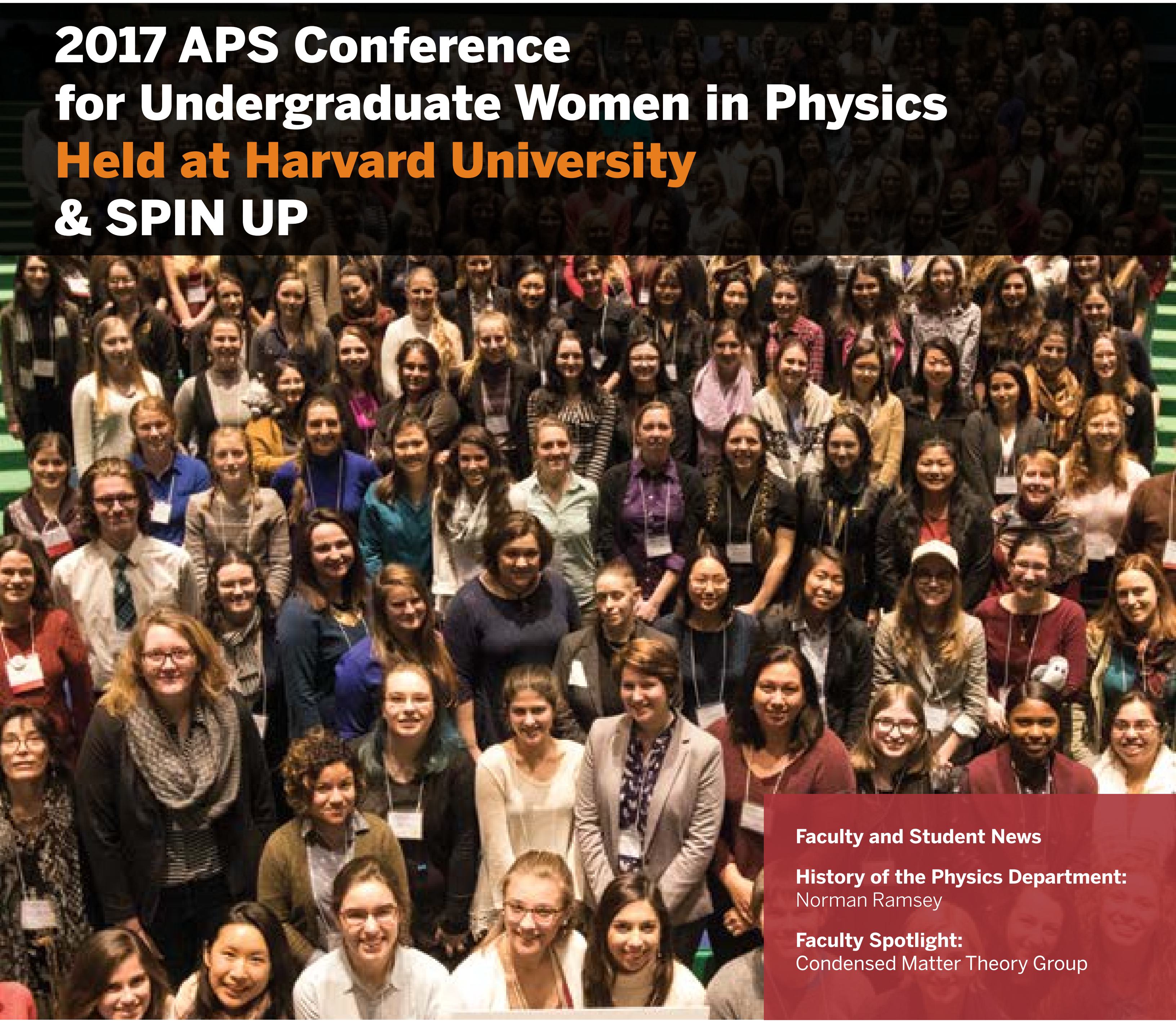
PHYSICS

Harvard University Department of Physics Newsletter

FALL 2017

2017 APS Conference for Undergraduate Women in Physics Held at Harvard University & SPIN UP



Faculty and Student News

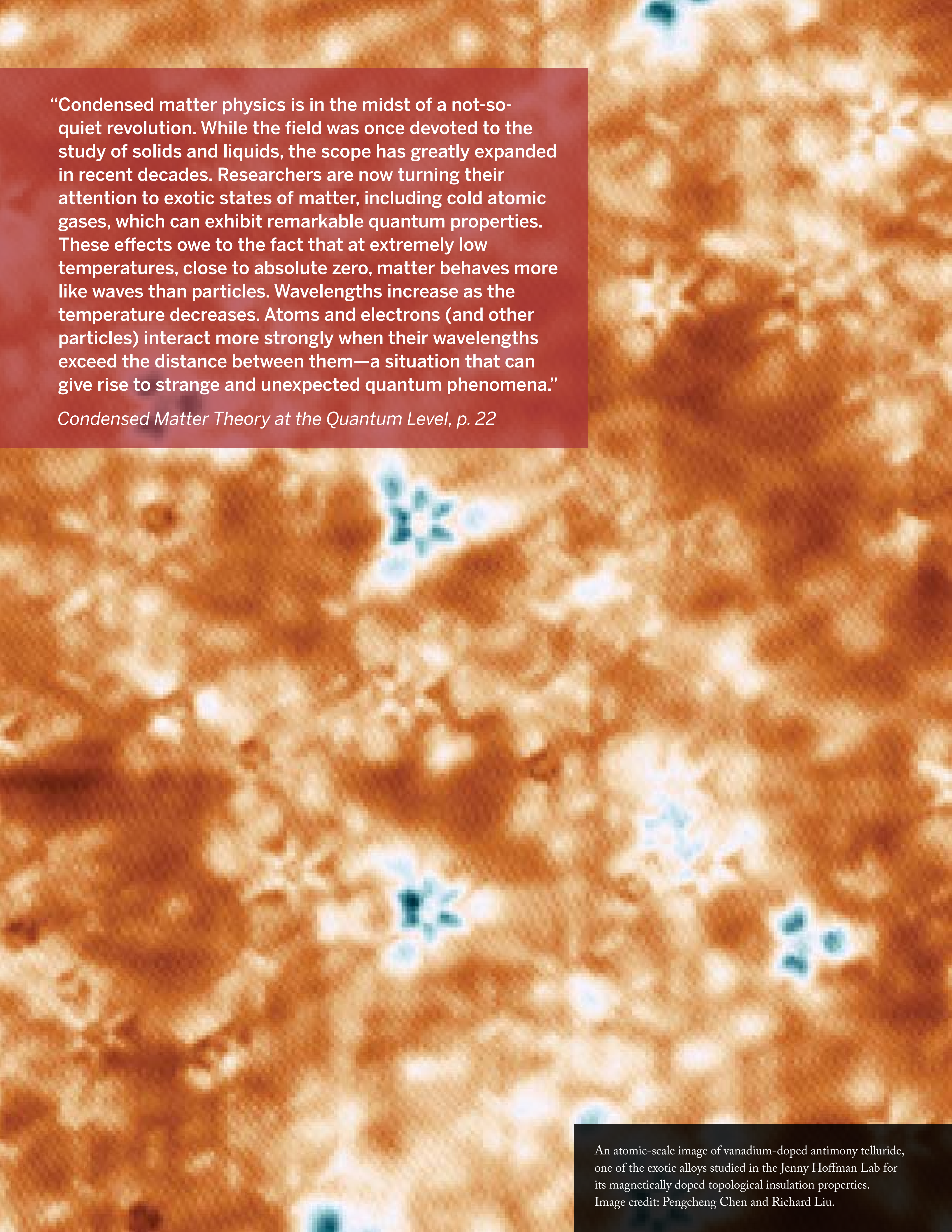
History of the Physics Department: Norman Ramsey

Faculty Spotlight: Condensed Matter Theory Group

HARVARD UNIVERSITY
Department of Physics

“Condensed matter physics is in the midst of a not-so-quiet revolution. While the field was once devoted to the study of solids and liquids, the scope has greatly expanded in recent decades. Researchers are now turning their attention to exotic states of matter, including cold atomic gases, which can exhibit remarkable quantum properties. These effects owe to the fact that at extremely low temperatures, close to absolute zero, matter behaves more like waves than particles. Wavelengths increase as the temperature decreases. Atoms and electrons (and other particles) interact more strongly when their wavelengths exceed the distance between them—a situation that can give rise to strange and unexpected quantum phenomena.”

Condensed Matter Theory at the Quantum Level, p. 22



An atomic-scale image of vanadium-doped antimony telluride, one of the exotic alloys studied in the Jenny Hoffman Lab for its magnetically doped topological insulation properties. Image credit: Pengcheng Chen and Richard Liu.

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ON THE COVER:

Photo by Tom Kates

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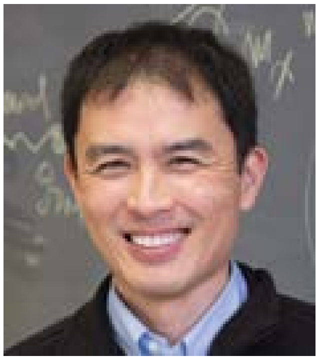
Letter from the Chair



Dear friends of Harvard Physics,

We are pleased to deliver this year's Department Newsletter. I'm writing this just after the 2017 Commencement Day. It was another bumper crop for the Department: 51 undergraduate concentrators and 28 graduate students received their degrees in Physics. I only wish that the weather had been better—those academic gowns aren't water resistant.

The cover story of this issue is the APS Conference for Undergraduate Women in Physics (a.k.a. CUWiP), which Harvard hosted in January, 2017. I can't help but brag about the three-day event, which attracted some 250 attendees, despite the fact that my only contribution to its success was to say "yes" to the wonderful people on the organizing committee (whose names can be found on page 13). Those students and postdocs came up with the idea, wrote the proposal to the APS, pitched it to the Deans and the Provost, reached out to the sponsors, recruited the volunteers, and made it all happen. They also came up with the first "SPIN UP" workshop for Supporting Inclusion of Underrepresented Peoples. It was a glorious weekend, and I hope you will get a little flavor of the sense of community and enjoyment from the articles.

On the research front, we feature our faculty in theoretical condensed matter physics in this issue. Bert Halperin (who graduated from the College in 1961), Rick Heller, Tim Kaxiras, Subir Sachdev, and Ashvin Vishwanath (who joined the Faculty last fall) describe their research from quantum hall effects to topological states. A long and storied tradition of condensed matter theory at Harvard runs ever stronger in the 21st century.

The Department has added a new faculty member, Assistant Professor Roxanne Guenette, profiled on page 5. Roxanne is an experimental particle physicist, and is a rising star in the field of neutrino oscillation. Her current experiment, MicroBooNE, is a liquid-argon time projection chamber (LArTPC) located at Fermilab. MicroBooNE's 170-ton bulk will be dwarfed by Roxanne's next experiment, a multi-kiloton LArTPC called DUNE, which will operate at 5000 feet underground in an old gold mine in South Dakota.

Also joining our faculty are Professors Michael Desai and John Kovac. Both Michael and John have been *de facto* members of the Department since they came to Harvard as Assistant Professors in OEB (Organismic and Evolutionary Biology) and in Astronomy, respectively. They both received tenure last year, and formally accepted joint appointments in Physics. Michael and John have been great colleagues for us and wonderful advisors for our students, and I hope their involvement in Physics will only increase.

I have just received more exciting news: Dr. Julia Mundy has accepted our offer to join the faculty, and will start as an Assistant Professor in 2018. Julia received her AB/AM from Harvard in 2006, and her PhD from Cornell in 2014. She is currently a President's Postdoctoral Fellow at Berkeley. In her experimental condensed matter research, Julia designs and synthesizes novel materials using molecular-beam epitaxy (MBE), and performs measurements to uncover their unusual properties. She is also a gifted communicator and a passionate teacher, who spent two years between her undergraduate and graduate studies with Teach for America. Stay tuned for a feature article on Julia in the next issue.

The last bit of news: this is my last Newsletter as the Department Chair. By the time you read this, I will be enjoying my sabbatical at the Brookhaven National Laboratory. I thank everybody in the Department for their generous help during my three years in the Chair's office. That the Department kept functioning under my watch, and even educated a whole cohort of brilliant students, speaks volumes about the talent and dedication of the people we have.

I hope, as always, that you will enjoy this newsletter. Please stop by the Department whenever you can. And we are very much looking forward to hearing from you.

Sincerely,
Masahiro Morii
EX-CHAIR AND PROFESSOR OF PHYSICS

Letters from our Readers

WE ALWAYS ENJOY HEARING FROM OUR READERS

"The fabulous Fall 2016 Harvard Physics Newsletter arrived with its great combination of reviews of new science in the department and historical context.

It inspired me to tweet today @dan_kammen with two of my wonderful mentors: Prof. Richard Wilson (whose 90th birthday party I attended in Cambridge in April) and Prof. Art Rosenfeld, whose 90th celebration event I'll be speaking at on November 17 in Berkeley, California.

The lineages are just too interesting: Dick was I. I. Rabi's student and Art was the last doctoral student of Enrico Fermi..."

DANIEL KAMMEN
MA '86, PHD '88

"I was most pleased to see in the Fall 2016 Newsletter that Richard Wilson, physics faculty emeritus, was noted for turning 90. I also came to Harvard in 1955 but as a freshman and Wilson became my physics advisor the following year and I worked with him during the summer of 1957 in the cyclotron lab. When I was a senior he quickly arranged for me to do my graduate D. Phil. study at Christ Church, Oxford where I had the opportunity to study at first under Nobel Laureate Willis Lamb who himself was a doctoral student of Robert Oppenheimer. I guess that makes me in some sense a "grandstudent" of Oppenheimer."

RICHARD SPECTOR
AB '59

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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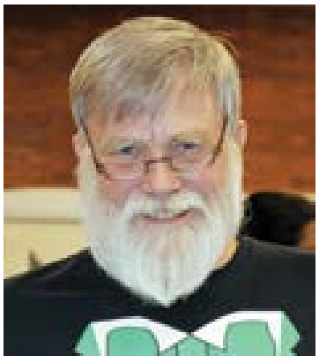
Three Birthdays of Note, Three Celebrations to Remember

by Steve Nadis



Howard Georgi

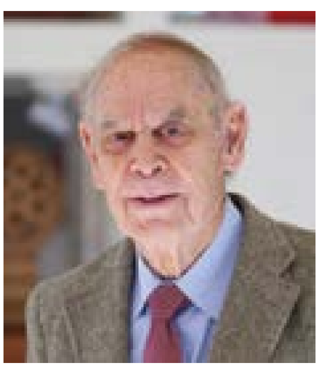
Howard Georgi, Mallinckrodt Professor of Physics, turned 70 earlier this year, and about 100 people celebrated that milestone at a "Grand Unified Party" held at Harvard on April 17, 2017. The event was so named because of Georgi's well-known work on Grand Unified Theories, which merge the electromagnetic, weak, and strong interactions into a single force.

Georgi got his BA from Harvard in 1967, returning to the university as a Junior Fellow from 1973 to 1976, after which he has been on the faculty ever since. From 1998 to 2015, he served as Master of Leverett House, which is where the party took place. More than a dozen people spoke on Georgi's behalf, including his former student, Lisa Randall, and his long-time collaborator Sheldon Glashow, who delivered the closing remarks.

Bertrand Halperin

Bertrand Halperin, Hollis Professor of Mathematicks and Natural Philosophy, was feted by the Department of Physics on January 31, 2017, on the occasion of his 75th birthday. Halperin has earned broad recognition for his work in theoretical condensed matter physics (described on pages 24–25 of this newsletter).

Talks by Halperin's colleagues and former students were held throughout the afternoon, with a reception in the Library and, later, a dinner at Cambridge's Evoo restaurant. More people spoke about Halperin, and toasted him, during dessert. The Physics Department presented him with a framed invitation for the event, as well as a Harvard coffee table book containing notes written by many of the attendees.



Gerald Holton

Mallinckrodt Professor of Physics, Emeritus, Gerald Holton—scientist, science historian, and widely published author, who began working at Harvard in 1943—celebrated his 95th birthday on April 5, 2017, at the Harvard Faculty Club. About 45 friends and colleagues came to this elegant dinner party, with Melissa Franklin, Peter Galison, and Masahiro Morii among those giving toasts. The most memorable talk was delivered by Holton, himself, who admitted to being "overwhelmed" at the time and speaking mostly from memory. Yet everyone in attendance found his speech to be quite eloquent and full of his characteristic wit, modesty, and charm. Holton paid tribute, in particular, to his professional home for the past seven-plus decades, saying: "I find myself compelled to use my few minutes to urge something here which our department never does, namely to celebrate itself!" The guests gladly did that with Holton, while also celebrating him.

Roxanne Guenette: Stalking the Wily Neutrinos

by Steve Nadis

Neutrinos, which John Updike mused upon in his poem "Cosmic Gall," are literally everywhere. In fact, says assistant professor Roxanne Guenette, "about 10^{11} neutrinos pass through my finger every second." While there is no shortage of these particles—the second most abundant in the universe—catching them is not easy because they zip around at close to the speed of light, rarely interacting with anything. But Guenette is particularly adept at setting traps, deep underground, that can capture these elusive particles and unlock some of the secrets they harbor. She recently brought those talents to Harvard, joining the Physics faculty earlier this year after serving as an Ernest Rutherford Fellow at Oxford since 2013.

As a child growing up in the northern Quebec village of Mont-Saint-Michel (pop. 631, or 632 when she's back in town), Guenette was drawn to the night sky, which was incredibly vivid in that remote setting, 150 miles northwest of Montreal. She was constantly dragging her family out to witness meteor showers, the Northern Lights, and other celestial displays.

She went to the University of Montreal as an undergraduate, intent on becoming an astrophysicist. She stuck to that plan as a graduate student, first at Montreal and then McGill, where she engaged in dark matter searches and gamma ray astronomy. Her introduction to neutrino physics came in 2010 when she was a postdoctoral researcher at Yale under the direction of Bonnie Fleming.

That's when Guenette realized neutrinos were possibly the perfect objects to study to enhance our understanding of the universe. While dark matter particles are immensely intriguing, no one has found one yet. The Large Hadron Collider, similarly, has not (as of this writing) discovered any new particles since the existence of the Higgs boson was confirmed in 2012. "With neutrinos, we know where to find them," Guenette says. "We just need to build bigger and better detectors to learn more about them."

And there should be much to learn because the revelation that neutrinos "oscillate"—spontaneously changing from one form to another—meant that these particles had mass and no longer fit comfortably into the Standard Model. Neutrinos, in other words, "may offer our first door into new physics beyond the Standard Model," Guennete notes. They could potentially help us figure out why the universe is dominated by matter rather than by antimatter, as well as shed light on the grand unification of forces physicists have been dreaming about since the days of Einstein.

To make progress on these and other questions, researchers need to establish the ordering of the masses of the three neutrino types—electron, muon, and tau—and also to determine whether any other types of neutrinos exist. To this end, Guenette is working to improve the liquid argon detectors that can lay bare the details of a neutrino's interactions. She is currently participating in the MicroBooNE experiment at Fermilab and laying plans for its successor, the Deep Underground Neutrino Experiment (DUNE), which should begin taking data in the mid-2020s.

DUNE will have the biggest liquid argon detector ever built, weighing in at 40 kilotons. Guenette is trying to develop a better readout system for that detector, which can wring more information out of each neutrino interaction event.

For a long time, neutrinos didn't seem all that interesting, but that has all changed, Guenette says. "We now think they might point us towards the theory that underlies the Standard Model itself."

Faculty Prizes, Awards, and Acknowledgments*

Clarivate Analytics (formerly Thomson-Reuters) Highly Cited Researcher 2016:

PROF. DOUGLAS FINKBEINER

Harvard College Professorship:

PROF. MELISSA FRANKLIN

2017 Osterbrock Book Prize:

PROF. GERALD HOLTON

Simons Visiting Fellow at the Isaac Newton Institute for Mathematical Sciences:

PROF. ARTHUR JAFFE

Clarivate Analytics Highly Cited Researcher 2016:

PROF. PHILIP KIM

2017 Joseph R. Levenson Memorial Teaching Prize:

DR. ANNA KLALES

Clarivate Analytics Highly Cited Researcher 2016:

PROF. MIKHAIL LUKIN

Willis Lamb Award for Quantum Optics and Laser Science:

PROF. MIKHAIL LUKIN

Presidential Early Career Award for Scientists and Engineers (PECASE):

PROF. JOHN KOVAC

Packard Fellowship for Science and Engineering:

PROF. KANG-KUEN NI

Harvard Humanist Award:

PROF. LISA RANDALL

Simons Fellow in Theoretical Physics:

PROF. LISA RANDALL

2017 Breakthrough Prize in Fundamental Physics:

PROF. ANDREW STROMINGER

Simons Distinguished Visiting Scholar, Kavli Institute for Theoretical Physics:

PROF. ANDREW STROMINGER

2017 Breakthrough Prize in Fundamental Physics:

PROF. CUMRUN VAFA

2017 Ellis Island Medal of Honor:

PROF. CUMRUN VAFA

Clarivate Analytics Highly Cited Researcher 2016:

PROF. AMIR YACOBY

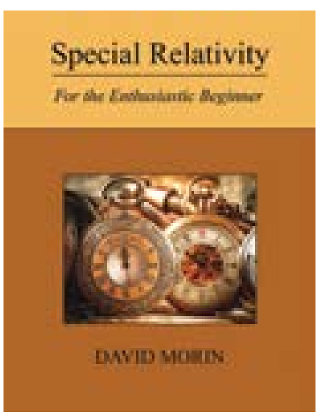
*Includes awards received since the publication of last year's newsletter.

Books by Faculty

Learning the Art of Electronics: A Hands-On Lab Course

Thomas C. Hayes with Paul Horowitz
Cambridge University Press, 2016

This introduction to circuit design is unusual in several respects. First, it offers not just explanations, but a full course. Each of the twenty-five sessions begins with a discussion of a particular sort of circuit followed by the chance to try it out and see how it actually behaves. Accordingly, students understand the circuit's operation in a way that is deeper and much more satisfying than the manipulation of formulas. Second, it describes circuits that more traditional engineering introductions would postpone: on the third day, we build a radio receiver; on the fifth day, we build an operational amplifier from an array of transistors. The digital half of the course centers on applying microcontrollers, but gives exposure to Verilog, a powerful Hardware Description Language. Third, it proceeds at a rapid pace but requires no prior knowledge of electronics. Students gain intuitive understanding through immersion in good circuit design.



Special Relativity: For the Enthusiastic Beginner

David J Morin
CreateSpace, 2017

This book is written for high school and college students learning about special relativity for the first time. It will appeal to the reader who has a healthy level of enthusiasm for understanding how and why the various results of special relativity come about.

All of the standard introductory topics in special relativity are covered: historical motivation, loss of simultaneity, time dilation, length contraction, velocity addition, Lorentz transformations, Minkowski diagrams, causality, Doppler effect, energy/momentum, collisions/decays, force, and 4-vectors. Additionally, the last chapter provides a brief introduction to the basic ideas of general relativity, including the equivalence principle, gravitational time dilation, and accelerating reference frames.

COVER STORY

2017 APS Conference for Undergraduate Women In Physics Held at Harvard University & SPIN UP

by Anne Hébert and
Ellen D. Klein

Trying Wild Things: A Journey to Build an Inclusive Physics Community

On a clear, winter weekend in January 2017, the Department of Physics hosted its first Conference for Undergraduate Women in Physics (CUWiP). For three days, Jefferson Laboratory and the Science Center welcomed almost 250 undergraduates interested in pursuing physics. We (the authors) and many attendees were surprised to see that there were this many women and femme folk physicists in the Northeast. ("Femme folk" refers to people who identify, to any extent, with some traditional feminine traits.)

Expanding since 2006, CUWiP is now a network of annual, simultaneous conferences across the United States and Canada that aim to increase the representation of women in physics by fixing the leaky pipeline at the critical undergraduate stage. Women earn only 20% of physics bachelor's degrees nationwide, despite near-parity female participation in physics at the high-school level. At these conferences, participants can build networks with each other, learn about research performed both by top physicists and their peers, explore a wide range of career opportunities available to those who study physics, and partake of liquid nitrogen ice cream.

In 2015, Jacob Barandes and Lisa Cacciabaudo, two members of the Harvard Department of Physics, went to a CUWiP at Yale to recruit graduate students. Shortly after, we started talking to them about how Harvard had recruited at many CUWiPs but had never hosted one.

We also talked to our fellow graduate students and postdocs, and discovered that many had attended or organized CUWiPs as undergraduates. Several of our peers had done summer research or started graduate school with friends that they first met at a CUWiP. These conferences had been such a positive experience for many members of the Harvard physics community that we decided to organize one here.

We reached out to the department and to parts of the broader university. The response we got was enthusiastic beyond our wildest expectations. The department faculty and staff, the Dean of Science, and fellow graduate students and postdocs were immediately supportive of our efforts and incredibly generous with their time and advice, as well as the funds needed to make it happen.

Ever physicists, we treated this endeavor as an experiment, asking: "What can we learn from previous conferences? How can we improve?" From talking to previous attendees and drawing on information from earlier events, we realized that for many participants this conference is unique because it's the first time that they are in the majority. Many of us have had to deal with being the only woman in a classroom, and some have never even had the chance to interact with a woman physicist further along on her career path. This makes the opportunities to develop peer and professional mentor relationships at CUWiPs all the more valuable.

However, even at CUWiPs, not all attendees share this experience of being in the majority. What many of us feel every day in male-dominated environments such as the classroom or lab, some participants may still feel at these conferences. Those are most often women and femme folk who are members of various underrepresented or underserved groups, including racial, ethnic,

Photo by Tom Kates

"One of the lessons we learned is that every facet of science is collaborative. We recognize that we must question the pipelines and barriers in place in order to change them, so that everyone has the chance to participate in the collaboration that is physics."

gender, and sexual minorities, people with disabilities, and first-generation student from low-income backgrounds. Members of these groups face additional hurdles and barriers that many of us do not have to confront and therefore may be unfamiliar with.

With this in mind, our goal was for CUWiP to be a place where every voice was encouraged, welcomed, supported, safe, and heard. Although we initially didn't know how to make this happen, we began by trying to educate ourselves. We benefited enormously from conversations with people in the physics world who were also active in the social justice movement. We learned about the burdens placed on people from marginalized groups who have to constantly advocate for themselves and their groups, explaining their experiences as well as their differences.

With the generosity of the activists who took the time to teach us, we slowly formulated a plan for a one-day workshop for up to 50 participants. The inaugural Supporting Inclusion of Underrepresented Peoples (SPIN UP) Workshop is described on page 13. At the time of this writing, many months later, we are still in awe over the strength, insight, and dedication of the speakers, panelists, and attendees. The participants were honest in their discussions of often very difficult experiences, and brave and creative in describing how they have persevered through challenges.

We'd like to thank the Department of Physics for encouraging us at every step of this journey. We'd also like to thank the SPIN UP and CUWiP organizing committees (whose names are listed on page 13) for helping us along the way. We have come to better understand the barriers that other physicists face, and that process has helped us grow. Now we have started to actively seek ways to be allies, and to find, or create, solutions that we can implement. We encourage you, as members of the broader physics community, to do the same.

Educating ourselves about other people's experiences is an exercise that each of us must take on. Additionally, making physics a more inclusive, diverse, and welcoming space is a responsibility that belongs to all members of the community. We took a step along this journey during SPIN UP and CUWiP. We hope that the conversations started continue beyond that weekend in January and are shared more widely.

One of the lessons we learned is that every facet of science is collaborative. We recognize that we must question the pipelines and barriers currently in place in order to change them, so that everyone has the chance to participate in the collaboration that is physics.

We would like to thank the CUWIP and SPIN UP attendees for their enthusiastic participation. We will take what we learned from them to continue building a more inclusive physics community, in which every voice is equal.

To quote our keynote speaker, Professor Nergis Mavalvala: "To inspire, you have to do kind of wild things." The CUWiP and SPIN UP attendees have inspired us to try wild things and to be bolder in our initiatives and dreams. We hope that you will join us in this effort.

Photos by Tom Kates (1, 2, 4, 6), Silvia Mazzocchin (3), Alejandro Avila (5)

SPIN UP and CUWiP participants

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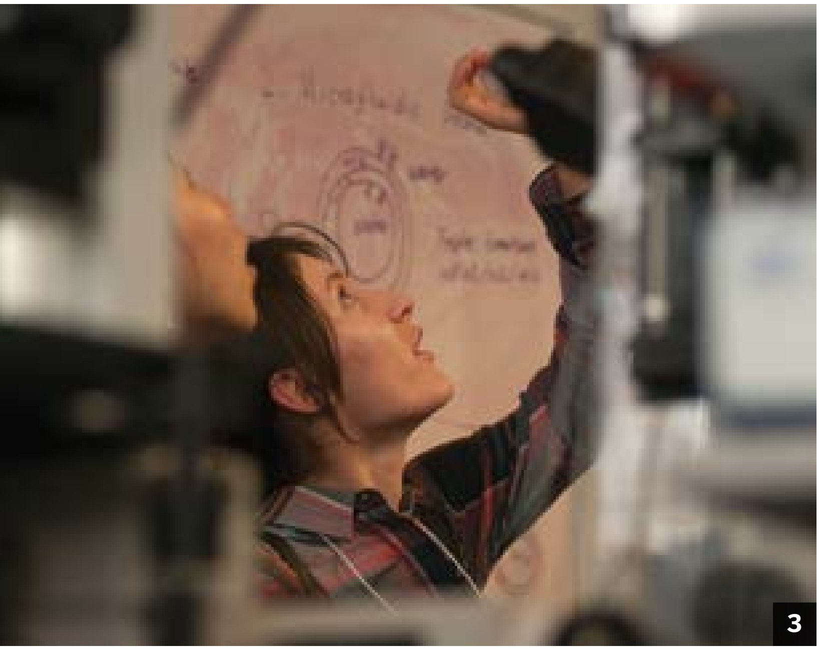

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SPIN UP and CUWiP participants


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SPIN UP

by Anne Hébert and Ellen D. Klein

On the day before CUWiP officially began, 50 undergraduates gathered for the first-ever Supporting Inclusion of Underrepresented Peoples (SPIN UP) workshop. Our hope for SPIN UP was to provide a supportive space for women and femme folk physics students who are members of racial and ethnic minorities, are members of gender and sexual minorities, have physical, mental, or learning disabilities, come from low-income backgrounds, are first-generation college students, or are members of other underrepresented or underserved communities.

We focused on the issues unique to their particular situations in an intimate, safe environment and provided many opportunities for participants to discuss their experiences and ask questions of mentors from diverse personal and professional backgrounds. In addition to the unstructured time for discussion, SPIN UP featured a research talk, a panel on combating discrimination, and a panel on the next steps after college.

The feedback from SPIN UP was overwhelmingly positive. Several participants and speakers said that they were pleasantly surprised by how welcomed and included they felt. Perhaps as a consequence of this, the conversations throughout SPIN UP were remarkably frank and open. Participants discussed instances of discrimination and harassment. Speakers and other attendees offered crucial advice about how they dealt with and overcame various setbacks.

For those of us who organized SPIN UP, the impact of the workshop is perhaps best encapsulated in the tweet of one panelist, Julia Salevan, a Yale graduate student active in the LGBT physics community: “It’s so rare for me to see other trans folks in physics, I forgot how much I value and need representation.” This expression of surprise at not being alone as an underrepresented minority is a strong reason why SPIN UP programs should continue in the future.

We encourage all of you to keep the conversation going, because even though the conference was a great first step, it was still just a start. There’s clearly more to be done, and we’d appreciate any help we can get.

THANKS TO THOSE WHO HELPED...

CUWIP LOCAL ORGANIZING COMMITTEE

Laurel Anderson, Agnese Bissi, Christie Chiu, Marlee Chong, Susannah Dickerson, Maya Anjur-Dietrich, Delilah Gates, Anne Hébert, Anna Klales, Ellen D. Klein, Aaron Krahn, Anna Laws, Meredith MacGregor, Anjalika Nande, Elise Novitski, Thomas Plumb-Reyes, Hechen Ren, Annie Stephenson, Steven Torrisi, Elana Urbach, Ashley Villar, and Ann Wang.

SPIN UP ORGANIZING COMMITTEE

Susannah Dickerson, Delilah Gates, Anne Hébert, Ellen D. Klein, Elise Novitski, Thomas Plumb-Reyes, and Ann Wang.

FACULTY

Melissa Franklin, Jenny Hoffman (speaker), and Masahiro Morii.

STAFF

Angela Allen, Jacob Barandes, Hannah Belcher, Gerry Byrne, Lisa Cacciabaudo, Carol Davis, Jolanta Davis, Barbara Drauschke, Silke Exner, Rob Hart, Colleen McMahon, Mary McCarthy, David Morin, Clare Ploucha, and Sydney Stuberg.

Photos by Tom Kates (1, 2, 3, 5, 6, 7),
Victoria DiTomasso (4)

by Steve Nadis

Supporting All in Physics

From January 12th through the 15th of this year, about 250 undergraduates from colleges throughout the Northeast—Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, and Rhode Island—descended upon Harvard to satisfy, and nurture, their interest in physics. These students had come to attend the Conference for Undergraduate Women in Physics (CUWiP), sponsored by the American Physical Society, as well as for an optional, one-day event that preceded it, the Supporting Inclusion of Underrepresented Peoples (SPIN UP) Workshop.

The enthusiasm among participants during the extended weekend was palpable. Harvard Physics chair Masahiro Morii was bowled over by the fact that "people were so energetic and so excited. It did not at all feel like a 'top-down' affair. Everyone wanted to participate; everyone acted as if this was where they belonged." The students themselves were equally exuberant, using words like "validating," "inspiring," and "phenomenal" to describe their experiences. "CUWiP has been very empowering," said Jacqueline Van Slyke, a sophomore at Siena College. "It has introduced me to a large and rich community of women physicists that I want to be part of."

The first ever CUWiP was held at the University of Southern California in 2006 with a few dozen participants, and the concept has grown steadily ever since. On that same weekend in January 2017, nine other CUWiPs took place at various sites in the United States, plus one in Canada, with an estimated 1500 attendees altogether.

The SPIN UP workshop, on the other hand, was a brand new idea originated by Harvard graduate students and postdocs. SPIN UP was specifically geared towards helping people, who are also members of other underrepresented groups, feel more comfortable and welcome at the larger CUWiP event and in the physics world as a whole. "Part of our goal for SPIN UP was to make sure that everyone felt there was a place for them in the physics community," said Delilah Gates, a Harvard Physics graduate student on the organizing committee. "And we wanted those attendees who were not members of underrepresented groups to learn about issues that other people in the physics community may face. The marginalization of any group—whether or not you, yourself, are a member of that group—is everyone's problem to solve." (See "SPIN UP" on page 13.)

About 50 people took part in the SPIN UP workshop held on January 12, some of whom spoke in great detail about the challenges they had contended with in their physics careers so far—such as dealing with disabilities, facing harassment and discrimination, lacking parental support, or enduring financial hardships. "As organizers, some of the challenges discussed were new to us, but the participants seemed to come out of these exchanges feeling less alone," said Elise Novitski, a Harvard Physics graduate student who helped organize both SPIN UP and CUWiP. "It made me appreciate the resources that people at places like Harvard are used to and that many people haven't had. Yet these students have persisted and envisioned themselves in physics careers, despite everything. They could bring a unique set of strengths to the field because the tenacity they've displayed is just what one needs to survive in physics."

Harvard Physics professor Melissa Franklin was similarly impressed, calling SPIN UP "an amazing experience that made me realize how narrow my

> "These mentors were amazingly generous with their time and admirable in their honesty in sharing deeply personal experiences and their hard-earned wisdom," said Novitski. "The best thing we did as organizers was in bringing together the participants and speakers, who themselves did the true work."

own little world was. We heard from people facing huge barriers, living in youth shelters with practically no resources, but what they really want to do is learn physics," Franklin said. "That was beautiful to hear, and it made me really happy."

CUWiP began a day later, with laboratory tours in the afternoon followed by opening remarks presented by Harvard Physics graduate student Ellen Klein, a member of the organizing committee. "This CUWiP is a place for all attendees to share their ideas," she told the animated crowd. "It is also a place to brainstorm ideas … for what all of us, as physicists, can do to improve the broader physics community and beyond."

That evening, everyone convened in the Northwest Labs Atrium to socialize, have dinner, and collaborate in an unusual and lively "Maker Event." The 250 or so participants divided into groups of four or five, each charged with making a simple, miniaturized, electronic piano using Arduino microelectronics kits. The event was intended to be an icebreaker, created just for the Harvard CUWiP, and it came together without a hitch. Within two hours, every group had a working model, and 50 or so instruments soon became part of an impromptu orchestra that played rousing versions of "Mary Had a Little Lamb" and the "Star Wars" theme song.

"The goal was to encourage participants to form a bond with someone they'd never met before," commented Harvard post-doctoral fellow and one of the organizers Susannah Dickerson. "People enjoyed themselves while working together, which made this a really fun event to kick off the conference."

On the first part of Saturday, January 14, students were in the spotlight. Dozens of them gave talks in the Science Center on subjects ranging from quasar light curves to the search for the sterile neutrino. Dozens more gave poster presentations, including Doralia Castillo, a sophomore at Montclair State University in New Jersey. Castillo talked about her work on fluid state interactions, happy to report that "I have found something I love to do"—namely physics research. Harvard sophomore Katie Fraser spoke of the summer she spent on the ATLAS team at the Large Hadron Collider. Fraser had never been to a conference before, calling it "fantastic to meet so many women and find out about all the interesting research they have done. It has also been very motivating to see so many women faculty who have managed to do important research while also managing their personal lives."

To department chair Morii, who spoke with many of these students, this conference had a much more intimate feel and more camaraderie than the typically larger, more impersonal affairs. "Normally, you put up a poster and wait for people to stop by, and often not many do," Morii noted. "The people here devoted much more attention to the talks and posters. And I think that provided more meaningful experiences to those who presented their ideas."

The keynote address was given later in the afternoon by MIT Professor Nergis Mavalvala and simultaneously broadcast to the nine other CUWiP sites. Mavalvala, a member of the LIGO team, recounted the story of one of the great scientific findings of our time: "how LIGO made the discovery of gravitational waves, the work of 1000 scientists spanning about 40 years." Mavalvala said she was like most people who "grew up looking at the stars and thinking they were wonderful. Little did I know that in darkness there was so much beauty."

She described the periods of "fumbling and stumbling" that she went through, as most people do at different stages of their careers, stressing the importance of having a good mentor—"someone who cares and will work with you and keep you afloat" in times of need.

> "We tried to offer students a diverse set of speakers and panelists, with a wide-ranging set of backgrounds, in order to emphasize how many different paths you can follow to get to physics and how many different paths you can follow from a physics degree."

But she also stressed the importance of students taking initiative. "Although you may think your professors are in charge, you guys should start pulling them in directions you find interesting," Mavalvala suggested. "If they go [with you], amazing things can happen."

On Sunday, the final day of the conference, Harvard physicist Jenny Hoffman talked about how she had contemplated careers in mathematics, high-energy particle physics, and cosmology before finding her place in low-energy condensed matter physics. Hoffman offered some survival tips to the students: Number one on her list was learning to write well. Number two, form a peer support group with people who are excited about science. Three, the best time to start a family is when you are ready. And four, find an extracurricular activity that can benefit your physical as well as mental health. For Hoffman, that happens to be 24-hour endurance running, but for others, 24 minutes of running, or some other activity, might suffice.

A panel discussion followed, in which people described academic and non-academic career opportunities. The geophysicist Mika McKinnon has taken a decidedly unconventional route, as part of her job involves consulting on science fiction movie and TV scripts. "If you don't fail, you're not pushing hard enough," McKinnon said. "The most recent thing I failed was to become a Canadian astronaut, so I went out and celebrated."

Another panelist, Kerstin Nordstrom, has pursued a more traditional academic path as an assistant professor of physics at Mount Holyoke. For college students interested in going to graduate school, Nordstrom said, "your trajectory is much more important than your grades. Are you doing independent work? Are you giving your professors enough material to be able to write a good recommendation letter?" While you don't want to have terrible grades, she added, other factors, such as how you distinguish yourself, could carry greater weight over the long run than the number of A's versus B's on your report card.

Edna Conway, a cybersecurity expert at the technology company, Cisco, encouraged everyone in the audience to network with each other, as well as with the panelists and speakers. "Twenty years from now," she said, "you're going to want to know the person sitting next to you."

Next up was an industry and graduate school fair, where attendees got a sense of career options available to them in the academic, commercial, and industrial realms. Representatives from about two dozen graduate schools and private companies spoke with students, as a group and individually, about various opportunities that they might consider.

With regard to the conference as a whole, Dickerson said, "We tried to offer students a diverse set of speakers and panelists, with a wide-ranging set of backgrounds, in order to emphasize how many different paths you can follow to get to physics and how many different paths you can follow from a physics degree."

The proceedings came to a satisfying conclusion with closing remarks delivered by Harvard graduate student Anne Hébert. "We thank you for joining us on this journey," she said. "We hope that you learned from it, enjoyed it, and were empowered by it."

In the end, Hébert, Klein and all the others who organized the Harvard CUWiP, putting untold hours into the preparations, were extremely pleased with how things unfolded. "This definitely exceeded our expectations," said Hébert. "We wanted to create a space for the participants to really engage and interact with each other, and that really happened."

Conference organizers: Top row, left to right: Elise Novitski, Marlee Chong, Anna Klales, Thomas Plumb-Reyes, Susannah Dickerson, and Ann Wang. Bottom row: Laurel Anderson, Delilah Gates, Ellen Klein, Anne Hébert, Anjalika Nande, Christie Chiu, Agnese Bissi, and Meredith MacGregor. Photo by Tom Kates.

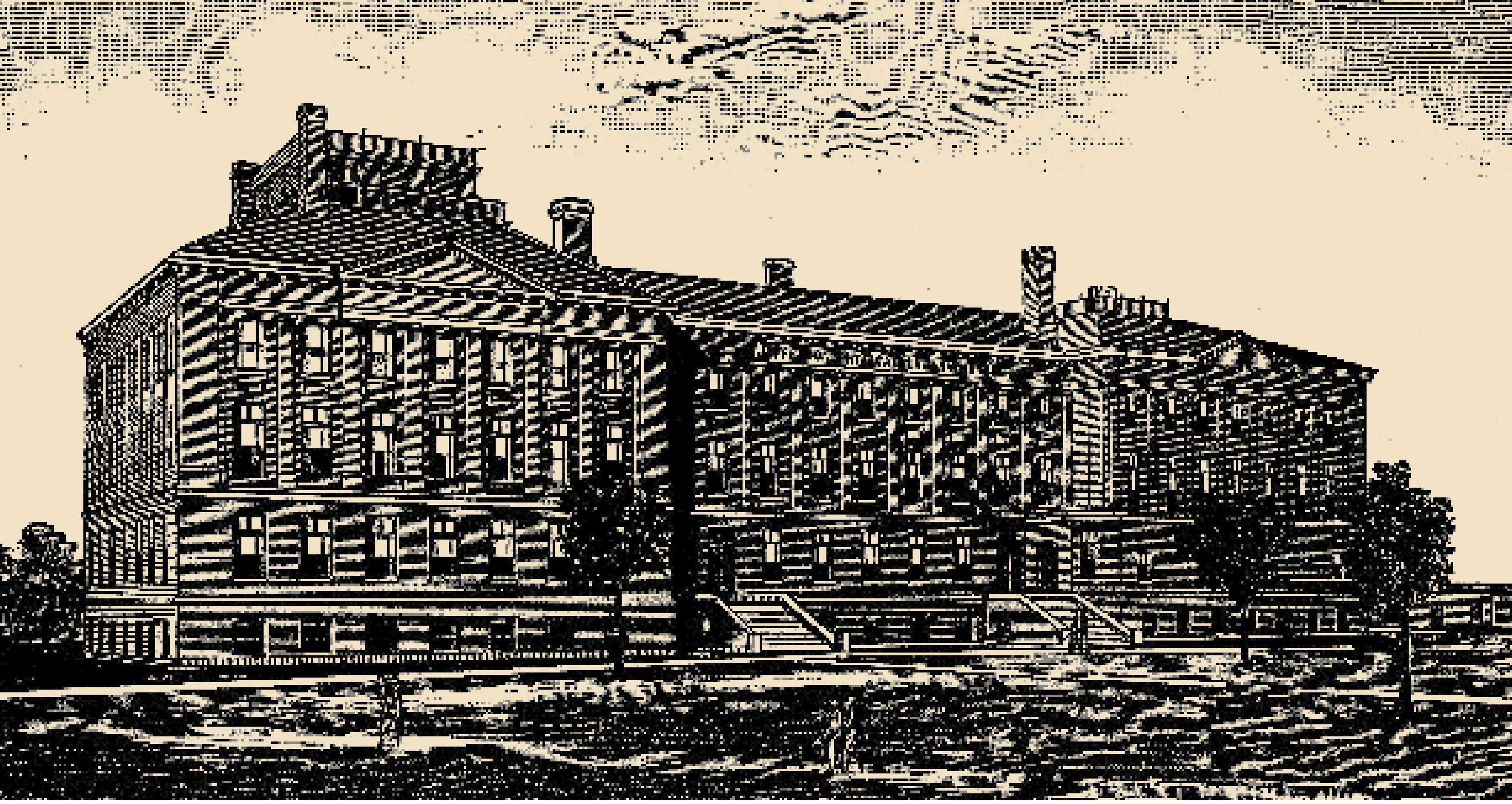
The participants were also able to interact to a significant degree with the panelists, speakers, and discussion session leaders, many of whom stayed for the entire conference, serving as mentors to the students. "These mentors were amazingly generous with their time and admirable in their honesty in sharing deeply personal experiences and their hard-earned wisdom," said Novitski. "The best thing we did as organizers was in bringing together the participants and speakers, who themselves did the true work."

The event organizers, meanwhile, scored high points from the faculty sponsors. They did "an amazing job," according to Franklin, and "incredible work," in the words of Morii. "I don't think I could have run that conference half as well," Morii admitted.

As for what could come from an event like this, he added, "For people who like physics but are not sure they are cut out for it, I hope they found out there are lots of others like them. By sharing their worries and concerns, I hope that people who love physics will become convinced that they can go out and do it."

The conference seems to have had that effect on many participants, among them, Jackie Erazo from CUNY Hunter College in New York. "CUWiP has opened my eyes to the number of women in physics," Erazo said. "It has inspired me to want to continue in this field." Her comments were echoed by many others who attended the conference, and by that measure alone it should be deemed a tremendous success.

Gates and others on the organizing committee were especially gratified to hear a comment from one of the event's presenters, who said, "If anyone wants to run a physics conference that is truly inclusive, they should talk to the organizers of SPIN UP and CUWiP at Harvard."



FOCUS

History of the Physics Department: Norman Ramsey

by Professors
Daniel Kleppner* and
Paul Horowitz

To those who knew him—his many students (some 84 graduate students, and thousands of undergraduates), his colleagues in the physics department, and his considerable circle of acquaintances in government and industry—Norman Ramsey left an indelible impression. He was a towering figure in the world of physics during the second half of the twentieth century—esteemed for his scientific accomplishments, his service as a statesman of science, his role as a teacher and mentor, and for the friendships he shared with people of all ranks around the world.

Ramsey was born to a military family, his education frequently interrupted as his father was ordered to new locations in the U.S. and abroad. Nevertheless he managed to graduate from Fort Leavenworth High School at the top of his class at age 15, and from Columbia University at age 19 with a degree in mathematics and a fellowship to Cambridge University, where in two years he acquired a second BA, this time in physics. Returning to Columbia in 1937, he joined the molecular-beam group of I. I. Rabi, in spite of the latter's admonition that the field was nearly exhausted (see next page, "Advice from Rabi"). A few months later, Rabi invented the molecular-beam magnetic resonance method and triggered a revolution in atomic physics. Ramsey's initial research effort led to the discovery that the deuteron is not spherical, the first major discovery to come from Rabi's laboratory.

In 1940, Norman married Elinor Jameson and accepted a faculty position at the University of Illinois. The onset of war diverted the newly married couple (their bags not yet unpacked) to the Boston area, where for two years he led the group developing short-wavelength airborne radar at the MIT Radiation Laboratory. In the summer of 1941 he flew to England to share technology, crossing the ocean on a PanAm

*Department of Physics, MIT, and former PhD student of Ramsey

Advice from Rabi

"The first advice I received from Rabi in 1937 when I applied to him to begin my research was that I should not go into the field of molecular beams since the interesting problems... had already been solved and there was little future to the field. I have often wondered how I... had the temerity to disregard this bit of advice from the master. However, I am grateful that I did since the advice was given only a few months before Rabi's great invention of the molecular beam resonance method... which led to such fundamental discoveries as the quadrupole moment of the deuteron, the Lamb shift, the anomalous magnetic moment of the electron, and numerous other discoveries and measurements."

Norman Ramsey

Photo by Jane Reed/Harvard University

Clipper. He discovered that the British had a decisive invention—a crystal diode detector for microwave radiation that was vastly superior to the vacuum tube triode detectors used in the U.S. He carried home a handful of the crystal diodes in his coat pocket, personally transferring the new technology to the Radiation Laboratory. Bell Telephone Laboratories picked up the development of these for the war effort, and subsequent interest in such solid-state devices led to Bell Labs' invention of the transistor.

After a brief stint advising War Secretary Stimson (during which the Air Force's skeptical view of radar evolved to enthusiasm), Ramsey joined the Manhattan Project at Los Alamos, where he headed the so-called delivery group. He spoke rarely about his work there, but in the now-declassified "History of Project A" we learn of Norman's keen intuition in solving a problem in aerodynamics, where drop-testing had revealed "an undamped wobble. As a desperate last resort, he suggested a drop be made with internal 45° baffle plates welded into the inside of the shroud as a field modification. To everyone's surprise the modification was successful, with the bomb being completely stable in its flight and with the ballistic coefficient being improved rather than decreased as anticipated."

Arriving at Harvard in 1947, Ramsey developed a program of theoretical and experimental research on magnetic interactions in molecules that led to his invention of the separated oscillatory field method (the "Ramsey method"), a technique important in the creation of precise atomic clocks, among many applications. Ramsey's molecular research had other consequences, including the theory of chemical shifts that are fundamental to NMR and magnetic resonance imaging. The hydrogen maser, another Ramsey invention, is among the most stable timekeepers, and lies at the heart of the global positioning system. He received the 1989 Nobel prize "for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic clocks."

His students remember those golden years fondly. As one of them said, "There was an intellectual excitement with a combination of solid scientific progress on magnetic interactions in molecules and forays on speculative ideas. The group was dominated by Norman's exuberant, ever-friendly personality, and booming voice. Norman's group meetings mixed serious science with playful ideas and endless anecdotes. He kept a collection of toys and puzzles that displayed scientific paradoxes that baffled us, and sometimes him. Norman was a famous storyteller and he could enjoy a story even if he were the butt of its humor."

When confronted with an offbeat question, Norman often surprised his interlocutor by having already pondered the problem. For example, when one of us noted that we took different paths going to and from the Faculty Club for our weekly departmental lunches, he immediately replied with his observation that at each fork we choose the path that points closest to the goal. Another example of Norman's

Norman's students learned the ropes by presenting at Friday afternoon group meetings. (Norman is in the center, standing on his head.)

puckish humor is his observation of the way to keep straight the two Wilson physicists (Robert and Richard): "There's R. R. Wilson, and there's *Our* R. Wilson."

Beginning in 1958, Ramsey served as the first science adviser to NATO, initiating programs for advanced study institutes, fellowships, and research grants that helped to restore European physics from the effects of war. As a scientific statesman, Ramsey is widely credited for his decisive role in the creation of Fermilab. To deal with conflicting visions, 25 universities formed the Universities Research Association (URA), with Ramsey as its president. His unique background as an atomic physicist who was also conversant with particle physics, his sterling reputation for fairness and accuracy, and his reputation for personal judgment uniquely qualified him for the job. In his new position, Ramsey quelled a simmering scientific civil war between the East and West coasts, served as an effective spokesman to the U.S. Congress, and oversaw the entire creation of Fermilab. The accelerator was completed 30% below estimated cost and with 60% higher energy. And when a scientific committee was established to investigate the acoustic evidence in the Kennedy assassination, Ramsey was appointed its chair; that committee showed conclusively that the purported evidence was unrelated to the assassination.

During the McCarthy era, Ramsey spoke out to defend intellectual freedom in the case of his colleague Wendell Furry, a victim of the Senator's witch-hunting. Furry was indicted, and several of the Harvard overseers called for his dismissal. Ramsey, along with Robert Pound, successfully defended Furry within the university, but the public charges by McCarthy were unrelenting. Ramsey responded on a national TV news program with a defense so persuasive that McCarthy offered him a job.

Ramsey's energy was legendary: he might fly from Cambridge to Washington for a morning meeting, exploit the time difference to get to Chicago for an afternoon URA meeting, return to Cambridge in the evening, and be up early the next morning to teach and conduct his legendary weekly group meeting. Norman hiked enthusiastically and traveled extensively, usually with his family, his students, or his many friends around the world. At age 81, he walked across England, and in his nineties he visited both the Antarctic and the Arctic, including a wilderness adventure in Alaska.

Norman made a strong impression on most everyone he met. A handsome, tall man with a broad smiling face and an open and friendly manner, he loved to tell stories with a booming voice that was legendary. Once, a visitor passing his office inquired about the noise. Told that it was Ramsey talking to someone in Chicago, he inquired, "Why doesn't Ramsey use a phone?" To students and colleagues, he was a role model of scientific integrity. He was meticulous about allocating credit. When introduced as the father of the atomic clock, he would scrupulously point out that the clock was originally proposed by Rabi, the first atomic frequency standard

Ramsey defending his colleague, Prof. Furry, on NBC's *Meet the Press* in December 1953.

was developed by Essen and Parry in England, and the first practical atomic clock was created by Zacharias at MIT.

In reflecting on his career, Norman said "During the time when I had graduate students, if I were asked to name my fifteen best friends, at least half of them would have been my current graduate students. That is the way we operated, on a first name basis." And in his Nobel autobiography Norman concluded with these words: "The research collaborations and close friendships with my eighty-four graduate students have given me especially great pleasure. I hope they have learned as much from me as I have from them."

In addition to the Nobel Prize, Ramsey's many awards included the National Medal of Science and six honorary PhDs. He married Ellie Welch after the death of Elinor; the combined family includes seven children and eight grandchildren.

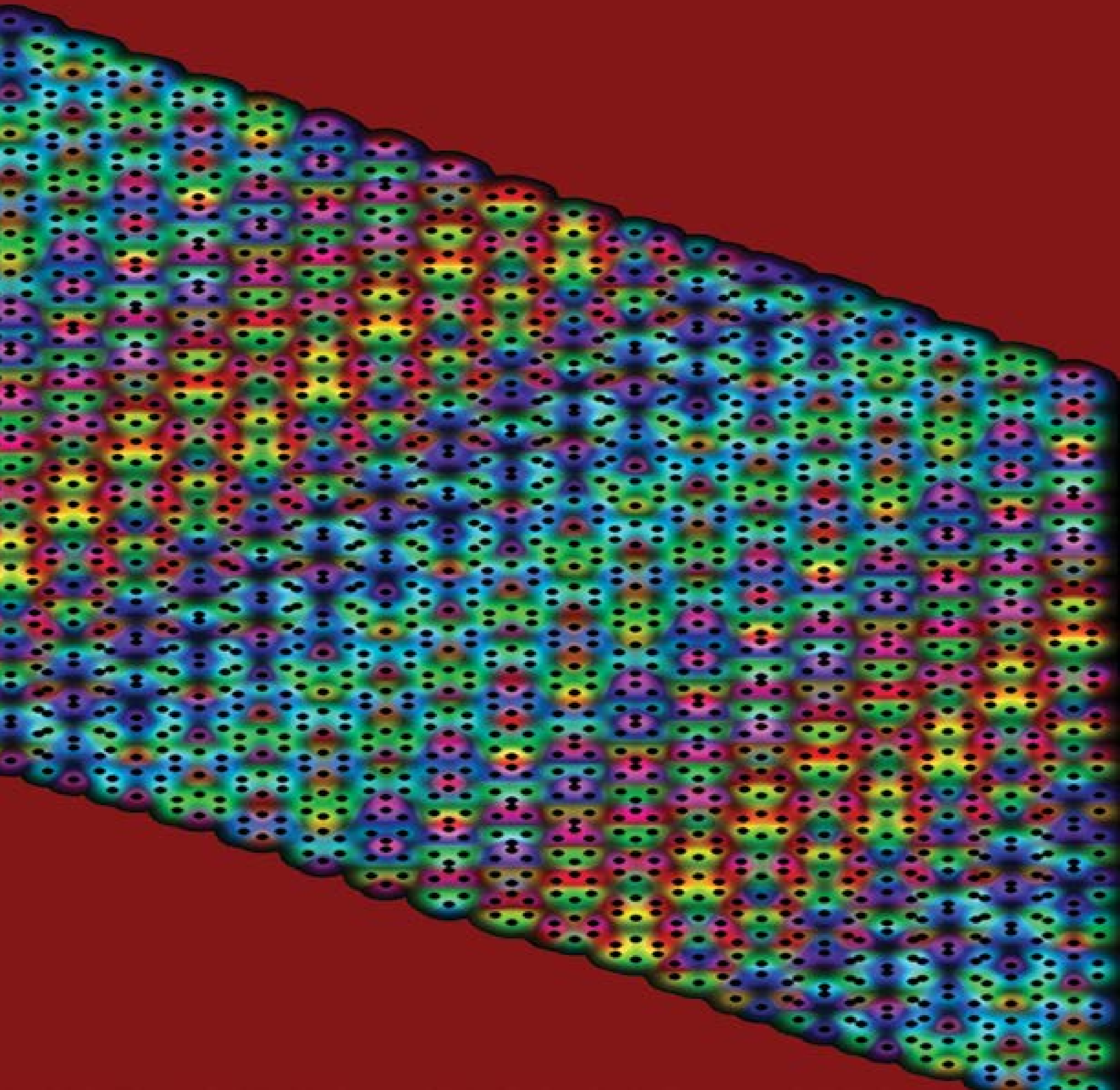
Toward the end of his life Norman became physically limited and eventually confined to a wheelchair. But his personality never altered: he never complained, never spoke unkindly of anyone, and was cheerful and ever thoughtful. In his final days, a visitor entered his room to find him dozing, totally unable to move. Norman looked up with a smile and said, "How kind of you to come. Let me get you a chair!"

As one of his students put it, Norman Ramsey was a role model for practically everything.

Norman (pictured here with his wife Ellie Welch) was a fearless hiker, skier, sailor, and world traveler. He treated his students to annual outings.

Condensed Matter Theory at the Quantum Level:

Harvard Physics Condensed Matter Theory Group



by Steve Nadis

Condensed matter physics is in the midst of a not-so-quiet revolution. While the field was once devoted to the study of solids and liquids, the scope has greatly expanded in recent decades. Researchers are now turning their attention to exotic states of matter, including cold atomic gases, which can exhibit remarkable quantum properties. These effects owe to the fact that at extremely low temperatures, close to absolute zero, matter behaves more like waves than particles. Wavelengths increase as the temperature decreases. Atoms and electrons (and other particles) interact more strongly when their wavelengths exceed the distance between them—a situation that can give rise to strange and unexpected quantum phenomena.

"Superconductivity and magnetism have long been staples for condensed matter physicists," notes Physics Professor Ashvin Vishwanath. "But there are now new kinds of matter, with new classes of phases, which have their own characteristic properties that we are only beginning to explore."

Indeed, things are moving so fast in this field—the largest and most active in contemporary physics—that experimentalists are often uncovering behaviors they cannot explain. That is one of the situations for which the talents of theorists are called upon. Theorists also play an important role in designing experiments, as well as in making sense of the results. "What we study, broadly speaking, is the quantum theory of large numbers of particles interacting with each other," explains Subir Sachdev, Herchel Smith Professor of Physics. And "large numbers," in this case, can mean as many as trillions of trillions of electrons and other particles.

There is another branch of the field, sometimes called "soft condensed matter," which focuses on materials—such as liquid crystals, polymers, gels, foams, and emulsions—that can be described through classical physics and where quantum mechanics plays a relatively insignificant role. While that, too, is a very exciting area of study, this discussion concerns the work of some members of Harvard's *quantum* condensed matter theory team—Bertrand Halperin, Eric Heller, Efthimios Kaxiras, Sachdev, and Vishwanath (Unfortunately, Eugene Demler, another condensed matter theorist in the group, could not be interviewed in time for this article.)

Vishwanath, who joined the faculty in 2016, decided about two decades ago to pursue condensed matter physics, rather than go into high-energy particle physics or string theory. He wanted to do research in an area where theory is closely tied to experiments that can be performed by small groups of people, working

Left: graphic representation of graphene, with a phonon on the lattice (black dots), and the electronic state shown in color. Image credit: Eric Heller in relatively modest laboratories that can be found at many research institutions—as compared to one-of-a-kind facilities like the Large Hadron Collider (LHC) in Geneva, Switzerland. Vishwanath is already realizing that vision at Harvard. During his first year on campus, he began working with three experimental groups in the department, and he is laying plans for other collaborations within the university in the near future.

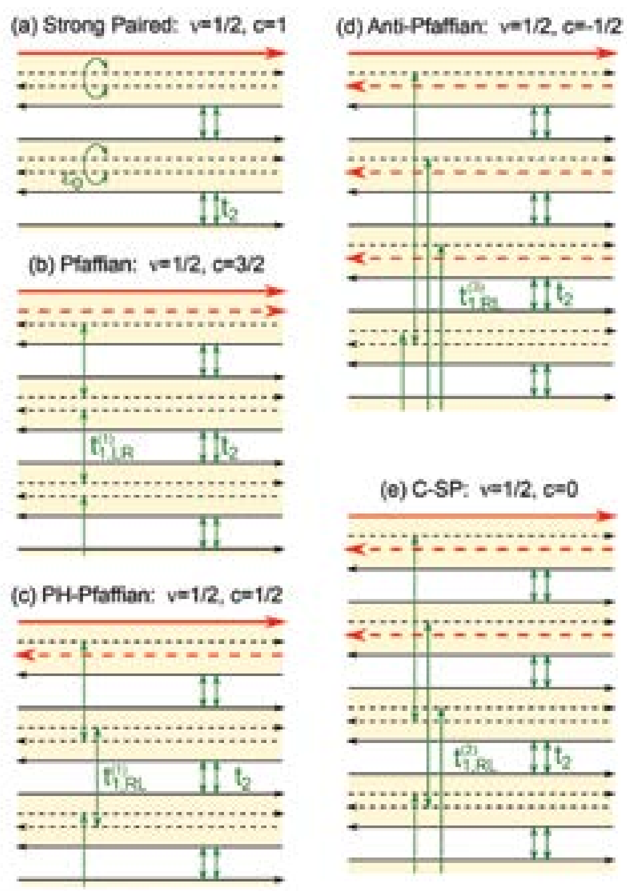
In some instances, Harvard's condensed matter theorists and experimentalists have offices within the same building. In other cases, they are housed in separate, though adjacent, buildings. "But there is a bridge between them, both literally and metaphorically," notes Halperin, Hollis Professor of Mathematicks and Natural Philosophy. "And we make use of that bridge every day in the course of pursuing this fascinating subject."

Bertrand Halperin: Roaming Harvard's Quantum Halls

Bertrand Halperin has had a long and successful run at Harvard, earning his undergraduate degree in 1961 and joining the faculty in 1976, after picking up a PhD from the University of California, Berkeley, in 1965 and working at Bell Labs for about a decade.

A winner of the Wolf Prize in Physics and the Lars Onsager Prize, Halperin made key contributions in the 1980s and 1990s to the theory of quantum Hall effects, which can be observed at low temperatures and high magnetic fields in two-dimensional electron systems. In one example of such a system, which has proved useful in the laboratory, electrons are confined to an extremely narrow region at the interface between two semiconductors. Scientists have discovered in experimental setups like this that the Hall resistance is quantized: electrical resistance in a direction perpendicular to the main current flow only assumes values that are multiples of a particular constant.

That was by no means the end of the story regarding the quantum Hall effect. Halperin has recently turned his attention to graphene, another example of a two-dimensional system comprised of just a single atomic layer of carbon. Over the last few years, Halperin says,



Schematic diagrams for quantum Hall states at v = 1/2.
From: Charles L. Kane, Ady Stern, and Bertrand I. Halperin, "Pairing in Luttinger Liquids and Quantum Hall States," arXiv:1701.06200v1. 22 Jan 2017.

“As demonstrated by researchers in the Kim and Yacoby labs, superconductivity can be induced in extremely narrow bands along the outer perimeter of these materials—so called one-dimensional edge channels. “These edge states are poorly understood at the moment,” Halperin says, “but they appear to have very intriguing properties that we’re eager to delve into.”

“experiments carried out by the groups of Philip Kim and Amir Yacoby have revealed a large variety of quantum Hall effects. Each effect essentially represents a different state of electron matter. And rather than behaving as individual particles, electrons in these states are highly correlated.” Halperin has helped Kim and Yacoby interpret a number of perplexing findings and has also made predictions for upcoming experiments.

Halperin and other Harvard researchers are also exploring novel juxtapositions of materials. “A thin semiconductor in contact with a superconductor can inherit the ability to conduct electricity without resistance, while keeping its intrinsic properties,” Halperin says. He and his postdoctoral fellow, Falko Pientka, are working with Yacoby and other collaborators to get a better grasp of how these hybrid semiconductor-superconductor devices work and what they’re capable of.

Another phenomenon has been recently observed in graphene under the same conditions of low temperature and strong magnetic fields that elicit the quantum Hall effect. As demonstrated by researchers in the Kim and Yacoby labs, superconductivity can be induced in extremely narrow bands along the outer perimeter of these materials—so-called one-dimensional edge channels. “These edge states are poorly understood at the moment,” Halperin says, “but they appear to have very intriguing properties that we’re eager to delve into.”

Other experiments currently underway involve the merging of semiconductors with graphene, and semiconductors with layers composed of mercury telluride or gallium arsenide. Much of this work is still in the exploratory stage, but there could be many possible, as well as important, applications down the road, including new kinds of transistors, integrated circuits, and sensors. “People build a device that’s supposed to work in a certain way, and then it does something weird,” Halperin says. “That’s when I like to step in and try to figure out what is going on.”

From Quantum Corrals to Rogue Waves: The Eclectic Path of Eric Heller

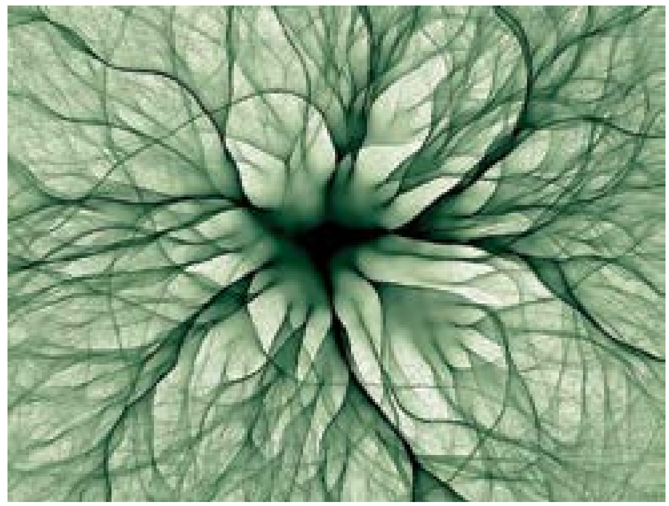
The fact that Eric Heller has had a diverse and broad-ranging career in condensed matter physics is no accident. It's a matter of personal preference. "I don't like sticking around in any one subject too long," admits Heller. "I try to grab the low-hanging fruit and move on."

His training, which earned him a PhD in chemical physics from Harvard in 1973, had been in scattering theory—the study of collisions between waves or particles. Heller got interested in condensed matter theory in 1993, the year he became a physics professor at Harvard. IBM researcher Don Eigler had just invented something called a "quantum corral"—an oval-shaped array of iron atoms that constitute tiny fences intended to confine free electrons. A year later, Heller worked out the theory of the "gorgeous" wave patterns produced by electrons in this unusual setting. "I pointed out that if this is a corral, the horses are getting out," Heller notes. "The waves survive one or two bounces before they escape." This was his first application of scattering theory to condensed matter theory, and it convinced him that a background in the former could be helpful when brought to bear on the latter.

Heller's training in scattering theory paid off again in 2001 when he and his group succeeded in explaining the curious patterns produced by electrons flying between layers of gallium arsenide semiconductors whose surfaces were riddled with bumps due to the presence of random impurities. Rather than flowing uniformly, in all directions, the electrons tended to move in a select number of narrow beams or branches—hence the term "branched flow" to describe the phenomenon.

In 2008, Heller and his Tulane University colleague Lev Kaplan suggested that a similar branched flow mechanism could lead to the emergence of "freak" or rogue waves, which sometimes rise 100 feet above the ocean's surface. Heller and a graduate student are currently looking into the possibility that microwaves emanating from pulsars—powerful beacons within our galaxy and beyond—provide another example of branched flow. They believe that clouds of interstellar gas refract microwave radiation in the same way that electron beams can be diverted by impurities in a semiconductor surface.

If Heller is correct, his methodology could help astronomers learn more about the makeup of interstellar clouds, just as mariners could learn more about the formation of potentially deadly rogue waves. "It's interesting that condensed matter physics may have implications for such far-flung fields as astrophysics and oceanography," Heller says.



Branched flow in a two-dimensional electron gas.
Image credit: Eric Heller

In connection with recent work at the Harvard Center for Integrated Quantum Materials, which is headed by Harvard physicist Robert Westervelt, Heller suggested looking into Raman scattering in graphene. This spectroscopic approach, pioneered by the Indian physicist C.V. Raman nearly 90 years ago, exploits the fact that when light is shone onto certain substances, some of the light that comes out has a different wavelength (and color), which can reveal information about the object it scattered off.

Heller quickly learned that the standard way of interpreting Raman scattering in graphene over the past 15 years—the so-called "double resonance" approach—was wrong. That was a momentous finding, implying that thousands of published papers, which utilized the double resonance technique, were based on a faulty premise. These researchers, Heller found, would have obtained more trustworthy results had they relied instead on the Kramers-Heisenberg-Dirac theory of Raman scattering, which was developed in the 1920s. "I felt bad about pointing that out," Heller says. "But it's in our job description to try to get the science right."

Efthimios Kaxiras: Theory in Service of the Practical

Theory, for Efthimios Kaxiras, John Hasbrouck Van Vleck Professor of Pure and Applied Physics, is not pie-in-the-sky esoterica without any connection to the real world. Kaxiras is drawing on highly sophisticated tools of theoretical physics so that people can build better practical devices like photovoltaic cells and batteries. And there's nothing ethereal about electrochemical batteries.

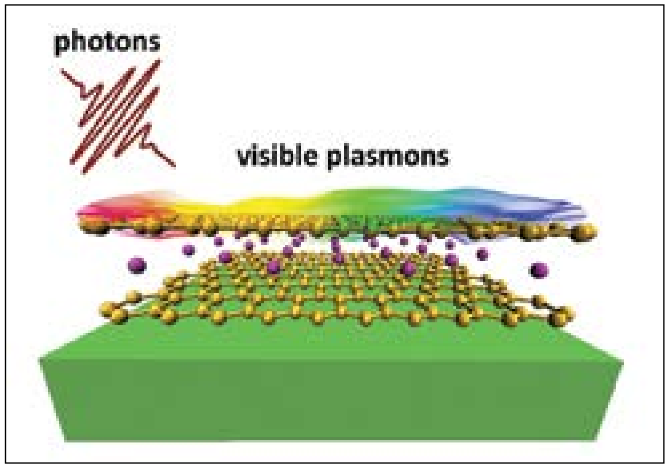
"We use elaborate computational methods to capture the properties of real materials and then use that understanding to predict the properties of new materials that could have desirable capabilities," Kaxiras explains. The goal of this exercise is simple and concrete: to contribute to the advent of faster, more efficient, and better performing devices.

He and his group members rely heavily on "density functional theory," first introduced by Walter Kohn in the mid-1960s, which, Kaxiras says, provides very effective methods for describing the properties of materials in all their complexity, including their chemical composition and atomic structure. "This is not an abstraction," he insists. "It's the real material we're talking about." Density functional theory is fully quantum mechanical, he adds. "It is essentially the Schrödinger equation for electrons and solids, and we can solve that for many different kinds of materials. This theory is able to capture it all, though the main price we pay is a large computational cost."

With tools like this in hand, Kaxiras is trying to boost our understanding of two-dimensional materials, working closely with Jenny Hoffman, Philip Kim, and others toward that end. He is particularly interested in multi-layered materials consisting of graphene, for instance, in combination with assorted semiconductors and insulators. "The question then becomes, how do you stack these layers to get the most desirable properties—be it electrical conductivity, heat conductivity, optical response, and so forth?" Kaxiras asks.

Kim's group has experimented with varying the orientation of the different layers by rotating one layer with respect to another. The result is a much more complicated material. When the lattices don't line up, Kaxiras explains, "instead of having a crystalline arrangement, we have something called an 'incommensurate arrangement,' which poses a big challenge for theorists because almost all our understanding to date has been based on crystalline order."

Kaxiras has joined forces with Mitchell Luskin, an applied mathematician at the University of Minnesota, to get a handle on this problem. "We now have equations that enable us to model incommensurate systems, which means that we have a reliable theory again." So far, the predictions made by Kaxiras and his colleagues have matched well with the experimental results of Kim and researchers at MIT.



Schematic of plasmon excitation in Li intercalated bilayer graphene. From: Shirodkar, S.N., et al, "Visible Quantum Plasmons in Highly-Doped Few-Layer Graphene," arXiv:1703.01558v1.

Kaxiras believes that a serious examination of the properties of layered materials might pave the way toward improved photovoltaic cells that convert sunlight into electricity. He and Harvard chemist Roy Gordon are looking into coating glass with a thin layer of so-called transition metal chalcogenides, which have the potential to convert every building window into a photovoltaic device.

Kaxiras is also engaged in the search for durable, lightweight materials for batteries that can hold up over repeated cycles of charging and discharging. Theory can suggest brand new materials whose synthesis has never been tried before, Kaxiras says. "This is a promising direction, which we're hoping to get into much more." And if he succeeds on both the energy storage and photovoltaic fronts, the prospects for a solar energy future could look brighter indeed.

Subir Sachdev: Forging a Strange Communion between High-Temperature Superconductors and Black Holes

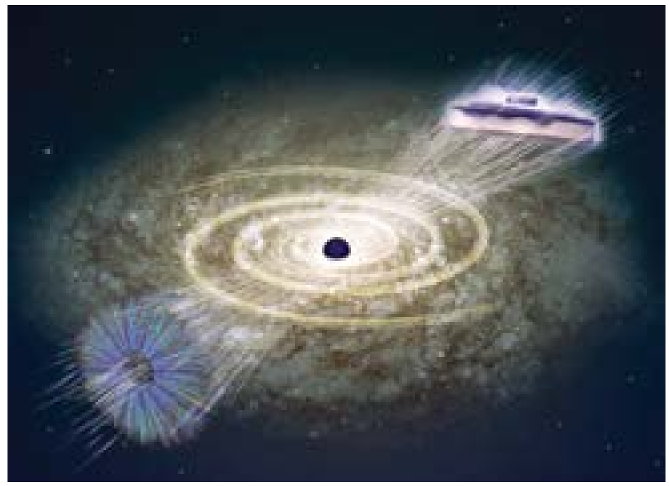
Subir Sachdev is bringing condensed matter physics—the science that describes the materials of our everyday lives—into the unfamiliar realm of string theory and black holes.

While the links between these different areas might be hard for us to perceive—and were even surprising to Sachdev at first—his efforts along these lines have been very fruitful.

Sachdev's unconventional journey stemmed from his early inquiries into high-temperature superconductors, which were first discovered in 1986. Above a critical temperature, these materials lose their superconductivity and instead assume a different form of matter called "strange metals." In ordinary metals and in ordinary (low-temperature) superconductors, electrons move in a kind of smeared-out swarm that behaves like an individual particle. These clouds of electrons are called "quasiparticles." Electron movements, under these conditions, can be described simply, using classical physics. Things are much more complicated in strange metals owing to "quantum entanglement." Electrons interact with each other and can no longer be treated as individual particles.

In 2007, Sachdev made a conceptual breakthrough upon realizing that the body of theoretical knowledge built up around black holes could help clarify the situation regarding strange metals. He was pointed in this direction for a couple of reasons. First, when both a black hole and a strange metal are perturbed, electrons do not behave like individual particles but instead exhibit bulk behavior more akin to the flow of molasses. The second parallel was even more striking: Two black holes in the process of merging will reach their equilibrium state, a perfect sphere, in a characteristic time, which is equal to the Planck constant divided by the so-called Hawking temperature. If a strange metal is shaken up, it too will return to its equilibrium state in the same characteristic time, again equal to the Planck constant divided by its temperature.

Sachdev was also motivated by an idea first advanced in 1997 by the physicist Juan Maldacena, who was then at Harvard. Maldacena's idea, "AdS/CFT," showed how theoretical problems related to black holes could be translated to very different physical settings. Sachdev wondered whether the correspondence proposed by Maldacena might apply to strange metals and other problems in condensed matter physics. He found out that it did. "If you take a black hole and inject energy into it, or change its density, it will eventually come to rest in a smaller or bigger spherical shape," Sachdev says. "The same equation can tell you how a strange metal will respond to changes in temperature or voltage and so forth." The reason for exploiting this connection, he adds, "is that the equations on the black hole side are generally much easier to solve than those on the strange metal side."



A facet of string theory, the currently favored route to a 'theory of everything', might help to explain some properties of exotic matter phases—such as some peculiarities of high-temperature superconductors.
Image credit: Zachary Zavislak

Insights from black holes enabled Sachdev to make predictions about the behavior of electrons in an exotic material like graphene. These predictions were subsequently upheld in experiments that he collaborated on with Philip Kim, the results of which were reported in 2016 in the journal *Science*. The parallels between black holes and quantum materials looked promising on paper, Sachdev says, "but you never know that this works in the real world until you do an experiment."

A model of strange metals developed by Sachdev and his colleagues is already leading to insights about both black holes and high-temperature superconductors. Many applications for the latter are easy to foresee. But who knows what uses physicists might ultimately conjure up for black holes?

Ashvin Vishwanath: Exploring Topological Phases and States in the New Material World

The new states of matter that condensed matter physicists are now grappling with can give rise to never-before-seen quantum phenomena that are far more subtle than superconductivity, contends Ashvin Vishwanath.

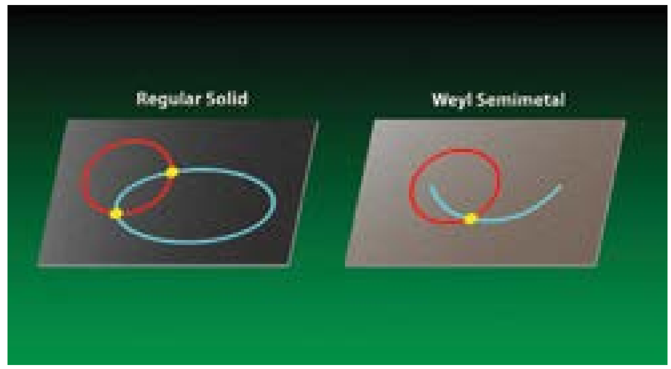
"The quantum Hall effect is one example, but that's just the tip of the iceberg in terms of the new states we're looking at."

In 2011, Vishwanath and his colleagues proposed a new class of solid materials called Weyl semimetals, which were analogous to particles originally proposed by the physicist Hermann Weyl back in 1929. Although Weyl's particles have not yet been seen in high-energy physics experiments, solid analogs of those particles—in keeping with the predictions of Vishwanath, et al.—were observed by three different research groups in 2015.

Vishwanath has been investigating the mysterious properties of Weyl semimetals ever since. These materials are also called "topological" metals, owing to the fact that the surface has special, anomalous features that are very different from those found in the interior. Weyl semimetals are closely related to "topological insulators," which look like insulators on the inside but are enveloped within a metal-like surface that can conduct electricity. "Conductivity propagates along the edge of this material," he explains, "but the bulk material in the center gives rise to this edge manifestation, and you can't separate the two.

"The surfaces of these materials always behave in a strange way," Vishwanath adds. "Even if it is a skin, you cannot peel off the surface because it is part and parcel of the whole. If you take away one layer, you get the same thing—the same physics happening—in the layer below it." A bar magnet offers a good point of comparison. If you try to snip off the north pole, it won't go away; instead, the same magnetic field will emanate from the point just below. A similar thing happens with topological insulators and semimetals, even though the conductivity appears to be something that only happens at the surface.

Topological states, or semimetals, have a related property that is equally unusual. Normally when impurities are added to a metal, the flow of electrons is impeded; if enough impurities are added, the erstwhile metal becomes an insulator. The surface of a topological semimetal, as the names applies, is metallic, but its conductivity is less affected by the addition of impurities, Vishwanath explains, "because the surface behavior mainly stems from the bulk."



Two possible Fermi surfaces (blue lines) for momentum states on the outer face of a material. (The Fermi surface in two dimensions is a line.) The closed Fermi circle at left represents the usual situation, while the open Fermi arc at right only appears in the context of a Weyl semimetal. The two can be distinguished by counting the number of crossings with an arbitrary closed loop (red). An odd number of crossings can only occur from the Fermi arc. (From: Ashvin Vishwanath, "Viewpoint: Where the Weyl Things Are," *Physics* 8, September 8, 2015.)

Vishnawath's group works more generally on topological phases or states, of which semimetals are just one example. "We're trying to see how far we can push these materials," he says. "We normally go to very low temperatures to see things clearly. But how high can we increase the temperature and still observe topological phenomena?" He's also curious as to what ingredients are absolutely needed. "Do we need electrons?" he asks. "Could atoms assume the form of topological phases?" Vishwanath believes the answer to the latter question is yes, but he continues to seek more answers, as well as more definitive answers. And in the course of doing that, he's sure to unearth additional questions that are likely to keep him and other researchers busy for a long while.

PROGRAMS

Undergraduate Program

Eric Lu (left) and Alex Nie present their project to Professor Cora Dvorkin during the Open House for "Principles of Scientific Inquiry," the lab component of Physics 15C: Wave Phenomena

Professor of Physics and Director of Undergraduate Studies, Howard Georgi
Photo by Jon Chase/Harvard University.

Words From the Director

Way back in September of 1997, twenty years ago this fall, I and my head TF David Morin started teaching Physics 16 for the first time. This class was the inspiration for the musical *Les Phys*, by Peter Dong, for Physics Nights at Leverett House, and for Physics Monkeybreads, among other things. Since then, David and I have had fun introducing thousands of students to physics at Harvard in 16 and 15abc. I am hoping that some of the students might want to participate in organizing a revival of *Les Phys* next year!

NEW CONCENTRATORS

Forty-nine enthusiastic sophomores signed up for the Physics and Chem/Phys concentrations last fall, many of them pursuing joint concentrations or secondaries in other fields. These fields include Astrophysics, Mathematics, Engineering, Computer Science, Statistics, Music, African American Studies, History, Archaeology, Economics, and Philosophy.

CAREER PATHS

This past year's graduating class consisted of 51 Physics and Chem/Phys concentrators; 23 of these students (nearly equaling last year's record number of 24) are heading off to graduate school at nine different institutions to study physics, biophysics, astronomy, materials science, artificial intelligence, math, and computer science. Others will be attending medical school, and still others have joined the workforce in software, consulting, data science, finance, industry, and law.

PRIZES & AWARDS

Seven graduating seniors were awarded National Science Foundation Graduate Research Fellowships for their upcoming studies in graduate school: Eric Anschuetz, Juliana Garcia-Mejia, Henry Lin, Andrew Mayo, Meg Panetta, Greg Parker, and Daniel Rothchild. Among these students, Juliana also won a Ford Fellowship, Henry won a National Defense Science and Engineering Graduate Fellowship, and Daniel won a Churchill Scholarship. Henry was this year's 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 summer, roughly 40 Physics and Chem/Phys concentrators are doing full-time research on campus. These students are working in physics, astrophysics, engineering, and other related fields. Many other students are pursuing off campus research at institutions in the U.S. and abroad.

Ben Sorscher has spent the last year working in Professor Aravi Samuel's group, applying techniques from physics to study a central question in neuroscience: how do networks of neurons represent sensory information and encode purposeful behaviors? This question is dauntingly complex in our own brains, which contain many billions of neurons. However, the roundworm *C. elegans* presents an excellent model organism, with a mere 302 neurons, each carefully identified and mapped in the first ever neural "connectome." Ben's project has centered around developing optical imaging techniques to monitor neuronal dynamics in the entire *C. elegans* brain for extended time scales. He applies assorted sensory and optogenetic stimuli to study how the *C. elegans* brain is able to encode this sensory information into behavior. Ben particularly loves the interdisciplinary nature of this research. His work has involved everything from genetic engineering to laser systems, to algorithms for identifying and tracking neurons, to statistical inference and mathematical modeling. Ben is grateful for the chance to have developed this diverse set of skills, and he is excited to bring them to bear on future research as he pursues graduate school.

WOMEN IN PHYSICS

Building on the success of the APS Conference for Undergraduate Women in Physics (CUWiP) held at Harvard (see page 8–17), the Harvard graduate-student Women in Physics organization has renewed its efforts to create a community of inclusion that allows ample space for discussion. Because there currently is no undergraduate women-in-physics group, the organization invited all female physics concentrators to join and attend their events. Additionally, Women in Physics has organized several events specifically for undergraduates. These varied from events designed for women in the department, such as the graduate-undergraduate mentor-mentee program, to those that were for all genders, such as "All about grad school" panels. Another new event was the "Lab tours and theorist chats," where graduate students gave lab tours and spoke about their research to physics concentrators and freshmen interested in the physics concentration. To finish off the semester, Women in Physics handed out (much appreciated!) cookies and juice after the Physics 15a and 15b final exams. All of these events were incredibly well received, and female physics concentrators have also begun to plan events for Women in Physics. The group is excited to grow, thanks to the involvement of undergraduates, and it hopes to bring the graduate and undergraduate communities even closer together.

PROGRAMS

Graduate Program

by Dr. Jacob Barandes

THE PHD CLASS ENTERING IN 2017

The incoming students entering the Physics PhD program in Fall 2017 are, as always, representative of great geographic diversity. They hail from the American states of Arizona, California, Colorado, Illinois, Massachusetts, Nevada, New Jersey, New Mexico, New York, Pennsylvania, Tennessee, and Virginia, and from the nations of Canada, China, Denmark, Iran, Israel, Italy, Japan, and Peru.

THE PHYSICS GRADUATE STUDENT COUNCIL

Created by our Physics PhD students in the spring of 2009, the Physics Graduate Student Council continues to play a key role in 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 is Elana Urbach, and its other members (in alphabetical order) are Christie Chiu, Jae Hyeon Lee, Cole Meisenhelder, Marios Michael, Aditya Parikh, Arthur Safira, Rhine Samajdar, and Steven Torrisi.

ALUMNI TALKS

To assist graduate students in connecting with alumni of the program and in learning more about careers inside and outside academia, the council has worked with the department over the past academic year to invite alumni from different sectors to visit and discuss career opportunities. These visiting alumni have included: Tony Pan (PhD '13), Founder and CEO of Modern Electron; Gregory Sobczak (PhD Astronomy '00), Head of Financial Engineering at the Chicago Trading Company; David Benjamin (PhD '15), Computational Biologist at the Broad Institute; Michael Shulman (PhD '15) and Georg Kucsko (PhD '16), both working in machine learning at Kensho Technologies; Areez Mody (PhD '04), Manager of Strategy Diversification at Quantlab;

The beginning and triumphant end of the graduate journey: orientation for new grads (left); celebrating the Commencement (above).

and Edlyn Levine (Applied Physics PhD '16), Senior Systems Engineer at the MITRE Corporation.

CAREER EVENTS

The department was also pleased to invite the following speakers: Prof. John Townsend and Prof. Peter Saeta, both from Harvey Mudd College, who talked to our students about physics career opportunities at liberal arts colleges; Emily Halket, who held an event about the Insight Data Science Fellowship; Prof. Steven Prawer, from the University of Melbourne, who shared his experiences working on bionic implants and human-machine interfaces; and Peer Hofstra, President of Hofstra Group, Ltd., who talked about careers in scientific-instrument engineering.

PANEL EVENTS

As part of our physics program's efforts to inform students about outside funding opportunities, the department organized a panel discussion on September 30 that addressed issues related to external fellowships. Moderated by the Director of Graduate Studies, Prof. Vinothan Manoharan, and the Associate Director of Graduate Studies, Dr. Jacob Barandes, the panel included (in alphabetical order) senior Physics PhD students Ben Augenbraun (atomic physics), Ellen Klein (soft matter), Harry McNamara (biophysics), and Elana Urbach (atomic physics), who shared their experiences and answered questions from the first- and second-year PhD students in attendance.

On February 28th, the department held a panel event to discuss the physics qualifying examination. Once again moderated by Prof. Manoharan and Dr. Barandes, the panel's members consisted of senior Physics PhD students Christie Chiu (experimental atomic physics), Monica Pate (quantum gravity), Matthew Turner (atomic physics and biophysics), and Dominik Wild (atomic physics).

On April 13, the department hosted a panel for our graduate students on how to navigate the process of securing a postdoctoral fellowship. Moderated by senior Physics PhD students Ellen Klein (soft matter) and Tom Rudelius (quantum gravity), the panelists included postdoctoral fellows Fabian Grusdt (condensed matter), Sarah Harrison (quantum gravity), Trevor Rhone (nuclear magnetic resonance), Christopher Rogan (particle physics), and Katrin Vogt (biophysics), as well as graduating Physics PhD student Alp Sipahigil (atomic physics).

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.

Shiang Fang

2017 GOLDHABER PRIZE WINNER

Shiang Fang received his BS in Physics at National Chung Cheng University in Taiwan, where he worked with Prof. Dian-Jiun Han on cold-atom experiments. Subsequently, he went to National Tsing Hua University (also in Taiwan), where he finished his MS degree in Physics. He worked with Prof. Daw-Wei Wang in the areas of theoretical cold atoms and strongly correlated systems. In the fall of 2012, he entered the Physics PhD program at Harvard.

In his graduate studies at Harvard, Shiang works on theoretical condensed matter and computational physics under the supervision of Prof. Bertrand Halperin and Prof. Efthimios Kaxiras. The research focuses on two-dimensional layered materials—their theoretical *ab-initio* modeling, heterostructures in stacks, and electrical and optical properties such as excitons and trions. Shiang's work also extends to the study of layers with topological phases, superconductivity, and magnetic properties. He collaborates with experimental groups to probe these materials using transport, scanning tunneling microscope, and optical pump-probe measurements.

The Goldhaber Prize is awarded annually by the department to its most outstanding current PhD students based on their research accomplishments, as determined by a vote of the faculty. Winners of this award give presentations at the Historical Lee Lecture. They are guests at the dinner held prior to the lecture, and each receive a $3,000 check.

Shannon Harvey

2017 GOLDHABER PRIZE WINNER

Shannon Harvey is a graduate student in Amir Yacoby's group studying spin qubits. She has worked on a number of projects aimed at improving entangling gates in her experimental system, which is a key step toward making spin qubits viable as the building blocks of a quantum computer. One of her main interests during her PhD research has been the origins of noise in semiconductors, and she has worked on developing measurement and fabrication techniques to investigate this issue. She attended college at Cornell University, where she studied math and physics and ran a small cooperative residential house.

Harvey's favorite aspect of graduate school has been the opportunity to learn about different fields and master new skills, an exciting challenge since she didn't know what a dilution refrigerator or cleanroom were when she began her studies here. In her free time she enjoys reading and cooking.

GSAS Merit Fellowship

The Merit Fellowship is awarded by GSAS to PhD 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 PhD students for the award each year. Students who win the award receive partial or complete stipend support from GSAS for one semester.

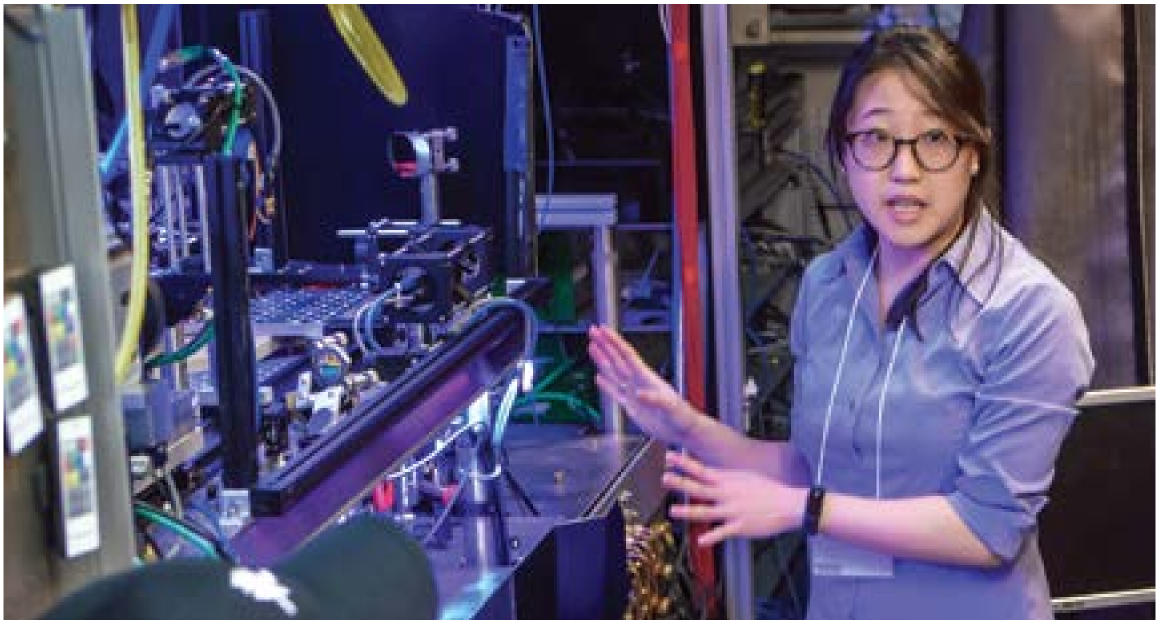
Aavishkar Patel

2017 GSAS MERIT FELLOWSHIP WINNER

Aavishkar Patel grew up in Bangalore, India. Before coming to Harvard, he did his undergraduate studies at the Indian Institute of Technology, Kanpur, where he obtained a Master's degree in physics. As an undergraduate, Aavishkar was drawn towards research in theoretical condensed matter physics. He sensed that the field would offer him a unique opportunity to solve challenging theoretical problems while simultaneously being able to explore their experimental implications—a combination he found hard to resist. He worked on several different problems on graphene and topological insulators, the most significant of which involved providing theoretical assistance to Nobel laureate Prof. Andre Geim's group in Manchester. There, Aavishkar participated in a pioneering experiment that uncovered evidence of the Hofstadter butterfly spectrum in graphene devices fabricated on hexagonal boron nitride substrates. He was also awarded the Best Project Medal at IIT Kanpur for research on non-equilibrium quantum dynamics in topological insulators, leading to his Master's degree.

At Harvard, Aavishkar works with Prof. Subir Sachdev on demystifying the physics of materials with strongly interacting electrons that lack discernible quasiparticle excitations. Such scenarios, which frequently arise in theoretical models of high-temperature superconductors and frustrated quantum magnets, might be responsible for a variety of results observed in experiments on these systems—the most famous being the poorly-understood "strange metal" phases with electrical resistance that scales linearly with temperature. Understanding the physics that gives rise to such unusual phases of quantum matter will provide valuable insights into the nature of these materials, which could eventually help in optimizing them for possible technological applications.

Aavishkar also works on precisely quantifying the microscopic processes governing thermalization of interacting quantum many-body systems perturbed away from equilibrium, and understanding their connections to quantum chaos and quantum information. Such work might eventually contribute to building a new framework for characterizing strongly interacting quantum matter without quasiparticles.



Graduate student Christie Chiu explains the apparatus in Greiner Lab to visitors. Photo by Alejando Avila.

Graduate Student Awards and Fellowships*

Amherst College: Forris Jewett Moore Fellowship

Andrei Gheorghe

Ashford Family Fellowship

Carissa Cesarotti

Bolsa de Doutoramento FCT

Bruno Balthazar

DOE Computational Science Graduate Fellowship

Steven Torrisi

Frederick Sheldon Traveling Fellowship

Karri DiPetrillo

Gertrude and Maurice Goldhaber Prize

Shiang Fang
Shannon Harvey

GSAS Merit Fellowship

Aavishkar Patel

Hertz Foundation Fellowship

Andrey Sushko

KITP Graduate Fellowship

Aavishkar Patel
Alexandra Thomson

National Defense Science and Engineering Graduate (NDSEG) Fellowship

Mihir Bhaskar
Iris Cong
Harry Levine
Andrew Pierce
Jessie Zhang

National Science Foundation Graduate Research Fellowship Program (NSF GRFP)

Delilah Gates
Jacob McNamara
Nicholas Mondrik
Grace Pan
Taylor Patti
LaNell Williams
Grace Zhang

Natural Sciences and Engineering Research Council of Canada (NSERC) Fellowship

Ian Kivlichan

P.D. Soros Fellowship for New Americans

Andrey Sushko

Quantum Computing Graduate Research Fellowship

Lucas Orona

*Includes awards from 2016–2017.





Congratulations
Harvard Physics
PhDs!


Recent Graduates

Matthew Eli Berck

Thesis: Reconstructing and Analyzing the Wiring Diagram of the Drosophila Larva Olfactory System

Advisor: Aravinthan Samuel

Michael William Coughlin

Thesis: Gravitational Wave Astronomy in the LSST Era

Advisor: Christopher Stubbs

Thomas Dimiduk

Thesis: Holographic Microscopy for Soft Matter and Biophysics

Advisor: Vinothan Manoharan

William Thomas Frost

Thesis: Tunneling in Quantum Field Theory and the Fate of the Universe

Advisor: Matthew Schwartz

Elizabeth Jerison

Thesis: Epistasis and Pleiotropy in Evolving Populations

Advisor: Michael Desai

Gareth Kafka

Thesis: A Search for Sterile Neutrinos at the NOvA Far Detector

Advisor: Gary Feldman

Ekaterina Kosheleva

Thesis: Genetic Draft and Linked Selection in Rapidly Adapting Populations

Advisor: Michael Desai

Sarah Valerie Kostinski

Thesis: Geometrical Aspects of Soft Matter and Optical Systems

Advisor: Michael Brenner

Ivan Kozyryev

Thesis: Laser Cooling and Inelastic Collisions of the Polyatomic Radical SrOH

Advisor: John Doyle

Rebecca Krall

Thesis: Studies of Dark Matter and Supersymmetry

Advisor: Matthew Reece

Eric David Kramer

Thesis: Observational Constraints on Dissipative Dark Matter

Advisor: Lisa Randall

Lucy Eunju Lee

Thesis: Network Analysis of Transcriptome to Reveal Interactions among Genes and Signaling Pathways

Advisor: Erel Levine

Igor Lovchinsky

Thesis: Nanoscale Magnetic Resonance Spectroscopy Using Individual Spin Qubits

Advisor: Mikhail Lukin

Alexandru Lupsasca

Thesis: The Maximally Rotating Black Hole as a Critical Point in Astronomy

Advisor: Andrew Strominger

Tobias Mansuripur

Thesis: The Effect of Intracavity Field Variation on the Emission Properties of Quantum Cascade Lasers

Advisors: Federico Capasso (SEAS)/Amir Yacoby

Andrew William Marantan

Thesis: The Roles of Randomness in Biophysics: From Cell Growth to Behavioral Control

Advisor: L. Mahadevan

Natalie Mashian

Thesis: Modeling the Constituents of the Early Universe

Advisors: Avi Loeb (Astronomy)/Christopher Stubbs

Anton Mazurenko

Thesis: Probing Long Range Antiferromagnetism and Dynamics in the Fermi-Hubbard Model

Advisor: Markus Greiner

Prahar Mitra

Thesis: Asymptotic Symmetries in Four Dimensional Gauge and Gravity Theories

Advisor: Andrew Strominger

Iulia Alexandra Neagu

Thesis: Evolutionary Dynamics of Infection

Advisors: Martin Nowak (OEB)/Mara Prentiss

Elizabeth Petrik West

Thesis: A Thermochemical Cryogenic Buffer Gas Beam Source of ThO for Measuring the Electric Dipole Moment of the Electron

Advisor: John Doyle

Thomas Rudelius

Thesis: Topics in the String Landscape and the Swampland

Advisor: Cumrun Vafa

Nabiha Saklayen

Thesis: Laser-Activated Plasmonic Substrates for Intracellular Delivery

Advisor: Eric Mazur

Alp Sipahigil

Thesis: Quantum Optics with Diamond Color Centers Coupled to Nanophotonic Devices

Advisor: Mikhail Lukin

Siyuan Sun

Thesis: Search for the Supersymmetric Partner to the Top Quark Using Recoils Against Strong Initial State Radiation

Advisor: Melissa Franklin

Ming Eric Tai

Thesis: Microscopy of Interacting Quantum Systems

Advisor: Markus Greiner

Emma Tolley

Thesis: Search for Evidence of Dark Matter Production in Monojet Events with the ATLAS Detector

Advisor: Masahiro Morii

Alyssa Michelle Wilson

Thesis: New Insights on Neural Circuit Refinement in the Central Nervous System: Climbing Fiber Synapse Elimination in the Developing Mouse Cerebellum Studied with Serial-Section Scanning Electron Microscopy

Advisors: Jeff Lichtman (MCB)/Aravinthan Samuel

PROGRAMS

Research Scholars

The academic year began with the September 7, 2016, all-department barbecue, attended by faculty, graduate and undergraduate students, research scholars, and staff.

On September 22, 2016, scholars enjoyed our fourth annual Post-Doc/Research Scholar Retreat at Rolling Ridge Retreat and Conference Center, North Andover, MA. The day-long event included a grants management talk by Dr. Stefanie Tompkins, Director of the Defense Sciences office at DARPA, a poster session, a trivia quiz moderated by Dr. Jacob Barandes, Director of Graduate Studies for FAS Sciences, and ended with the plenary speaker, Dr. Emanuel Derman, Director of the MS Program in Financial Engineering and Professor of Professional Practice, Columbia University. The Retreat continues to be a great opportunity for scholars to spend a day away from campus learning about the research in our department and sharing their own research with their colleagues.

The Retreat was followed by our annual poster session on October 27, 2016, to which the entire Department was invited so that everyone had the opportunity to see the scholars' Retreat posters.

During this academic year, the Research Scholar Advisory Committee organized two panels titled "How to Get a Faculty Position." The first panel on November 17, 2016, was moderated by Harvard Post-Doctoral Fellows Sandra Eibenberger and Nicholas Hutzler and included the junior faculty from Harvard and other universities: Professors Charles Doret (Williams College), Cora Dvorkin (Harvard), Swati Singh (Williams College), Alexander Sushkov (Boston University), Toeno van der Sar (who starts his faculty position at the Kavli Institute in the fall of 2017), and Ilija Zeljkovic (Boston College). The second panel on November 29, 2016, was moderated by Harvard Post-Doctoral Fellow Susannah Dickerson and Harvard Research Associate Richard Schmidt. The panelists were Harvard senior faculty members: Professors Melissa Franklin, Howard Georgi, Philip Kim, Subir Sachdev, and Ashvin Vishwanath.

On April 13, 2017, the research scholars themselves presented a similar panel to our graduate students, this time drawing on their own experience: "How to get a Post-Doc Position." The moderators of this panel were Harvard Physics graduate students Ellen Klein and Tom Rudelius; the panelists included Post-Doctoral Fellows Fabian Grusdt, Sarah Harrison, Trevor Rhone, and Katrin Vogt, as well as Christopher Rogan, a Research Associate, and Alp Sipahigil, a graduating PhD student.

The Department continues its bi-monthly lunches, which provide scholars with frequent opportunities for social interaction with their colleagues.

We have set our fifth annual Retreat for September 13, 2017, at the Nantasket Beach Resort in Hull, MA. The mathematician and hedge fund manager James Simons, who heads the Simons Foundation (https://en.wikipedia.org/wiki/James_Harris_Simons), will be the plenary speaker. He's likely to deliver an interesting talk, as the Financial Times has called Simons "the world's smartest billionaire."

And Professor Thomas Eisenmann of the Harvard Business School (http://www.hbs.edu/faculty/Pages/profile.aspx?facId=6452) will present one of his HBS case studies during the afternoon of the Retreat. We are excited to be able to offer our scholars an HBS exercise that will provide real-life applications to a science-based business.

Photo by Al Takeda

Faculty in the News

Sisyphus Laser Cooling of a Polyatomic Molecule

John Doyle

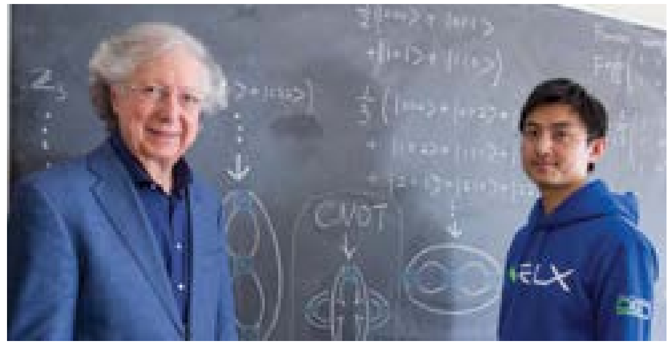
Building on this proposal and earlier work in their group, the Doyle team now reports the first observation of laser cooling of a polyatomic molecule.

Using a technique they pioneered, the authors produced SrOH molecules in a so-called cryogenic buffer-gas beam. They then selected those molecules with a transverse velocity slow enough for efficient laser cooling, corresponding to a transverse temperature of about 50 mK. Next they directed these molecules into a region where they interact with pairs of laser beams that are transverse to the molecular beam and are tuned near one of two optical resonances in the SrOH molecule. By measuring the transverse velocity distribution of the molecules after they have passed through the laser-cooling region, they inferred that not only did they cool the molecules, but they also observed Sisyphus cooling, which produced molecules with transverse temperatures of only 750 μK.

In Sisyphus cooling, the molecules, like their doomed Greek eponym, are forced to climb a potential hill created by a standing wave of laser light, only to stumble when they spontaneously emit into a magnetic state that does not interact with the laser. A small magnetic field is used to bring the molecules back into the original state, so they can climb the potential hill again and continue to lose kinetic energy. In this manner, the molecules are quickly cooled; in fact, Doyle and colleagues observed that the molecules are cooled from 50 mK to 750 μK by scattering only about 200 photons in 100 μK—corresponding to an acceleration nearly 1000 times bigger than the acceleration due to gravity.

From: Paul Hamilton and Eric R. Hudson, "A Diatomic molecule is one atom too few," Physics *10 (2017).*

Image: APS/Alan Stonebraker



A 3-D Picture-Language for Mathematics

Arthur Jaffe

Galileo called mathematics the "language with which God wrote the universe." He described a picture-language, and now that language has a new dimension.

The Harvard trio of Arthur Jaffe, the Landon T. Clay Professor of Mathematics and Theoretical Science, postdoctoral fellow Zhengwei Liu, and researcher Alex Wozniakowski has developed a 3-D picture-language for mathematics with potential as a tool across a range of topics, from pure math to physics.

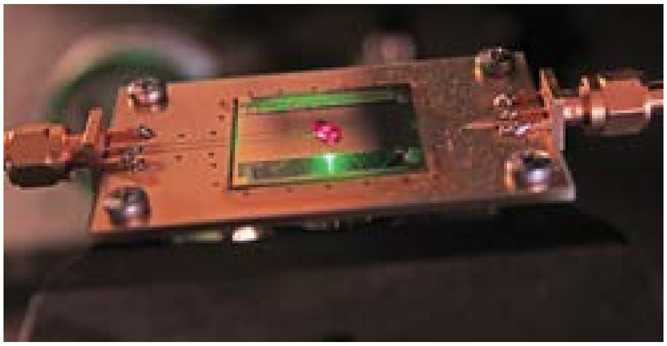
Though not the first pictorial language of mathematics, the new one, called quon, holds promise for being able to transmit not only complex concepts, but also vast amounts of detail in relatively simple images. The language is described in a February 2017 paper published in the Proceedings of the National Academy of Sciences.

"It's a big deal," said Jacob Biamonte of the Quantum Complexity Science Initiative after reading the research. "The paper will set a new foundation for a vast topic."

"This paper is the result of work we've been doing for the past year and a half, and we regard this as the start of something new and exciting," Jaffe said. "It seems to be the tip of an iceberg. We invented our language to solve a problem in quantum information, but we have already found that this language led us to the discovery of new mathematical results in other areas of mathematics. We expect that it will also have interesting applications in physics."

From: Peter Reuell, "Making math more Lego-like: 3-D picture language has far-reaching potential, including in physics," Harvard Gazette*, March 2, 2017.* http://news.harvard.edu/gazette/story/2017/03/making-math-more-lego-like.

Photo by Rose Lincoln/Harvard



Time Crystals

Mikhail Lukin

At Harvard, physicist Mikhail Lukin tried to do something similar, but in a very different system—a 3D chunk of diamond. The mineral was riddled with around 1 million defects, each harbouring a spin. And the diamond's impurities provided a natural disorder. When Lukin and his team used microwave pulses to flip the spins, they saw the system respond at a fraction of the frequency with which it was being disturbed.

Physicists agree that the two systems spontaneously break a kind of time symmetry and therefore mathematically fulfil the time-crystal criteria. But there is some debate about whether to call them time crystals. "This is an intriguing development, but to some extent it's an abuse of the term," says Oshikawa.

Yao says that the new systems are time crystals, but that the definition needs to be narrowed to avoid including phenomena that are already well understood and not nearly so interesting for quantum physicists.

But Monroe and Lukin's creations are exciting for different reasons, too, says Yao. They seem to be the first, and perhaps simplest, examples of a host of new phases that exist in relatively unexplored out-of-equilibrium states, he says. They could also have several practical applications. One could be quantum simulation systems that work at high temperatures. Physicists often use entangled quantum particles at nanokelvin temperatures, close to absolute zero, to simulate complex behaviours of materials that cannot be modelled on a classical computer. Time crystals represent a stable quantum system that exists way above these temperatures—in the case of Lukin's diamond, at room temperature—potentially opening the door to quantum simulations without cryogenics.

Time crystals could also find use in super-precise sensors, says Lukin. His lab already uses diamond defects to detect tiny changes in temperature and magnetic fields.

From: Elizabeth Gibney, "The quest to crystallize time," Nature *543 (2017). Reprinted by permission from Macmillan Publishers Ltd:* Nature *©2017.*

Image courtesy of Georg Kucsko

Mathematical Framework Explains Diverse Plant Stem Forms

L. Mahadevan

It is well known that as plants grow, their stems and shoots respond to outside signals such as light and gravity. But if all plants have similar stimuli, why are there so many different stem shapes? Why does a weeping willow grow downward while nearby poison ivy shoots upward? Using simple mathematical ideas, researchers [...] constructed a framework that explains and quantifies the different shapes of plant stems.

The research is published in the *Journal of the Royal Society Interface.*

"We have combined, in one theory, a plant's ability to sense itself and its environment while being constrained by gravity and its elastic nature," said L. Mahadevan, the Lola England de Valpine Professor of Applied Mathematics, of Organismic and Evolutionary Biology, and of Physics. "By accounting for these factors, we can explain the range of shapes seen in nature without the need for complex growth strategies. This, in turn, implies that the diversity of morphologies seen in your garden may follow from very simple causes."

Mahadevan and co-author Raghunath Chelakkot describe plant shoots as "sentient," meaning they can sense their own shapes and the direction of gravity and light through mechanochemical pathways.

From: Leah Burrows, "Why weeping willows bend and poison ivy doesn't," Harvard Gazette*, March 23, 2017.* http://news.harvard.edu/gazette/story/2017/03/harvard-researchers-develop-framework-to-explain-shape-of-plant-stems/.

Photo by Francesco Gallarotti/StockSnap

Metallic Hydrogen

Isaac Silvera

Last October, Harvard University physicist Isaac Silvera invited a few colleagues to stop by his lab to glimpse something that may not exist anywhere else in the universe. Word got around, and the next morning there was a line. Throughout the day, hundreds filed in to peer through a benchtop microscope at a reddish silver dot trapped between two diamond tips. Silvera finally closed shop at 6 p.m. to go home. "It took weeks for the excitement to die down," Silvera says.

That excitement swirled because by squeezing hydrogen to pressures well beyond those in the center of Earth, Silvera and his postdoc Ranga Dias had seen a hint that it had morphed into a solid metal, capable of conducting electricity. "If it's true it would be fantastic," says Reinhard Boehler, a physicist at the Carnegie Institution for Science in Washington, D.C. "This is something we as a community have been pushing to see for decades." [...]

Scientists have already made liquid metal hydrogen—the substance thought to form the interior of giant planets like Jupiter—by ramping up pressure at higher temperatures. Silvera wanted to work at low temperatures and transform hydrogen into something still more exotic: solid metal. At cryogenic temperatures, hydrogen is a liquid. As the pressure rises, the liquid quickly becomes a nonmetallic solid. In 1935, Princeton University physicists Eugene Wigner and Hillard Bell Huntington predicted that beyond 25 GPa, the nonconductive solid hydrogen would become metallic. But experimentalists passed that threshold decades ago with no sign of a solid metal.

Silvera and Dias claim they've pushed their cell into an unexplored realm of low temperature and extreme pressure, succeeding in part because they avoided continuous high-intensity laser monitoring that they say can also cause an anvil's diamonds to fail. Eventually, as they neared 500 GPa, the black sample became shiny and reddish.

From: Robert F. Service, "Metallic hydrogen created in diamond vise," Science *355 (27 Jan 2017). Reprinted by permission from AAAS ©2017.*

Transmitting Spin Information through Superconductors

Amir Yacoby

A whole field of applied physics, called spintronics, focuses on how to harness and measure electron spin and build spin equivalents of electronic gates and circuits.

By using superconducting materials through which electrons can move without any loss of energy, physicists hope to build quantum devices that would require significantly less power.

But there's a problem.

According to a fundamental property of superconductivity, superconductors can't transmit spin. Any electron pairs that pass through a superconductor will have the combined spin of zero.

In work published recently in *Nature Physics*, the Harvard researchers found a way to transmit spin information through superconducting materials.

"We now have a way to control the spin of the transmitted electrons in simple superconducting devices," said Amir Yacoby, Professor of Physics and of Applied Physics at SEAS and senior author of the paper.

It's easy to think of superconductors as particle super highways but a better analogy would be a super carpool lane as only paired electrons can move through a superconductor without resistance.

These pairs are called Cooper Pairs and they interact in a very particular way. If the way they move in relation to each other (physicists call this momentum) is symmetric, then the pair's spin has to be asymmetric—for example, one negative and one positive for a combined spin of zero. When they travel through a conventional superconductor, Cooper Pairs' momentum has to be zero and their orbit perfectly symmetrical.

From: Leah Burrows, "Physicists pass spin information through a superconductor," Science Daily, *October 14, 2016.* https://www.sciencedaily.com/releases/2016/10/161014214554.htm.

Image courtesy of WikiCommons

Forging a New Tradition to Bring Faculty and Staff Together

Instructional Physics Labs staff member Rob Hart and Dr. Jacob Barandes playing with the children of Harvard physics.

by Steve Nadis

In September of this year, the third Annual Physics Reception will be held at the MIT Endicott House—a sprawling, 25-acre estate located in Dedham, Massachusetts. These yearly gatherings, intended to bring the faculty and staff of the Department of Physics closer together, are the idea of Professor Cumrun Vafa and his wife Afarin. The Vafas have generously offered to pay for the first ten of these get-togethers to support the physics community at Harvard.

Vafa has recently won two notable prizes that carry monetary awards—the 2014 Physics Frontiers Prize and the 2017 Breakthrough Prize in Fundamental Physics—and he is using a portion of the proceeds to host these parties for the faculty and staff. "I received some recognition for work that I did at Harvard," Vafa says, "and this is a way of giving back to the department I've been at since 1985."

The Endicott House, he says, "provides a nice place for people to meet in a casual setting. Afarin and I thought we should have more community building within our department. I've seen this sort of thing at other universities, but nothing along these lines within Harvard Physics." Vafa has especially enjoyed meeting the families of other faculty and staff members. "You get a chance to know your colleagues as people, not just as scientists."

He and Afarin have left event planning details to department administrators and are pleased with how things have turned out. "We feel good about this gift," he says. "It's exactly what we wished for."

Altogether, more than 150 people attended the afternoon events held in 2015 and 2016. Buffet lunches were served, and a variety of games—including volleyball, wiffle ball, Frisbee, and croquet—were played. In 2015, a caricaturist was on hand to do portraits, and in 2016, people could take pictures in a photo booth with physics-related backdrops—stars, planets, a superconductor, a scanning tunneling microscope, and the Large Hadron Collider.

"Not only have these events been a lot of fun, they've also helped strengthen our social bonds," notes Director of Administration Anne Trubia. "Cumrun serves as an exceptional role model for establishing a sense of collegiality throughout our physics department."

Photos by Jolanta Davis (Above, 2,4,5),
New England Photo Booth (1, 3)

Harvard physics staff members Paola Martinez, Jean O'Connor, Clare Ploucha, Hannah Belcher, and Liz Alcock 1

Miriam Saric 2

Prof. Cumrun Vafa 3

Staff member Angela Allen with nephew Jace 4

Prof. Arthur Jaffe, Usha Pasi, and Prof. Peter Galison 5

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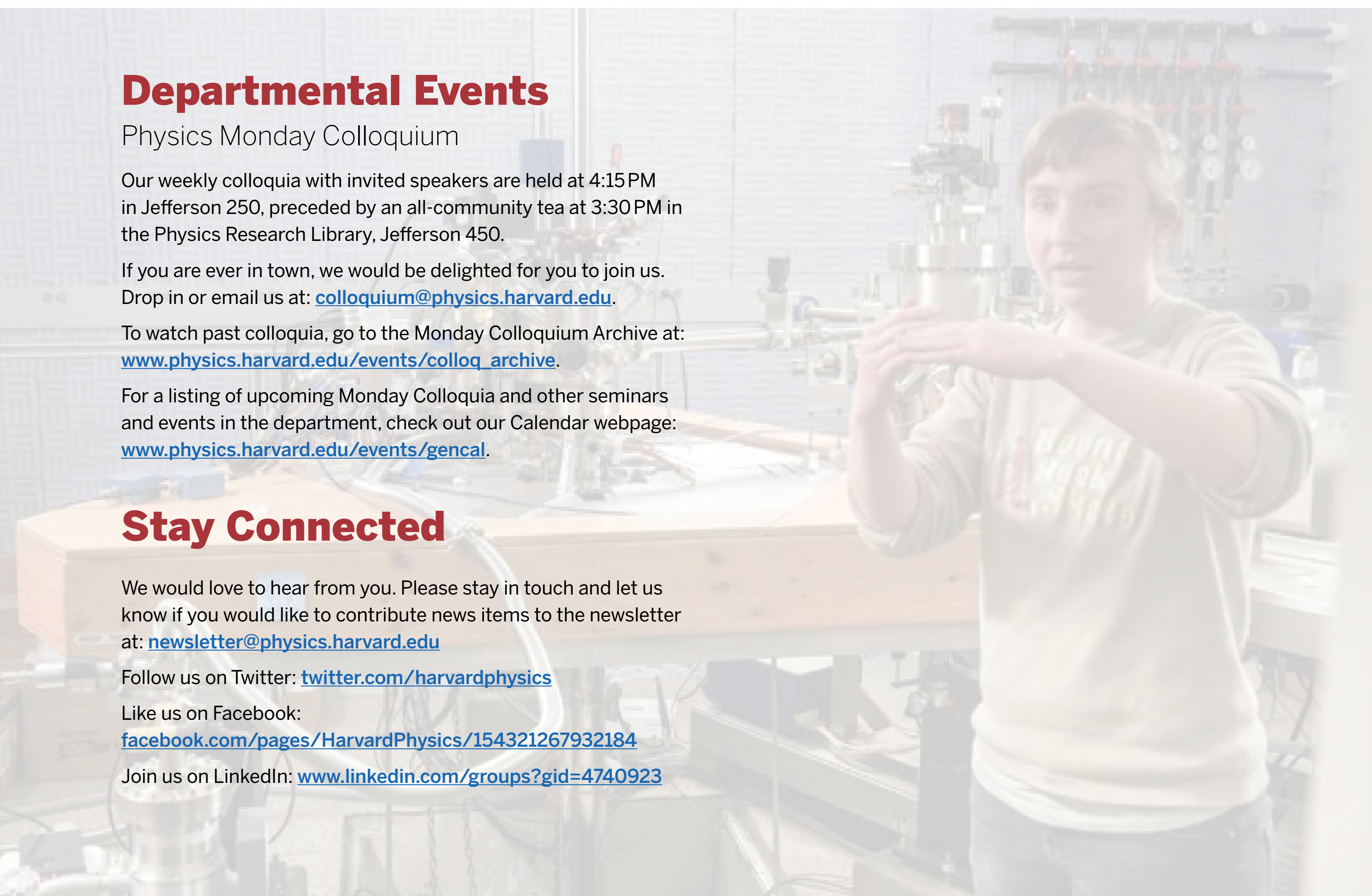

Departmental Events

Physics Monday Colloquium

Our weekly colloquia with invited speakers are held at 4:15 PM in Jefferson 250, preceded by an all-community tea at 3:30 PM in the Physics Research Library, Jefferson 450.

If you are ever in town, we would be delighted for you to join us. Drop in or email us at: colloquium@physics.harvard.edu.

To watch past colloquia, go to the Monday Colloquium Archive at: www.physics.harvard.edu/events/colloq_archive.

For a listing of upcoming Monday Colloquia and other seminars and events in the department, check out our Calendar webpage: www.physics.harvard.edu/events/gencal.

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