you for sending me this newsletter—the first I've received. It's fascinating to see how women have progressed in physics. I was a lowly undergraduate in physics in 1964. There were 3 women in my class who majored in physics. I do not recall any female professors or graduate students.

I wound up in medicine which was perfect for me. I was interviewed for medical school on the day I delivered my second child. I am quite certain I was admitted because I held a degree in physics from Harvard. Many thanks!

JUDITH PAUL OSHA, A.B. 1964

It has been 50 years since I did any physics, but I very much enjoyed the latest newsletter.

One story about Prof. Schwinger struck a chord. Cooper said that at the Nobel ceremony, Schwinger told the audience, "I woke up this morning, and the problems I couldn't solve yesterday, I can't solve today." I was an undergraduate when he won the prize. I didn't attend the first class he conducted after the announcement (I wasn't as advanced as my classmate Howard Georgi), but I had friends who did. The classroom in Jefferson was standing room only. He began the lecture, or so I was told at the time, by saying, "I woke up this morning, and the problems I couldn't solve yesterday I can't solve today. And that's all I'm going to say about it." Those standing then departed.

HARRIS HARTZ A.B. 1967

Thank you for your work in putting the newsletter together and keeping all of us up to date on what is happening with Physics at Harvard. It's great to be able to keep some connection to the program.

NOAH BRUEGMANN, A.B. 2010
(Chemistry and Physics)

I read the emailed Newsletter you sent me with mounting amazement. It is a prime example of what it takes to be one of (or the) top departments of physics, historically and today, as well as being one of Harvard's most distinguished departments. I also appreciated greatly the humanistic emphasis on the many people featured.

GERALD HOLTON, M.A. 1946, PH.D. 1949

HARVARD UNIVERSITY
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Departmental Events

Our weekly colloquia with invited speakers are held at 4:30 PM in Jefferson 250, preceded by an all-community tea at 3:45 PM in the Physics Reading Room, Jefferson 450. Among the colloquium speakers this academic year are Immanuel Bloch, Lawrence Bacow, Charlie Marcus, and Margaret Kivelson. If you are ever in town, we would be delighted for you to join us.

Our next Loeb Lecturers will be Zhi-Xun Shen (Stanford) on Nov. 4-6, 2019. The Lee Historical Lecture speaker will be David Ruelle, emeritus Professor at the Institut des Hautes Études Scientifiques, on April 27, 2020.

For more details about our upcoming colloquia, lectures, and other events, please consult the Harvard Physics Calendar webpage: www.physics.harvard.edu/events/gencal.

Stay Connected

We would love to hear from you. Please stay in touch and let us know if you would like to contribute news items to the newsletter at: newsletter@physics.harvard.edu.

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Join us on LinkedIn: https://www.linkedin.com/groups/4740923/.

Watch the videos of various events on our website: https://www.physics.harvard.edu/events/videos.

Don't miss the April 3, 2020, Physics Graduate Alumni Symposium and Reunion! More information is forthcoming.