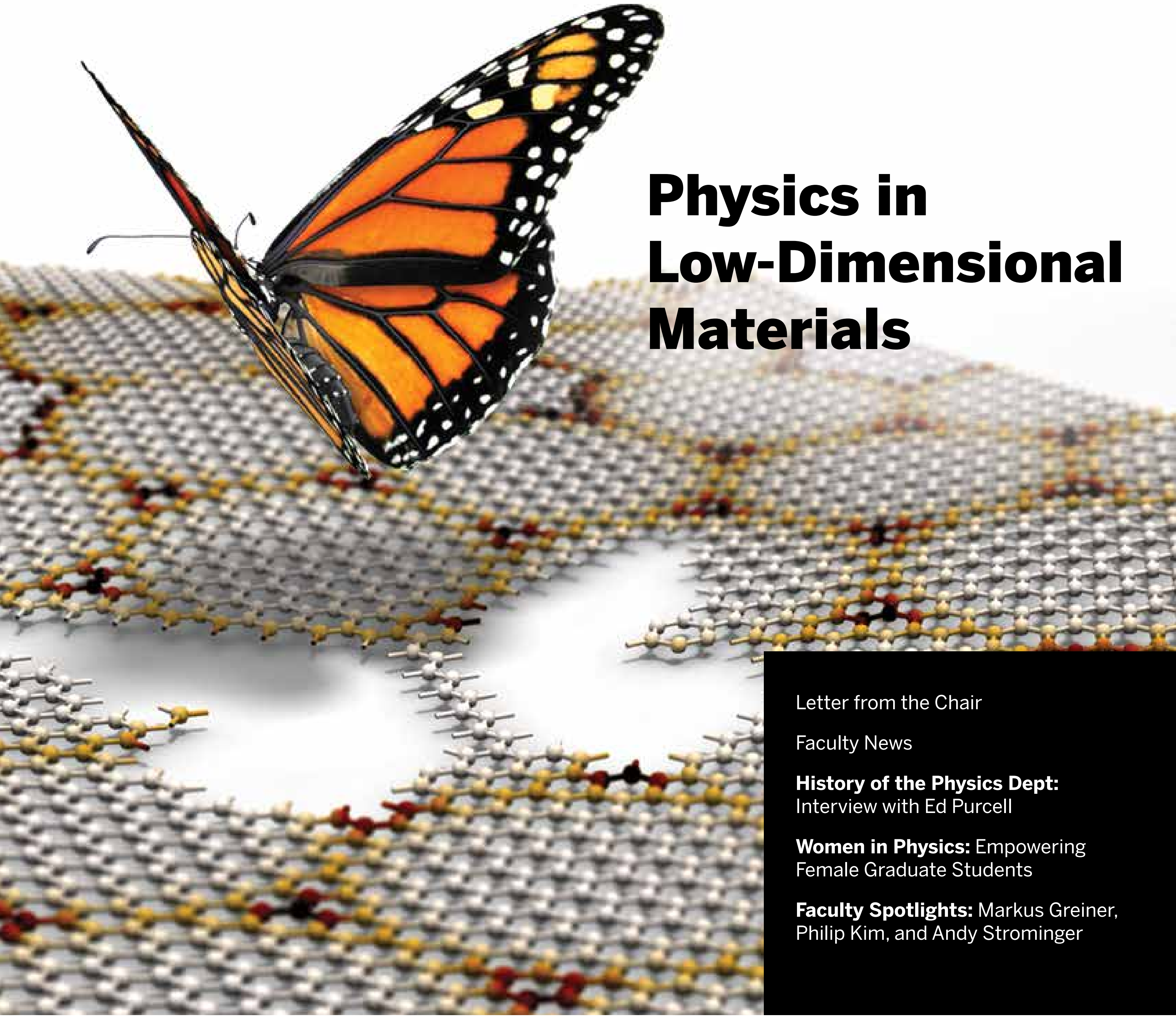
PHYSICS

Harvard University Department of Physics Newsletter

FALL 2015



Physics in Low-Dimensional Materials

HARVARD UNIVERSITY
Department of Physics

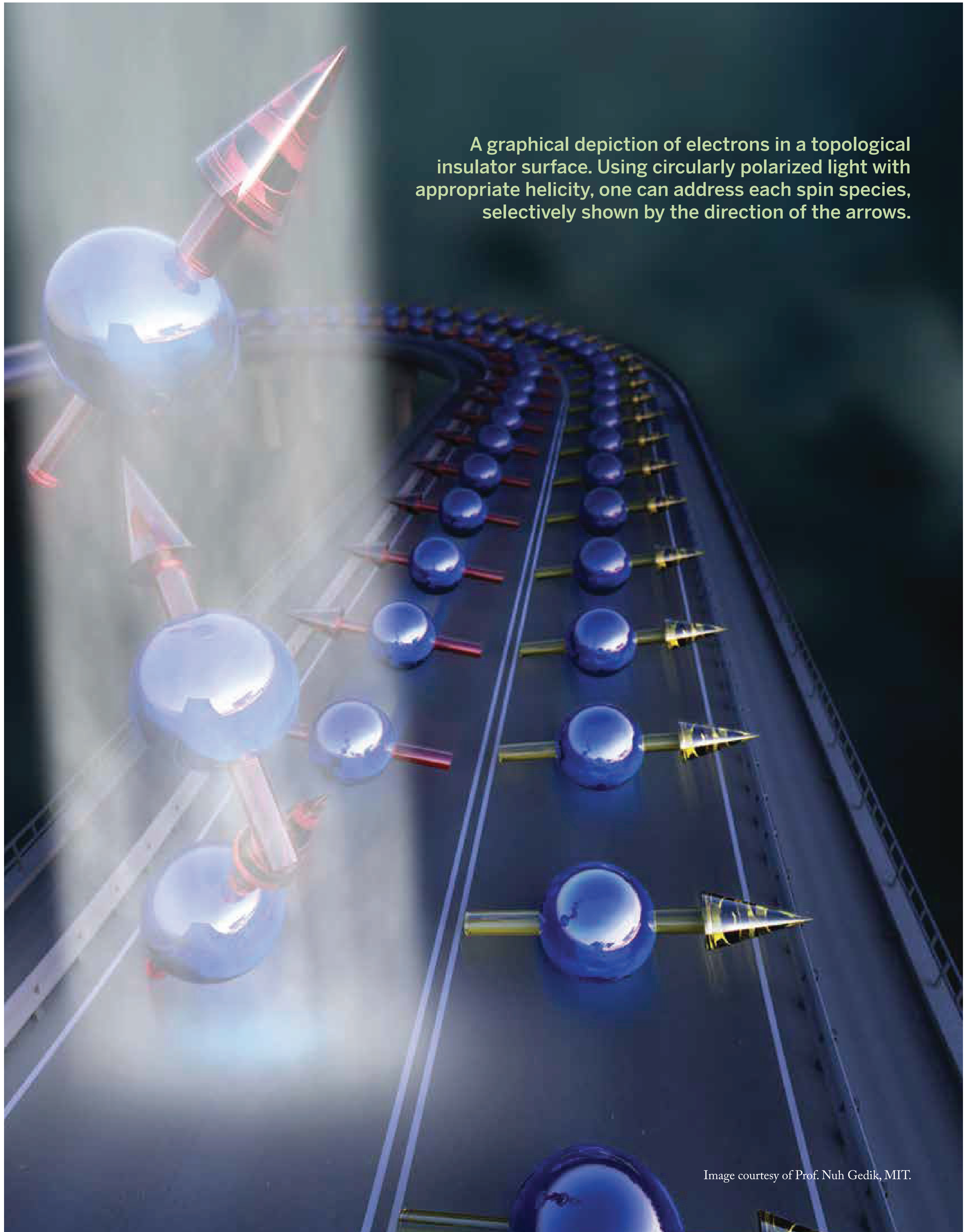


Image courtesy of Prof. Nuh Gedik, MIT.

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An artistic illustration of a butterfly departing from the graphene moiré pattern formed on the top of an atomically-thin boron nitride substrate. Electron energy in such graphene moiré structures exhibits a self-recursive, fractal quantum spectrum. Illustration by James Hedberg.

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Letter from the Chair

We are pleased to deliver the second issue of the Department of Physics Newsletter to your (virtual or real) mailbox. I hope I can start calling it the annual newsletter with a straight face now.

My first year as the Department Chair has gone by in such a blur that I cannot remember exactly why it felt so busy. Flipping through this newsletter gives me a chance to look back and recognize that, yes, a lot of things did happen even though I was winging it. Which goes to show that a ship with a great crew can sail even if the captain is directionally challenged.

Forty-one prospective graduate students accepted our offer of admission this year. The matriculation rate was 61%, the highest in recent record. If 61% of the smartest students choose to pursue their dreams in our Department, we surely must be doing something right. I am also proud to note that 31% of them are women. These numbers speak to the strength of our Department. I congratulate our graduate advising team, Vinny Manoharan, Jacob Barandes, and Lisa Cacciabaudo, and the faculty members on the graduate admissions committee chaired by Tim Kaxiras.

The latest addition to our faculty is Cora Dvorkin, who is profiled on page 4. Cora, a theoretical cosmologist, is coming to our Department from the Harvard Smithsonian Center for Astrophysics. We are thrilled by her arrival, which will strengthen the intellectual connection between Physics and Astronomy.

Three members of our faculty, Jenny Hoffman, Matt Schwartz, and Xi Yin, have received tenure. Each of them represents a powerful combination of top-flight research and outstanding teaching. Our joy is tempered, however, by Jenny's decision to move to the University of British Columbia. I hope that her career will flourish even higher in Vancouver, and that there will be future opportunities for us to work with her.

Our classrooms continue to change. Physically, we have new and improved teaching space in Jefferson 356 and the "SciBoxes" in the Science Center. Jefferson 356 used to be an ugly duckling of a classroom, but it's now been converted into the most attractive lecture space in the Department, with comfortable seating, pleasant acoustics, and advanced audio-visual equipment. See the article on page 26 to learn more about the three SciBoxes, which offer flexible teaching spaces for interactive classes that engage students with group and project-based learning.

Pedagogically, Physical Sciences 2, 3, and 12a/b have been transformed from traditional lectures into more interactive learning experiences, led by Logan McCarty, Louis Deslauriers, Tim Kaxiras, and Chris Stubbs. The teaching laboratories for Physics 15a/b/c now involve student-driven projects thanks to Amir Yacoby, Mara Prentiss, and Markus Greiner, among others.

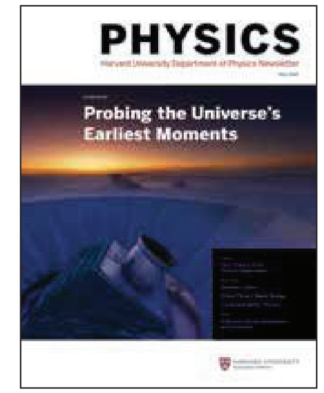
Before closing, I wish to express our gratitude for those who recently chose to support the Department: the Della-Pietra Fund for Theoretical Physics has been established by the gift of Stephen and Vincent Della-Pietra; and the Bershadsky Distinguished Visiting Fellowship in Physics has been established by a gift from Michael and Victoria Bershadsky. These generous donations allow us to embark on new initiatives that promote intellectual connections across the Department.

I hope you will enjoy this newsletter. As always, if you happen to be near the campus, please drop by the Department to see how we are evolving while, at the same time, striving to remain at the forefront of research and education.

Sincerely,

Masahiro Morii
CHAIR AND PROFESSOR OF PHYSICS

Letters from our Readers



The first annual Harvard Physics Newsletter received an enthusiastic response. We were pleased to have heard from a number of delighted readers.

Writing from Santa Barbara, California, David D. Lynch (PhD Physics, '67) said, "I have received the Fall 2014 issue of Physics and enjoyed it very much."

"Thank you so much for the Physics Newsletter. I thoroughly enjoyed hearing about what's going on in the department. I do hope you will keep sending it," wrote Bill Bean (AB '65).

Hailing from the San Francisco Bay Area, Dave Landhuis (PhD Physics, '02), a Data Center Systems Engineer at Google, wrote: "A very nicely produced newsletter with great content. Brought back a lot of memories of people connected with the department. To all who worked on the newsletter: nice work, and thank you!"

"Thanks for your excellent publication." added Nick Percival (AB '64).

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:
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Faculty News

Cora Dvorkin

FOLLOWING DATA TO THE UNIVERSE'S FIRST MOMENTS

While most new professors face challenges at the start of their careers, Cora Dvorkin—a theoretical cosmologist who joined the Harvard Physics faculty as an assistant professor in August—has set an especially difficult agenda for herself: She wants nothing less than to understand the physics of the very early universe, as she tries to unravel the mysteries of the Big Bang, dark matter, dark energy, and other puzzles.

A fascination with deep questions is by no means new for Dvorkin. Upon graduating from high school in Argentina, she—like the rest of her college-bound peers—had to choose her undergraduate major. She'd always been inclined toward math but decided to apply her math skills toward fathoming nature at its most basic level.

After graduating from the University of Buenos Aires, she went to the University of Chicago to study cosmology. One of the areas she focused on there involved drawing on clues from the cosmic microwave background (CMB)—the vestigial light from the Big Bang—to test the idea of inflation, a brief epoch occurring a tiny fraction of a second after the Big Bang during which the universe expanded at an exponential rate. She continued to explore this subject and others during postdoctoral appointments at the Institute for Advanced Study in Princeton and, more recently, as a Hubble Fellow and Institute for Theory and Computation Fellow at the Harvard-Smithsonian Center for Astrophysics.

In the latter stint, Dvorkin joined a team that incorporated data from the Planck satellite to find out whether a South Pole telescope experiment called BICEP2 had detected signals from the Big Bang. (The verdict was that there is no conclusive evidence for a signal of primordial origin.) She also worked on developing a method that uses data from cosmology to constrain the mass of neutrinos—elementary particles whose properties are not well explained by the so-called "Standard Model" of particle physics.

Dark matter will be another important avenue for her research at Harvard. She plans to identify physical processes in which different types of dark matter interactions might come into play, probing these interactions with data from the CMB and large-scale structure surveys. As her work in general is "data driven," she's always on the lookout for new empirical inputs from cosmology that hold the potential for stimulating theoretical insights.

Dvorkin believes she is well situated to continue her research at Harvard. "Given the number of experimentalists engaged in taking measurements of the CMB and the universe's large-scale structure, and theorists tackling a broad range of topics from particle physics to astrophysical problems," she says, "this is an ideal place to do cosmology."

Photo by Kris Snibbe
Harvard University.

Jennifer Hoffman

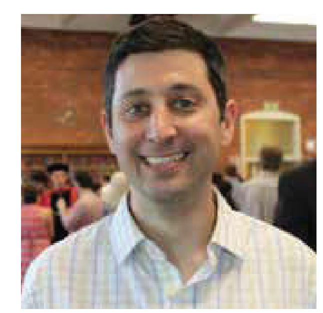
PROFESSOR OF PHYSICS

The Department is delighted to announce the promotion of Jennifer Hoffman to Professor of Physics with tenure. Jenny received her BA in Physics from Harvard in 1999. She went to Berkeley to study experimental condensed-matter physics with J.C. Seamus Davis, earning her PhD in 2003. After being a postdoc at Stanford, Jenny came back to Harvard as an Assistant Professor of Physics in January 2005.

Jenny's lab, located underground in the Laboratory for Integrated Science and Engineering (LISE), houses some of the most sensitive scanning probe microscopes in the world—ultra-delicate devices that map the surface properties of materials by bringing the tip of a probe needle to near-contact and then scanning it across the specimen in sub-atomic steps. Her scanning tunneling microscope, force microscope, and spin-polarized scanning tunneling microscope—all hand-built at Harvard—operate at low temperatures and in high magnetic fields. With these instruments, Jenny and her team of students and postdocs study a variety of novel materials, including high-Tc superconductors and topological insulators.

As a professor, Jenny has earned a reputation as an outstanding instructor. She is best known for her inspiring lectures in Physics 15c. She has been a recipient of the Spark Award (2009), Fannie Cox Award (2012), and Roslyn Abramson Award (2012). From 2006 to 2010, she was a Resident Tutor of Kirkland House, where she shared her time and advice with the students, many of whom chose to experience research in her lab.

In December 2014, Jenny was offered and accepted a Canada Excellence Research Chair in Quantum Materials and Devices Based on Oxide Heterostructures, under which she'll pursue her research at the University of British Columbia in Vancouver. Starting this fall, she will be on leave from Harvard and building up her new lab at the UBC. We wish her even greater success in Vancouver and hope that she will return to Harvard before too long.



Matthew Schwartz

PROFESSOR OF PHYSICS

The Department is delighted to announce the promotion of Matthew Schwartz to Professor of Physics with tenure. Matt received his BA in Mathematics and Biophysics and MA in Mathematics from the University of Pennsylvania in 1998. He went to Princeton, where he received his PhD in Physics in 2003. After doing postdocs at Berkeley and at Johns Hopkins, he joined Harvard as an Assistant Professor in 2008.

Matt has worked on a wide variety of theoretical topics in particle physics. His recent efforts range from formal studies of the structure of quantum field theory (QFT) to phenomenological work related to the Large Hadron Collider (LHC). In the latter area, he has developed applications of effective field theory to make precise predictions of the Standard Model measurements performed at the LHC and on studies of substructures inside hadronic jets. He even joined the ATLAS Collaboration, one of the two large experiments at the LHC, as a Short Term Associate to work directly on data analysis, drawing from his theoretical ideas.

Matt has overhauled the way quantum field theory is taught at Harvard. Students from both Harvard and MIT flock to his QFT course, Physics 253a, despite his reputation for giving hard homework and even harder exams. He has written a textbook, *Quantum Field Theory and the Standard Model,* which is praised highly by professors and students alike, and is fast becoming a standard textbook on the subject. At the introductory level, Matt is working with Professor Howard Georgi and Dr. David Morin to bring the Physics 15 series into the 21st century. We hope to report on the progress of this endeavor in next year's newsletter.

For his part, Matt admits to being "humbled and deeply honored to join Harvard's permanent faculty. Working in a community with some of the world's best scholars and students has been a great privilege for me," he says, "and one that I look forward to extending for many years to come."

Xi Yin

PROFESSOR OF PHYSICS

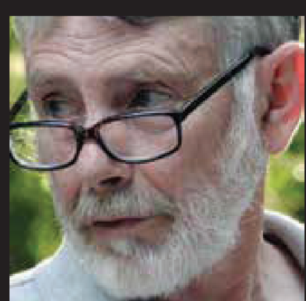
The Department is delighted to announce the promotion of Xi Yin to Professor of Physics with tenure. Xi received his BS in Physics from the University of Science and Technology of China in 2001. He came to Harvard GSAS, where he studied under Prof. Andy Strominger. After receiving his PhD in 2006, Xi was selected as a Junior Fellow by the Harvard Society of Fellows. He joined the Department of Physics as an Assistant Professor in 2008.

Xi's research in theoretical physics spans across field theory, string theory, gravity, and mathematical physics. He is known for tackling hard-to-crack problems, far off the beaten path, and coming up with striking new developments that utilize his dazzling mathematical prowess. Such was the case with his joint work with Simone Giombi, which uncovered a new type of holographic duality between higher spin gravity and critical vector models, and transformed previously little known theories of higher spin gravity into a new hot field of research.

Among the students, Xi is admired for his enthusiastic lecture style and encyclopedic knowledge. He is best known for teaching graduate courses on string theory. Students appreciate his clear lectures, meticulous preparation, and friendly demeanor. His penchant for gym clothing in the classroom reflects his passion for sports, especially long-distance running.

Xi and Matt's promotions represent a very significant strengthening (from 4 to 6 tenured professors) of the high-energy theory group in the Department. We are now entering another golden era of theoretical physics at Harvard.

In Memoriam

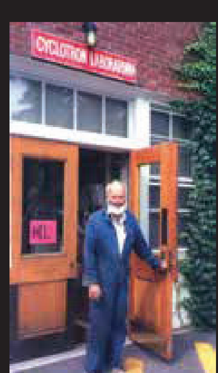


Douglass Goodale

Douglass (Doug) Goodale, who had been a member of the Natural Sciences Lecture Demonstration Service group since 1989, passed away at the age of 66 on March 18, 2015 after a brief illness.

Doug joined the Lecture Demo group in 1989, and worked as a lecture demonstrator and machine shop supervisor. Many of us, either as students or members of the teaching staff, remember watching with great anticipation and amazement as Doug worked his magic in the Science Center lecture halls. As the machine shop expert-in-residence, Doug built many lecture demos that still educate and entertain students in physics courses at all levels. He also served as head teaching assistant for Physics E-1 at the Harvard Extension School from 1997 through 2014.

Doug's meticulous workmanship and keen knack for science education made him an indispensable part of the Lecture Demo team. We will miss Doug as a friend for his generosity, unassuming smile, and dry sense of humor.



Andreas Koehler

Andreas (Andy) Koehler, who was a Director of the Harvard Cyclotron Laboratory (HCL), passed away on May 16, 2015 at the age of 85.

Born in Germany in 1930, Andy studied physics at Harvard and then became a technical assistant at the HCL, which he would later lead as the Director. In the early 1960s Andy was instrumental in the joint effort with the Massachusetts General Hospital to use the Cyclotron for cancer treatment. The pioneering work on proton-beam therapy at the HCL continued for many years. All told, more than 9,000 patients were treated over four decades until the Cyclotron was decommissioned in 2002.

Andy's contributions to radiology research at the HCL are wide-ranging but not as widely appreciated outside of Harvard as they should be. Nevertheless, the legacy of his work lives on at numerous particle-therapy facilities around the world. We are grateful to have had among our colleagues such a dedicated scientist as Andy.

Faculty Prizes, Awards & Acknowledgments*

Raymond and Beverly Sackler International Prize in Biophysics, 2014:

PROF. HOWARD BERG

'Distinguished Scholar' at the Max Planck Institute of Quantum Optics, 2015:

PROF. EUGENE DEMLER

Carl Friedrich Siemens Research Award, 2015:

PROF. EUGENE DEMLER

2015 Simons Fellow in Theoretical Physics:

PROF. EUGENE DEMLER

Shutzer Assistant Professorship at the Radcliffe Institute for Advanced Study, 2015-2018:

PROF. CORA DVORKIN

2015 Simons Investigator in the Mathematical Modeling of Living Systems:

PROF. MICHAEL DESAI

Fannie Cox Prize for Excellence in Science Teaching, 2015:

PROF. GENE GOLOVCHENKO

2015 Gutzwiller Scholar, Max Planck Institute for the Physics of Complex Systems:

PROF. ERIC HELLER

Canada Excellence Research Chair in Quantum Materials and Devices Based on Oxide Heterostructures, 2015:

PROF. JENNIFER HOFFMAN

2015 Friedrich Hirzebruch Lecturer, Max Planck Institute for Mathematics:

PROF. ARTHUR JAFFE

2015 Alfred P. Sloan Research Fellow in Physics:

PROF. KANG-KUEN NI

2015 AFOSR Young Investigator Program Award:

PROF. KANG-KUEN NI

Elected Vice President of OSA, The Optical Society, 2015:

PROF. ERIC MAZUR

National Medal of Technology and Innovation, 2014:

PROF. CHERRY MURRAY

Museum of Science Walker Prize, 2015:

PROF. LISA RANDALL

Dirac Medal for the Advancement of Theoretical Physics, Australian Institute of Physics and the University of New South Wales, 2015:

PROF. SUBIR SACHDEV

Oskar Klein Medal, Royal Swedish Academy of Sciences, 2014:

PROF. ANDREW STROMINGER

2015 Breakthrough Prize in Fundamental Physics:

PROF. CHRISTOPHER STUBBS

American Association for the Advancement of Science Fellowship, 2014:

PROF. AMIR YACOBY

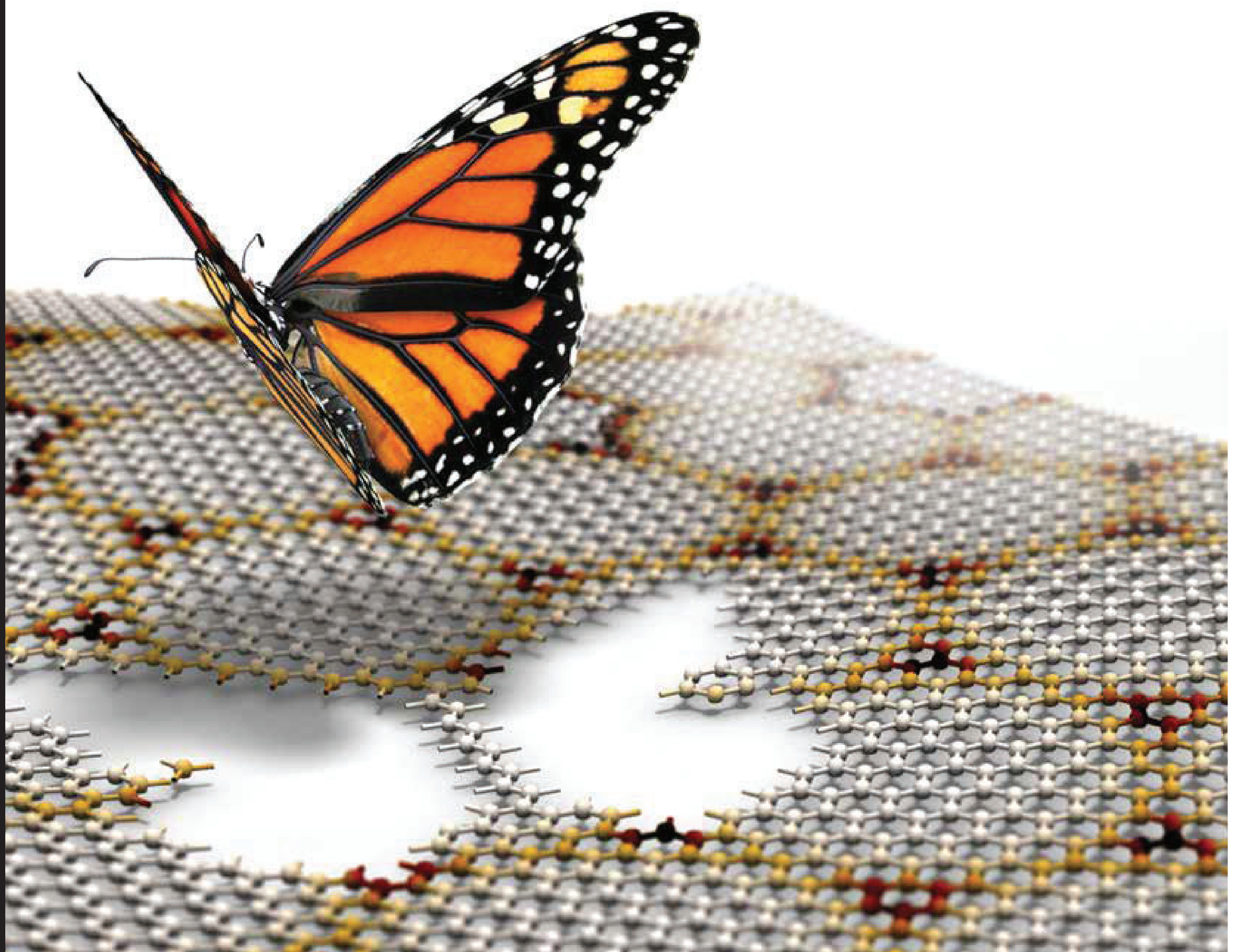
National Academy of Science Award in Molecular Biology, 2015:

PROF. XIAOWEI ZHUANG

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

COVER STORY

Physics in Low-Dimensional Materials



Edwin Abbot, in his 19th-century satirical novel, *Flatland: A Romance of Many Dimensions*, describes life in two dimensions. The narrator, named Square, is a knowledge-able scholar in his two-dimensional flatland.

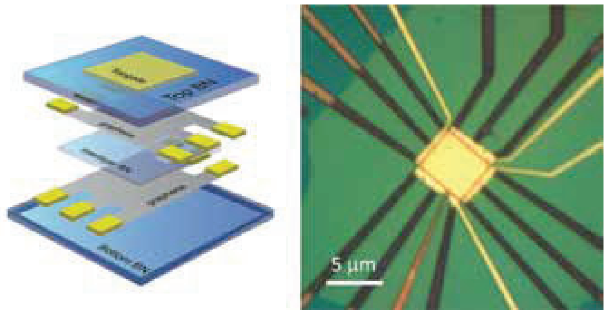
by Prof. Philip Kim

Through the course of the novel, he realizes that many scientific mysteries in Flatland can be elegantly explained through the addition of an extra third dimension. Out of this elucidation, Square says, "Three Dimensions seems almost as visionary as Land of One or None."

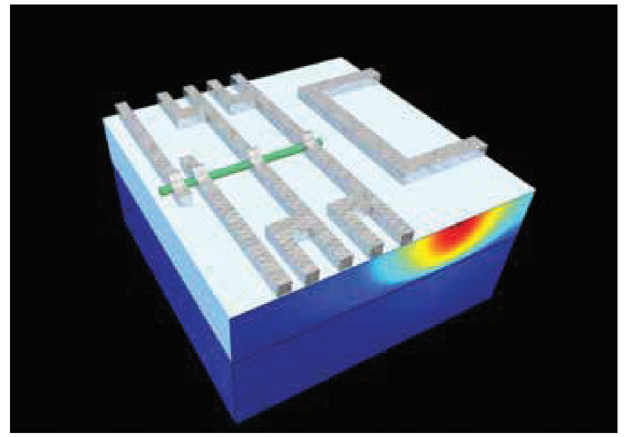
Similarly, physicists have been considering the concept of a multi-dimensional universe in order to explain the mysteries of our own three-dimensional world. The idea of a four-dimensional space-time provided the foundation for Einstein's theory of relativity. Today, in efforts to explain the underlying structure of the universe, physicists are considering as many as ten or more dimensions. However, through the study of these "extra" dimensions we might have missed the intricacy and beauty of the physics that happens at the other extreme: the reduced two- or one-dimensional worlds.

The notion of reduced dimensionality is often considered a purely mathematical idea and is seen as an abstract concept that cannot be realized in an actual physical or material world. Yet, quantum physics teaches us how to effectively describe a three-dimensional object within the confines of a reduced dimensional system. Imagine a particle confined to a box. If we start to flatten the box, quantum mechanics tells us that the energy of the spatially confined particle becomes discontinuous. The separation between energy levels increases as the box is flattened even further. Eventually, the particle's motion along the direction in which the box is flattened freezes as the discrete and quantized energy scale becomes larger than any other characteristic energy in the system. Thus, in our flattened box, the particle is restricted to two dimensions—essentially an object in Abbot's Flatland, although it still exists in the three-dimensional world.

It turns out that these reduced dimensional systems are already crucial to modern electronic devices. Transistors, the core element of today's electronics, employ electrons in an effective, two-dimensional space formed at the interface between the silicon surface and its oxide layer. The reduced dimensionality of the space electrons inhabit often enables an unusual quantum mechanical effect. In particular, in a strong magnetic field and at ultra-low temperatures, the electron orbit can be completely quantized. In this case, the resistance along the direction of the current vanishes completely, indicating a non-dissipating flow of electrons, just like in superconductors. Additionally, the Hall effect —characterized by the resistance measured perpendicular to the current (see details in the latter part of this article)—exhibits discrete steps with defined plateaus over large intervals of magnetic fields. This quantization is called the quantum Hall effect. Two Nobel prizes have been awarded in this subject, one for the discovery of the quantization at integer multiples of e^2/h in 1985 (von Klitzing) and another for fractional multiples in 1998 (Stormer/Tsui/Laughlin). Over the years, Harvard's condensed-matter physics group has also made important contributions to the study of these beautiful quantum mechanical effects.



Van der Waals heterostructure of graphene and hexa boron nitride to form a mesoscopic quantum device



Quantum engineered thermoelectric and thermal transport

In order to create low-dimensional semiconductor structures, physicists often borrow microfabrication technology developed over the past half century. Microfabrication, combined with nanotechnology, produces effectively 2-dimensional (2D) or even 1-dimensional (1D) semiconducting devices in the forms of the quantum wells, quantum wires, and quantum dots. Ironically, to create these tiny structures we often need to access huge facilities, properly equipped with sophisticated instruments for material manipulation, fabrication, and characterization. Harvard physicists enjoy world-class microfabrication facilities at the Center for Nanoscale Systems (CNS), which provides shared research space dedicated to the fabrication and characterization of nanometer-scaled devices. (See the sidebar, “Center for Nanoscale Systems.”)

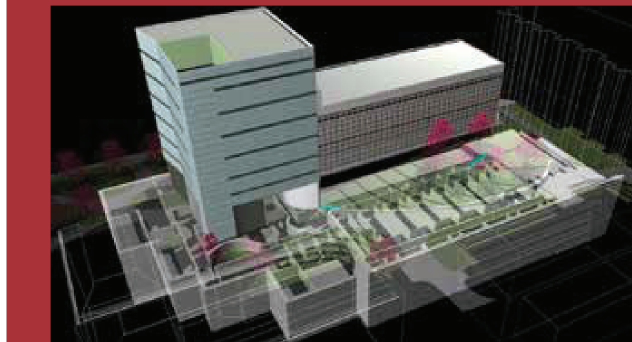
Historically, reduced dimensional semiconducting structures have been fabricated in a top-down method in which a larger system splits to create smaller ones. A completely different approach, the bottom-up assembly method of nanostructures, was first used in nanoscience and technology starting in the 1990s. The bottom-up method, when applied to materials science and chemistry, assembles molecules to create larger material structures. Among these material structures, carbon-based nanostructures have attracted the most interest. The first kind of carbon nanostructure was the C_{60} “buckyball.” This spherical molecule consists of 60 carbon atoms forming a cage connected via hexagonal and pentagonal rings of carbon. Richard Smalley and his colleagues, who discovered C_{60} in 1985, were awarded the Nobel Prize in Chemistry in 1996, celebrating the arrival of this new type of chemical nanostructure. Within a few years, the buckyball was followed by carbon nanotubes, a 1D form of the tubular-shaped hexagonal carbon ring that was discovered in 1991 by Sumio Iijima. Unlike their predecessor, nanotubes immediately attracted the attention of many physicists as an idealization of quantum wires that can confine electrons in a 1D system. Nanotubes also carry the promise of many potential applications. Their excellent electronic, optical, thermal, chemical, and mechanical properties, resulting from reduced dimensionality, have inspired their use in the development of a wide variety of technologies. Interestingly, the 2D form of carbon nanostructure, graphene, was theoretically hypothesized by the Canadian physicist, Philip Wallace, more than 60 years ago. However, the actual experimental discovery was made only 10 years ago. In late 2004, Andre Geim and Konstantin Novoselov at Manchester University experimentally demonstrated the existence of 2D graphene, later winning the 2010 Nobel Prize in Physics.

Graphene is a two-dimensional, hexagonally-arranged layer of carbon that is only a single atom thick. In a way, graphite, which you can find in pencil lead, can be regarded as a three-dimensional (3D) stack of atomic graphene sheets that are held together by weak interactions, often referred to as van der Waals bonding. It is this weak van der Waals coupling between graphene layers that allows graphite to be cleaved easily. In fact, the Nobel duo at Manchester University initially used scotch tape to exfoliate a piece of graphite down to the thickness of a few atomic layers to demonstrate the existence of graphene—a procedure that fully exploited the weak interaction between graphene layers.

It turns out that the electronic properties of graphene are exceptional, as well as unique. Although the electrons in graphene are the same electrons that we find in free space, their behavior in graphene is drastically different. The quantum mechanical description of the Bloch wave of electrons in graphene renders a new kind of quasiparticle—a concept used in condensed-matter physics to describe the alteration of the original particle’s properties. Quasiparticles move like electrons that have completely lost their mass, following an analogous description of the Dirac equation. The idea of massless Dirac particles has been used to describe the relativistic quantum mechanical behaviors of spin-½ fermions traveling at the speed of light, independent of their energy or momentum. Similar to these relativistic particles, quasiparticles in graphene always move at a constant speed, about 1/300th the “real” speed of light. Except for the scaled down “speed of light,” the quantum dynamics of graphene’s quasiparticles are completely relativistic. This analogical mapping to the Dirac equation of electrons in graphene, however, can be rather intriguing since many “high energy” experiments can be realized in the setting of a condensed-matter physics laboratory. For example, the Klein tunneling of Dirac fermions, a relativistic quantum tunneling through a barrier, enables a perfect tunneling of Dirac fermions through any barrier due to the particle-antiparticle pair generated at the interface. Experimentally, Klein tunneling has already been observed in graphene devices fabricated using the microfabrication techniques discussed above.

Following the discovery of graphene, several other crystals, also one atomic layer thick, have been created in laboratories using similar experimental approaches. In fact, it turns out that nature provides us with many different “flatlands.” In these layered systems, as we’ve seen in graphene, strong covalent chemical bonds exist within the single atomic layer, and weak van der Waals (vdW) forces hold the different layers together. The exciting news is that these vdW materials can exhibit very diverse electronic behaviors. Some of them are semiconductors with exceptional magnetic properties, some are superconductors at relatively high temperatures, and some are strongly correlated metals exhibiting exotic charge density waves. Building on graphene research, we are now exploring the new subfield of physics enabled by this emerging class of reduced dimensional material systems.

Furthermore, the recent advent of vdW material systems has also given rise to a new type of heterogeneous quantum material with atomically sharp interfaces. As discussed above, one unique feature of vdW materials is their rich functionality in 2D electronic systems.



Center for Nanoscale Systems at Harvard

Center for Nanoscale Systems

DIRECTOR: ROBERT WESTERVELT
EXECUTIVE DIRECTOR: WILLIAM WILSON

The Center for Nanoscale Systems (CNS) at Harvard provides world-class facilities for users in academia and industry, supporting research that pushes the frontiers of electronics, photonics, materials science, and bioengineering.

IMAGING AND ANALYSIS

The center is equipped with sub-angstrom resolution Transmission Electron Microscope and Scanning Transmission Electron Microscopes, an automated Cryo-Bio TEM, an Atom Probe for 3D Tomography with atom identification, Scanning Electron Microscopes with Energy Dispersive Spectroscopy and Electron Backscatter Diffraction Analysis (EBSD), and sample preparation facilities.

NANOFABRICATION

A full range of nanofabrication techniques are available, including: Electron-beam Lithography; Optical Lithography; Reactive Ion Etching (RIE); Chemical Vapor Deposition (CVD); Atomic Layer Deposition (ALD); Physical Vapor Deposition (PVD); Metrology; and Wet-Processing Tools.

NANO/BIO/SOFT MATERIALS

The tools include Atomic Force Microscopy, X-ray Photoelectron Spectroscopy, X-ray Fluorescence, X-ray Computed Tomography, Fourier Transform Infrared Spectroscopy, Optical and Confocal Microscopy, and a soft lithography facility to construct Microfluidic systems.

STAFF AND RESOURCES

- CNS provides the staff and resources needed to train and assist students, postdocs, faculty, and industry investigators in the use of our advanced facilities.
- CNS offers internal and external users open access to our equipment.
- CNS provides lab courses and summer internships for undergraduates.
- CNS promotes collaborations between faculty groups and commercial firms.
- CNS hosts seminars and workshops on a broad range of topics.

The Hofstadter butterfly is a butterfly-shaped fractal energy spectrum. Fractals are infinitely repeating, self-recursive geometrical structures. They often appear in complex classical systems but rarely in the quantum mechanical world.

Capitalizing on the weak vdW interaction between two separate single-atom-thin vdW layers, we can simply stack them to form a heterogeneous blend of materials. This atomic stack can provide ample opportunities for the realization of novel collective interfacial quantum phenomena.

One interesting example of these new interfacial phenomena is our recent experimental realization of "Hofstadter's butterfly." Predicted by Douglas Hofstadter in 1976, the Hofstadter butterfly emerges when electrons are confined to a 2D sheet and subjected to both a periodic potential energy and a strong magnetic field. The Hofstadter butterfly is a butterfly-shaped fractal energy spectrum. Fractals are infinitely repeating, self-recursive geometrical structures. They often appear in complex classical systems but rarely in the quantum mechanical world. In fact, the Hofstadter butterfly was one of the first quantum fractals theoretically postulated in physics. In the past, experimental efforts to study the Hofstadter butterfly attempted to use artificially created structures to achieve the required periodic potential energy. In our experiment, we used an effect called a moiré pattern that arises naturally when two similar atomic lattices overlap. We stacked a single atomic layer of graphene on top of a boron nitrate (BN) substrate, which has the same honeycomb atomic lattice structure as graphene, to create a vdW heterostructure with a periodic potential. (See figure page 10.) We mapped the graphene energy spectrum by measuring the electronic conductivity of the heterostructure at very low temperatures in extremely strong magnetic fields. For this experiment, we had to travel to the National High Magnetic Field Laboratory, where we could use a large magnet with immense magnetic fields—up to 35 Tesla, consuming 35 megawatts of power. Remarkably, our measurements showed the predicted fractal energy spectrum pattern, providing the strongest direct evidence to date of the Hofstadter butterfly.

From the early days of graphene and other 2D materials research, Harvard has been a powerhouse in exploring reduced-dimensional materials and their heterostructures. Recently our research has been further accelerated by the Center for Integrated Quantum Materials (CIQM), a science and technology facility funded by NSF. The mission of CIQM is to study extraordinary new quantum materials with striking nonconventional properties. (See the CIQM sidebar for further details.) My research group, located in the Laboratory of Integrated Science and Engineering (LISE), one of Harvard's most advanced laboratory buildings, has been an active participant in CIQM-sponsored programs. At CIQM, we are developing functional heterostructures of different 2D vdW materials to investigate the interaction between various correlated vdW layers.

In condensed-matter physics, fundamental discoveries can often be directly applied to engineering. Professor Edwin H. Hall, the discoverer of the Hall effect, joined the faculty in 1881 and served as a Professor of Physics at Harvard University from 1895 to 1921. His seminal work on measuring Hall resistance, the ratio between the transverse voltage to the longitudinal current, experimentally confirmed the existence of a magnetic force on a moving charge. It also gave rise to many practical applications. The Hall effect is one of the essential tools in characterizing semiconductors in the electronic industry. His work also provided the basis for the discovery of the integer and fractional quantum Hall effects a hundred years later, as mentioned before.

Interestingly, Professor Hall's experiment was made possible by using what was then considered a "thin" metal film to increase the current density to amplify weak signals. The thin specimen that brought him his initial success was gold leaf, which was about a micrometer thick and was probably the thinnest material that physicists could reliably access in his time. Today, we are investigating a new class of 2D materials—more than a thousand times thinner than the Hall's gold leaf—and possibly the thinnest material we can ever find. Just as the Hall's gold leaf was the lynchpin to his success, the heterogeneous vdW quantum structures have given us a glimpse of exciting new interfacial quantum effects and potential applications. These promising new findings have hinted at the prospect of "stacked Flatlands," which could yield both exciting new physics and many technological advances in the coming years.

CIQM CENTER for INTEGRATED QUANTUM MATERIALS

Science & Technology Center for Integrated Quantum Materials

HARVARD UNIVERSITY
(DIRECTOR & PI: ROBERT WESTERVELT)
HOWARD UNIVERSITY (CO-PI: GARY HARRIS)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(CO-PI: RAYMOND ASHOORI)
MUSEUM OF SCIENCE, BOSTON
(CO-PI: CAROL LYNN ALPERT)

The Science & Technology Center for Integrated Quantum Materials was created in October 2013 through a 5-year renewable grant from the National Science Foundation.

MISSION:

Transform electronics and photonics from 3D structures to 2D atomic layers, 2D electron surface states, and single-atom devices using Quantum Materials:

Atomic layer materials - Graphene, BN, Transition Metal Dichalcogenides
atomic-scale devices that are only a single atom or molecule thick

Topological Insulators
topologically protected data channels using surface edge states

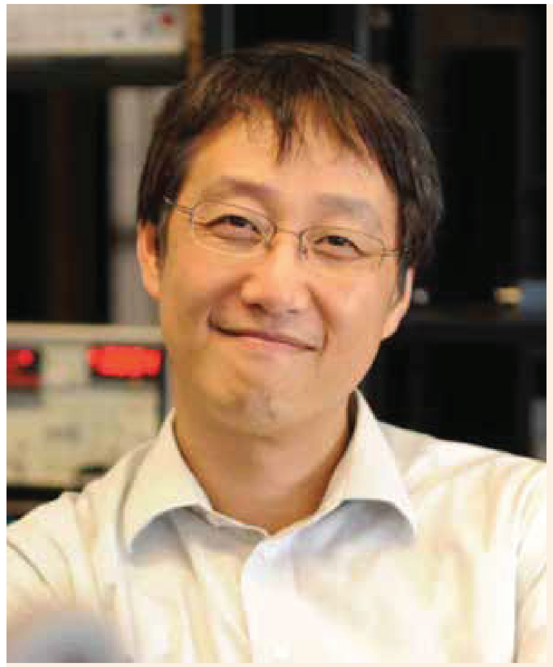
Nitrogen Vacancy (NV) Centers in Diamond
atomic memory sites and ultrasensitive magnetosensors

Broader Impacts:
Attract young students to careers in science and engineering.
Engage public audiences in the quest for new frontiers.
Commercialize science through new technologies and products.

College Network:

Share Center facilities and expertise with young students to encourage them to enter careers in science and engineering:

Bunker Hill Community College (co-PI JoDe LaVine)
Gallaudet University (co-PI Paul Sabila)
Mt. Holyoke College (co-PI Katherine Aidala)
Olin College (co-PI Rebecca Christianson)
Prince George's Community College (co-PI Scott Sinex)
Wellesley College (co-PI Robbie Berg)



For Philip Kim, Small is Beautiful—and Interesting

by Steve Nadis

Physics Professor Philip Kim has long been fascinated by the behavior of materials, and, for him, the smaller those materials get the more fascinating that behavior becomes. At really small scales—approaching the level of individual atoms and molecules—quantum effects become significant, and that's when the story gets even more interesting.

In the late 1980s, Kim was just starting college at Seoul National University in Korea when high-temperature superconductivity was discovered. Superconductivity is a quantum mechanical property of certain materials, which lose all electrical resistance when cooled below a critical temperature. Kim stayed in Seoul to pursue graduate work in high-temperature superconductors, earning a master's degree in 1992.

Two years later, after fulfilling his mandatory military requirements in Korea, Kim started an applied physics doctoral program at Harvard, hoping to continue this same line of research. He joined the laboratory of Harvard chemist Charles Lieber. "It was a natural fit for me in terms of interest," Kim says. "But back then, in the mid-1990s, it was somewhat unusual for a physics student to work in chemistry." Although some people told him that would be an unwise career move, he notes, "I was naïve enough not to worry about that. And, in hindsight, I was lucky to be there."

During his time in Lieber's lab, Kim shifted his focus from superconductors to new nanomaterials of "low dimensionality," such as one-dimensional carbon nanotubes. He learned, among other things, how to grow these materials from scratch.

Meanwhile, across Oxford Street in the physics complex, researchers led by Michael Tinkham and Robert Westervelt were pursuing a different approach: They started with relatively large semiconducting and superconducting materials and carved them down until they reached the nanometer scale. Kim was intrigued by that strategy, and after getting his PhD in 1999, he decided to investigate these so-called "mesoscopic" methods during a postdoc at Berkeley.

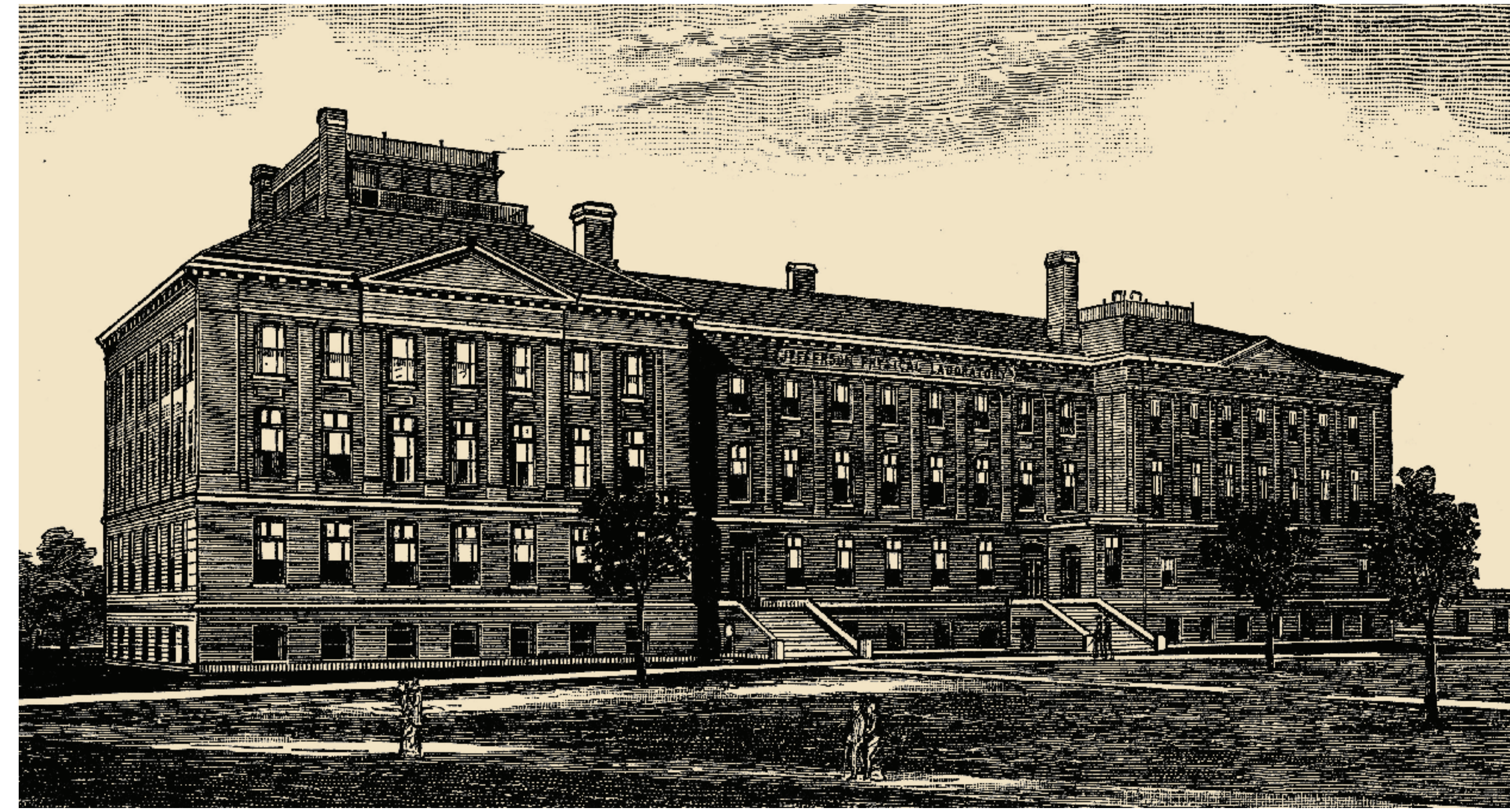
Before completing his postdoctoral studies, where he developed new microfabrication techniques for measuring thermal properties of carbon nanotubes, Kim contemplated the next stage: opening up the tubes into two-dimensional sheets called graphene, a material that was still hypothetical. He explored this notion at Columbia, following his appointment as an assistant professor in 2002. Graphene, if it could be made, would be like a single atomic sheet of graphite, consisting of hexagonal rings of carbon arranged in a surface.

Finally, he and his graduate student hit upon an idea: Perhaps they could lay down a sheet of graphite simply by writing with a mesoscopic scaled carbon pencil. Their paper on this subject came out in 2004, but a team from Manchester University in the UK, headed by Andre Geim, had carried out similar experiments, achieving somewhat better results, as Kim put it. Within a year, however, both his team and Geim's team independently observed some remarkable features of graphene, including the fact that its electrons move as if they have no mass and can thus be treated as relativistic particles.

This discovery, the first demonstration of the "quantum Hall effect" in graphene, offered a novel way to study relativistic physics in tabletop experiments. A boom in graphene research ensued, with Kim helping to lead the charge.

While this work has been "really exciting," he says, "graphene is just a beginning, as nature provides many other examples of low-dimensionality systems." For example, he has synthesized organic crystals that come in layers. The crystals can then be pared down to single layers, which are stable enough to be studied. "You can take these layers and stack them together to create new materials that have never been seen before," says Kim.

After hearing about the latest, exciting direction that Kim's research had taken, Harvard asked him to come back. Kim accepted the offer, joining the faculty in 2014. "And here I am," he says, "setting up shop on the other side of Oxford Street"—the physics side, which had been his intention all along.



FOCUS

A Story from the History of the Physics Department: Ed Purcell's Early Days

by Prof. Gerald Holton

If someday the history of Physics at Harvard were to be written—as well it might—its author may be puzzled by some contrary but persistent characteristics: Our Faculty's reigning habit of stellar performance in research, teaching, publishing, and mentorship, on the one hand, is consistently counterbalanced, on the other hand, against our Department's persistent preference for a degree of unwarranted modesty.

The same sort of duality also pervades the personal history interviews of many of our faculty members conducted during 1976-77 by Katherine Sopka (our own Department's BA, MA, and PhD in the History of Science). These interviews were transcribed by the AIP and are available online. They are frank, revealing, surprising, and sometimes hilarious. The interviewees included Bainbridge, Bloembergen, Coleman, Glashow, Kemble, Purcell, Ramsey, Street, Tinkham, Van Vleck, and Wilson.

For this issue of the Newsletter, the focus is on remarks Edward Purcell made in his interview about his early life, and especially on what brought him to physics. (The whole interview, which took place during two sessions, can be found at the "Oral History Interviews" section of the AIP website.)

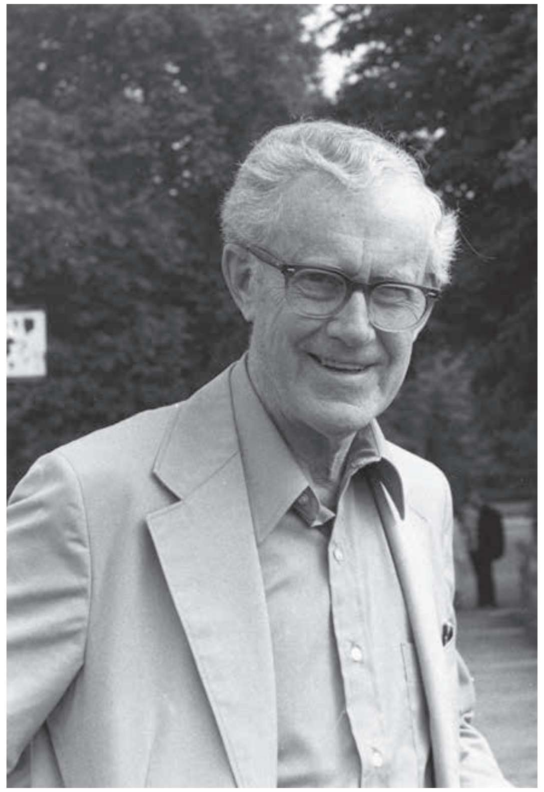


Image courtesy of AIP Emilio Segrè Visual Archives, Segrè Collection.

"Oldenberg's lab course I remember. That was a nice course. In fact, for me again that course was something so new and lovely in that we didn't have to write lab reports. And there at Purdue, God, as an engineering student, I had to write lab reports all the time. And I don't like lab reports."

Ed started the conversation by mentioning that he was born in 1910 in Taylorville, a small town in Illinois. His mother, he said, "had an MA from Vassar in classics" and had been a high school teacher in Latin. "My father was a businessman, manager of the local telephone company."

"I had no interest that you would identify as scientific when I was in Taylorville, being young. However, the fact that my father was working for the telephone company had already begun to have some influence. The telephone office, as we called it, was a place that had a back room where all the switchboards and technical equipment was. In the basement there were discarded sections of cable and wire, and I could bring home items like that from the telephone office. It was my source of wire and of lead, because if you got an old hunk of telephone cable, you could melt the lead sheath and then take the paper insulation off the wire, and you had the makings for a lot of things."

Ed had a friend with whom he did "a lot of home chemistry experimenting. And I think it was our joint activity and friendship then that probably further stimulated my interest in some kind of science or engineering." In high school his physics teacher "was a woman... She introduced me to physics in a humane way that probably was important."

A second thing that led him towards science at an early age came about almost by accident. Ed's father's office routinely received issues of AT&T's publication, *The Bell System Technical Journal*. Since nobody there was interested in them, Purcell said, "I could take those things home and read them. They were fascinating because for the first time I saw technical articles obviously elegantly edited and prepared and illustrated, full of mathematics that was well beyond my understanding. It was a glimpse into some kind of wonderful world where electricity and mathematics and engineering and nice diagrams all came together." (Typical articles of that era had titles like "Some Contemporary Advances in Physics," which was published in 1923 by Karl K. Darrow.)

Ed kept these journal issues when he went to college at Purdue University, reinforcing his conviction that he wanted to be an electrical engineer. "The idea of being a physicist at that point," he said, "just wasn't an image that one had to consider somehow.

You see, in the '20s the idea of chemistry as a science was extremely well publicized and popular, so the young scientist of shall we say 1928—you'd think of him as a chemist holding up his test tube and sighting through it or something. And that was the result of the experience and history of World War I, where the United States had to develop its chemical industry practically from scratch because German industry had previously supplied all that."

"In fact, I've sometimes remarked that to me at that time the name Steinmetz was more familiar and exciting than the name Einstein, because Steinmetz was the famous electrical engineer at General Electric and was this hunchback with a cigar who was said to know the four-place logarithm table by heart and all that kind of thing. So it was only gradually as a student at Purdue that I began to learn not only what physics is but what it would be to be a physicist."

While Ed was at Purdue, the person who had the most influence over him was Professor Karl Lark-Horovitz. "He [Lark-Horovitz] was from Vienna... His coming to Purdue was really quite important for American physics in many ways. It was he who subsequently, over the years, brought many important and productive European physicists to this country; they came to Purdue, passed through. And he began teaching; he began having graduate students and teaching really modern physics, as of 1930, in his classes."

And there came the kind of event that many physicists remember as the turning point—the time when they really fell in love with the subject. For Purcell, this occurred in the basement of the physics building at Purdue, where there was some intriguing research underway on electron diffraction. "These [experiments] reflected Lark-Horovitz's own interests, and they were, of course, very much on the forefront of laboratory research at the time. People were also living down there in the cellar, sleeping on cots in the research rooms, because it was the Depression and some of the graduate students had nowhere else to live. I'd come in in the morning and find them shaving. Yearian [an instructor] was very nice to me, tolerated my mistakes, and taught me a great deal. That was such an exciting time. I'd never really developed photographic emulsion before. Cameras had never been my hobby. I'd never done anything like that."

"And the first photographic emulsion I ever developed, when I turned on the light in the dark room, I had Debye-Scherrer rings on it from electron diffraction—and that was only five years after electron diffraction had been discovered. So it really was right in the forefront. And as just an undergraduate, to be able to do that at that time, was fantastic."

This experience might be called the moment when Ed was captured by physics as a profession. Now, we'll briefly take a look at how Harvard captured him.

Before embarking on graduate study, he wrote to several universities, but money was tight. "Well, I had to get a scholarship. So I wrote letters and again I think Lark-Horovitz helped me there and wrote to two or three different places for a graduate scholarship and got a reply from Harvard that said (I forget what they called it) … but it was just free tuition. I think it was $400. I had to consult my parents and see if they thought they could swing the rest of it. So … I knew where I was going to be the next year. I was coming to Harvard."

Once there, Ed first took a mathematics course (Math 13) and nearly flunked the final. "The night before, I had proved every theorem in the course, and I went to the exam and simply froze," he recalled. "I couldn't do anything. I couldn't solve a quadratic equation."

He also audited a course in cosmology by A. N. Whitehead, who was still here, "a beautiful gentleman. I didn't get very much out of it. I did some of the reading." And then: "I took courses with Kemble. That first year I guess I had electricity and magnetism, classical E & M… And then Kemble's quantum mechanics. And I had a course with Furry—I don't know what; I can't remember…"

"Oldenberg's lab course I remember. That was a nice course. In fact, for me again that course was something so new and lovely in that we didn't have to write lab reports. And there at Purdue, God, as an engineering student, I had to write lab reports all the time. And I don't like lab reports… I remember Oldenberg's practice was: You just put the result down on a little card, a 3" by 5" filing card, and you wrote down the result of your experiment. As a physicist, you see, I've never kept a laboratory notebook. I don't think I've ever had one."

"Then Bainbridge suggested what became my thesis topic of looking at the focusing of charged particles in a spherical condenser. At that time, of course, everybody was all full of the lore about the focusing in magnetic fields, including the sector focusing, you know, where you have a sector of a magnetic field, which in fact was one component of Bainbridge's mass spectrograph and the mass spectrograph of Aston and others. So I did a little calculating on that—it looked very interesting. I set out to build an electron model, so to speak, to show that electrons would be focused by such a device, and to make it actually run. Again, it isn't clear why building it was a useful exercise except to get a PhD thesis; there was nothing dubious about the equation of motion for the electron in the electrostatic field. Nevertheless it was a great experience to try and make this thing, which I finally succeeded in doing.

Now Purcell was onto his physics doctorate at Harvard.

And the rest, as they say, is history.

FEATURED

Empowering Female Graduate Students in Physics and Science Through Advocacy and Mentorship

by Jean Fan, Julia Rogers, and Jing Shi

This year, the Harvard Graduate Women in Science and Engineering (HGWISE) program celebrated its 10th anniversary. Since its creation in 2005, HGWISE has grown into an organization with over 2000 members, including over 50 active board members across more than 30 departments from both the Cambridge and Longwood campuses

Opposite: Members of HGWISE: Front row (L to R): Jing Shi, Jean Fan, Kaia Mattioli, Nicole Black

Back row (L to R): Tamara Pico, Jane Huang, Elise Wilkes, Shuyan Zhang, Allyson Morton, Julia Rogers, Leonora Brittleston, Vivian Hemmelder

From informal social and networking events to workshops and career panels, HGWISE focuses on career development, community involvement, and advocacy for women and other minority groups. HGWISE also runs the largest mentoring program at Harvard, with mentors including Harvard faculty, postdocs, and alumni working in different industries in the Boston area.

HGWISE EVENTS

HGWISE is known for the numerous and diverse events it organizes on campus. HGWISE holds informal coffee hours that allow students to talk with interesting female faculty members and women working in science outside of academia. These exchanges provide opportunities for students to ask and learn about ways to succeed in their professional and personal lives. Some notable figures who have participated in these sessions include Professor Melissa Franklin, the previous chair of the physics department, as well as Professor Cherry Murray when she was the Dean of the Harvard School of Engineering and Applied Sciences. HGWISE organizes career panels to inform students of a wide array of career options, including academia, teaching, management consulting, data science, and other niche areas such as technological consulting. HGWISE holds professional development workshops on topics such as assertiveness, networking, negotiation, and "imposter syndrome." In addition, there are numerous personal enrichment and social activities throughout the year, including pumpkin carving, strength training, belly dancing, beer tasting, ice cream socials, and more. In both professional and social settings, HGWISE has fostered a community where women scientists and engineers can discuss their interests and support one another.

ADVOCACY EFFORTS

In addition to creating a community among women graduate students, HGWISE also advocates for the interests of graduate students at large. HGWISE has been a major force in raising the awareness of gender issues and driving policy changes at Harvard. In particular, HGWISE worked with the GSAS administration and the Graduate School Council to establish a paid parental time-off policy for graduate students in 2013. It has also been pushing for improvements to the sexual harassment policy at the university level, in addition to working with GSAS to better educate students, faculty members, and staff members about these policies. Over the past two years, a growing number of departments have been provided with relevant resources on sexual harassment. The topic of harassment was also addressed at the Graduate School of Arts and Sciences incoming students' orientation for the first time in 2014 Fall. The continuing effort of HGWISE on advocacy has led to gradual improvements in graduate student life.

MENTORING PROGRAM

One of the highlights of HGWISE is its Mentoring Program. When navigating a career in the male-dominated realm of science, female graduates often face challenges that are not present for their male counterparts. On the other hand, it is also difficult for female graduate students to connect with suitable female mentors due to the relatively small number of women in professorships and higher-up industry positions in a wide range of science, technology, engineering, and mathematics (STEM) fields. The HGWISE mentoring program matches graduate students with mentors in a variety of careers and positions. It also provides resources and support for mentoring groups by organizing workshops on effective mentoring and by hosting other informal get-together events on campus for mentoring groups.

Since its inception in 2008, the program has grown dramatically to include 73 mentors and 137 mentees in the 2014-2015 academic year. Mentors include female faculty members, alumni working in different industries, postdoctoral scholars, and a few male faculty members. Mentoring teams are paired up based on responses to detailed questionnaires concerning the backgrounds and preferences of both mentors and mentees.

Mentors advise mentees and provide academic support in various ways: by giving advice for qualifying exams, attending the student's talks, and generally acting as an outside sounding board on scientific matters. Mentors from outside academia help mentees explore career options and can connect them with contacts in different areas. To recognize the dedication of exceptional mentors, the Mentor of The Year award is given out at the annual mentoring program dinner in May. As one of the mentees noted during the nomination of her mentor this year: "She shows us what's behind the curtain of being a professor … and most of all, she truly listens to us, cares about us, makes time for us, and is thoughtful about guiding the mentoring group to discuss topics that matter to us. She's been a steady, calming, inspiring, insightful, nonjudgmental presence throughout my graduate career." The HGWISE mentoring program fosters personal relationships within mentoring groups that can continue well beyond graduation.

OUTLOOK

Over the last few decades, the environment for women in STEM has improved tremendously, but obstacles still remain. Research studies point to persistent unconscious biases resulting from decades of cultural conceptions of women and their capabilities. These biases tend to arise in the initial hiring and selection stages, resulting in a lower representation of women in a number of industries, including those in STEM fields. HGWISE strives to level the playing field for women in science by raising awareness of unconscious biases and other factors that create subtle and not-so-subtle barriers for women in STEM fields. HGWISE continues to empower women and minorities in overcoming adversity through collaborations with groups such as Women in Science at Harvard-Radcliffe (WISHR) and Minority Biomedical Scientists of Harvard (MBSH), as well as with outside nonprofit organizations such as cuSTEMized (cuSTEMized.org) that encourage young girls interested in STEM fields. Beyond these collaborations, HGWISE advocates for the implementation of university policies that support women in academia, including improved sexual harassment education, increased parental leaves, and access to affordable childcare options. Through these efforts, HGWISE acts as a wide-reaching network that is active within Harvard and the surrounding community, working toward improving the STEM work environment for all genders and creating a fairer gender balance.

HGWISE

www.hgwise.org
hgwise@gmail.com

HGWISE mailing list: To register for weekly emails about upcoming HGWISE events, outreach opportunities, and off-campus women-in-science events, please visit: http://projects.iq.harvard.edu/hgwise/join

Mentoring program:

HGWISE is always looking for mentors from both academia and different industries outside academia. If you would like to join our mentoring program as a mentor, please contact: hgwisementors@fas.harvard.edu.

HGWISE is grateful for the support from the Harvard Graduate School of Arts and Science (GSAS), Harvard Integrated Life Sciences (HILS), Graduate Student Council (GSC), Harvard College Women's Center (HCWC), and Biomedical Graduate Student Organization (BGSO).

Strominger Group Research Summary

by Bruno Balthazar, Temple He, Dan Kapec, Alex Lupsasca, Prahar Mitra, Sabrina Pasterski, Monica Pate, Abhishek Pathak, Achilleas Porfyriadis, Ana Raclariu, and Lily Shi

The fourth floor of Jefferson Laboratory consists of a single hallway joining the library to a common area filled with giant chalkboards, tables, and most importantly, a coffee maker. In contrast to its inconspicuous appearance, it is a hive of activity where high energy theorists brew ideas and coffee nonstop.

Above: Artist's rendering of a black hole. Image credit: NASAJPL-Caltech

Against the backdrop of the crimson brick walls, new theories are born, cultivated, and disseminated. This is where Andy Strominger, a pioneer in quantum gravity, black holes, and string theory, as well as an avid and caring teacher, works with graduate students and postdocs to tackle problems in modern physics.

Strominger believes we are in the middle of an exciting and revolutionary era of physics, reminiscent of the early twentieth century when general relativity and quantum mechanics gradually supplanted Newtonian classical mechanics. He has recently been instrumental in exciting new developments in black hole physics and quantum field theory (QFT). In particular, he uncovered an infinite number of exact symmetries of nature that had previously gone unnoticed. Interpreted correctly, these symmetries simplify our understanding of the universe and provide us with powerful new computational tools. The Strominger group is exploring their rich mathematical structure, teasing out physical implications, and actively exploring ways in which upcoming experiments may test these new symmetry principles. This line of investigation promises to have applications in a broad range of contexts, including the black hole information paradox, jet physics at the LHC, string theory, the holographic structure of spacetime, gravity wave experiments, and the Event Horizon Telescope.

Current and former students of Professor Strominger at a recent celebration of Andy's 60th birthday.

SOFT THEOREMS AND ASYMPTOTIC SYMMETRIES

Over the last two years, Strominger has established a precise equivalence between a class of infinite dimensional symmetries, known as asymptotic symmetries, and so-called soft theorems in QFT. This crucial discovery has connected two disparate topics that had been studied intensively, but separately, for over half a century.

Typically, QFT scattering amplitudes are notoriously difficult to compute and exact statements of any kind are rare. However, a striking simplification occurs when the momentum of a photon, gluon, or graviton emerging from a scattering event approaches zero. In this soft limit, the ratio of any amplitude with and without the soft particle is characterized by a universal 'soft factor'. These soft theorems for QFT scattering amplitudes were first discovered by Low and Weinberg in the 50s and 60s, and now play a central role in both our conceptual and practical understanding of QFT. In a nutshell, the new discovery is that the infinity of relations between scattering amplitudes expressed in the soft theorems is both an immediate consequence of, and directly implies, an infinite number of asymptotic symmetries. The latter, in turn, imply an infinity of conservation laws. For example, every multipole moment of the incoming electromagnetic or gravitational field must equal the reflected outgoing multipole moment. These insights have enabled our group to discover both new soft theorems and new symmetries of nature.

Graduate students Temple He, Prahar Mitra, and Monica Pate are currently studying soft theorems and symmetries in quantum electrodynamics and non-abelian gauge theories, while Daniel Kapec, Sabrina Pasterski, and Ana Raclariu are studying soft theorems and symmetries in quantum gravity. These projects continue to expose surprising new connections between scattering theory in particle physics and the asymptotic symmetries first explored in general relativity, effectively bridging the two disparate fields.

Soft theorems and asymptotic symmetries in gravity are alternate manifestations of yet a third phenomenon, discovered by Zeldovich and Polnarev in the 70s, known as gravitational memory. When a gravity wave passes through a detector, it locally warps space and time, causing oscillating distortions in clocks and measuring sticks. Interestingly, even after the wave has passed and the oscillations have ceased, there remains a net spatial displacement at the ends of interferometers: they retain a "memory" of a gravitational wave's passage. Pasterski, Strominger, and postdoc Alexander Zhiboedov successfully showed that classical memory effects of general relativity are also consequences of the soft scattering theorems and hence have their origin in symmetry principles as well. This insight led them to the discovery of a new type of gravitational 'spin' memory. Experimentalists hope that a new generation of detectors, such as the proposed evolved Laser Interferometer Space Antenna (eLISA), will observe some of these effects.

CRITICAL BEHAVIOR OF SPINNING BLACK HOLES

Black holes are among the most fascinating objects in our universe. They result from the collapse of sufficiently massive stellar objects. Nothing, not even light, can escape their gravitational pull, and the surface delineating the point-of-no-return is called the event horizon. While Strominger is well-known for studying the thermodynamics of string theoretic black holes, he is currently investigating more realistic astrophysical black holes. Such black holes generically rotate, and in the process drag spacetime around with them: the closer one comes to the black hole, the harder it is to maintain a fixed angle relative to a distant observer. A black hole that rotates at its maximally allowed velocity exhibits an infinite-dimensional geometrical symmetry, known as conformal symmetry, in the high-redshift region near its horizon. This constitutes an example of critical behavior in astronomy. The same infinite-dimensional conformal symmetry emerges, in much the same fashion, in a wide variety of condensed matter systems near low-energy critical points. Our group hopes to find observable signals of this critical behavior.

Graduate students Bruno Balthazar, Alex Lupsasca, Achilleas Porfyriadis, and Lily Shi, together with postdocs Sam Gralla and Maria Rodriguez, are exploiting this symmetry to obtain exact, analytical solutions describing a wide range of black hole phenomena. One context for exploring such ideas, which is of interest for eLISA, is the infall of "small" compact objects (e.g. neutron stars, stellar mass black holes) into rotating supermassive black holes. For extremely rapidly rotating black holes, the small compact object begins its rapid descent into the black hole very near its event horizon. Harnessing the power of the conformal symmetry present in this region, the group successfully computed the exact spectrum of gravitational wave emissions. It is believed that the next generation of gravity wave detectors will have the capacity to detect these signals.

This analytic symmetry-based approach also proved fruitful in a related astrophysical problem. The sky contains a variety of objects, such as pulsars and quasars, that produce extravagantly energetic signals like collimated jets of electromagnetic radiation. In many cases, the energy source powering these signals is suspected to be a rapidly rotating black hole. It is widely believed that this mechanism is described by the nonlinear equations of force-free electromagnetism, introduced in this context by Blandford and Znajek. In recent work, the group considered these equations near the horizon of a rapidly rotating black hole where the energy extraction takes place. Once again appealing to the conformal symmetry, new exact solutions to these equations were found. As an application of these results, and with help from colleagues in the astronomy department, Strominger's group hopes to predict what the Event Horizon Telescope will see when it images the supermassive black hole at the heart of the nearby galaxy M87. These techniques are also being employed to predict the luminosity as a function of redshift for the iron line emission from the rapidly spinning black hole at the center of the nearby galaxy MCG-6-30-15.

BLACK HOLE INFORMATION

Fundamental new scientific challenges arise when the effects of quantum mechanics on black holes are considered. As famously shown by Bekenstein and Hawking in the 1970s, a quantum black hole has an entropy proportional to the area of its event horizon. In this respect, black holes are radically different from other physical systems, whose entropies typically scale with their volumes. A longstanding open problem in quantum gravity is to count black hole microstates and hence derive the area entropy law from statistical mechanics. This is related to the (in)famous so-called "black hole information puzzle" —the apparent conflict between quantum mechanical unitarity and the impossibility of retrieving information from behind an event horizon.

Progress in this direction was made in 1997 when Strominger and his colleague Cumrun Vafa famously calculated the black hole entropy statistically for a special class of supersymmetric black holes in string theory. Strominger and Vafa showed that string theory and supersymmetry imply conformal symmetry, and in turn used universal properties of conformal systems to count microstates. The next challenge is to repeat this success for astrophysical black holes. Recently it has been understood that in the case of rapidly rotating black holes, the emergence of conformal symmetry can be deduced, and microstates thereby counted, without assuming string theory. Currently, graduate students Abhishek Pathak and Achilleas Porfyriadis, along with postdoc Oscar Varela, are subjecting this proposal to stringent tests through an analysis of quantum corrections.

The insights into asymptotic symmetries and soft theorems are also highly relevant to the black hole information puzzle. The conservation laws associated with the symmetries impose an infinite number of constraints on the Hawking radiation emitted by the black hole, thereby enhancing its information-carrying capacity. In the process, they reveal the existence of an infinite amount of quantum "hair" on all black holes. The evident implications for the black hole information puzzle are currently under investigation by Strominger, in collaboration with Cambridge colleagues Stephen Hawking and Malcolm Perry.

Photo by Kris Snibbe/Harvard University.

Andrew Strominger—and his "long and tortuous path to physics"

by Steve Nadis

"Never trust anyone over 30" was a popular saying from the 1960s, although graduates of that era may now have a different perspective.

The theorist Andrew Strominger, Harvard's Gwill E. York Professor of Physics, is a former member of the "Flower Power" generation who turned 60 this past summer. A conference in his honor—attended by scores of physicists from all over the world—was held on July 30th, his actual birthday, and on July 31. (See box, "Andy Fest 2015.")

While Strominger was happy to see so many friends and colleagues, he is not ready to reminisce about a career that has yielded many accomplishments and brought him many awards, including the Fundamental Physics Prize in 2013 and the Dirac Medal and Oskar Klein Medal in 2014. Instead, he is thoroughly absorbed in his current research on black holes, string theory, and the overlap between the two. (See the accompanying article by Strominger and his research group.)

Even though Strominger is not yet in a retrospective frame of mind, he is, with some prodding, willing to talk about the winding road that led him to physics. He was exposed to science at an early age, in part because his father, Jack Strominger, is a renowned biochemist currently at Harvard.

As a kid, the younger Strominger and his brothers spent hours playing in their father's various labs in the U.S. and England. As a high school student, Strominger read the *Feynman Lectures* on his own and was also inspired by an enthusiastic physics teacher, an immigrant from Mexico. Despite his interest in the subject, Strominger says, "it was hard to focus on physics in the era of sex, drugs, and rock & roll."

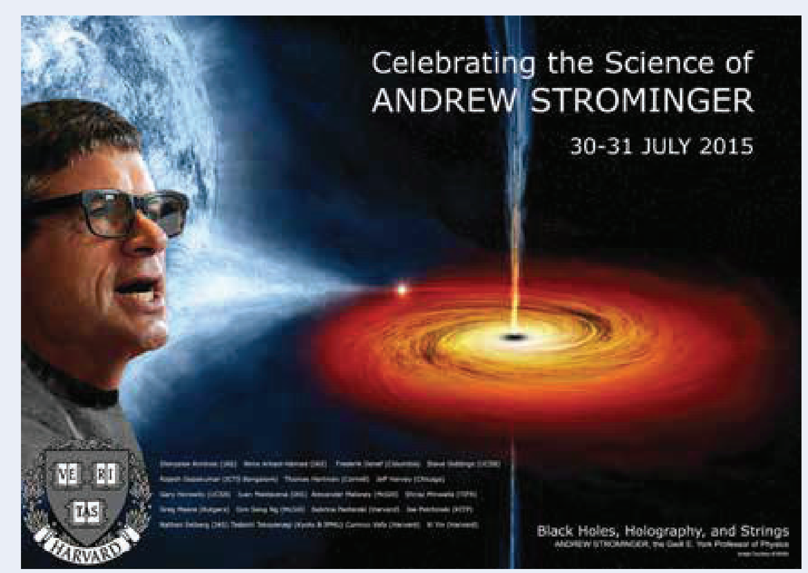
Strominger finished high school early, at the age of 15, and joined a commune in New Hampshire where he grew organic vegetables. "I wasn't planning to be a physicist," he says, "but the knowledge that physics and math came easily to me was something I didn't forget." He entered Harvard as an undergraduate but went back to the commune after his freshman year, staying for about a year-and-a-half until the commune collapsed. He returned to Harvard for another year, studying Chinese and general relativity, among other things, before heading to China where he worked on a commune, in a factory, and as a reporter for a communist newspaper. He had hoped to understand the communist system, but after six months abroad he found the experience confounding. "I came out of that not knowing how I could contribute to the world through social movements," he says.

Strominger returned to Harvard again, at the age of 19, this time determined to become a theoretical physicist. A self-professed "seeker," he concluded that he was unlikely to figure out the meaning of life but might still make some inroads into deep questions about the physical universe. "My advisors didn't think I had what it takes, because I had strayed too long," he says. "But I didn't listen to them."

As a physics graduate student at MIT, Strominger also ignored the counsel of his thesis supervisor, Roman Jackiw, who told him that if he pursued his interest in quantum gravity—an attempt to merge quantum mechanics and general relativity—he would never get a job. But Strominger has fared spectacularly well in this area, turning out a steady stream of advances in string theory (a proposed theory of quantum gravity) and related topics. While introducing Strominger at an MIT colloquium, Jackiw admitted to being grateful his former student had disregarded that advice, with many important developments in physics occurring as a result.

ANDY FEST 2015

In late July, some 180 physicists from fourteen countries in North America, Europe, and Asia joined a gathering at Harvard to honor Professor Andrew Strominger on the occasion of his 60th birthday. The event was officially called "Black Holes, Holography, and Strings" though more affectionately referred to as "Andy Fest 2015." Attendees came from as far as India and China—and from as near as the office across the hall from Strominger's—to celebrate his scientific contributions and passion for physics. Speakers included several current Harvard physics faculty (Cumrun Vafa and Xi Yin) and former faculty (Nima Arkani-Hamed, Frederik Denef, Juan Maldacena, and Shiraz Minwalla). Current and former students (including Dionysis Anninos, Thomas Hartman, Alexander Maloney, Gim-Seng Ng, and Sabrina Paterski) also spoke on their mentor's behalf. Peng Gao, a mathematical physicist at Harvard, called Strominger "a role model for many people in the field, certainly myself" and someone whose presence was "both very moving and scientifically enriching."



Poster created by Sabrina Pasterski for recent conference: *Black Holes, Holography, and Strings.*

CHANGING CLASSROOMS

The SciBox: A new space for teaching, learning, and innovation

by Dr. Logan McCarty

Above: Logan McCarty, Director of Physical Sciences Education, in the new, innovative learning environment, "SciBox."

Imagine you're sitting in a classroom learning physics—you might be in a lecture hall, with fixed seats, or perhaps in a small classroom surrounded by chalkboards. Everyone is seated, except the instructor. Now picture yourself in a research lab or workshop, surrounded by all kinds of equipment, with students wandering around, tinkering, soldering, building, measuring, computing. The space is humming with activity. Can you imagine a classroom with that kind of energy and vitality?

This was the question that Professor Melissa Franklin and I considered back in 2011 when she was department chair. During the previous several years, we had worked with other faculty to create innovative lab experiences for students in our key introductory physics sequence (Physics 15). Students were no longer doing "cookbook" labs: they were working on independent projects, building models, writing computer simulations, and presenting their work to their peers.

We were also rethinking how to teach physics in the classroom, based on research by Professor Eric Mazur and others that shows that active learning is much more effective than passive listening, which is the norm in a lecture course. We realized that we needed new kinds of classroom spaces to encourage new approaches to teaching.

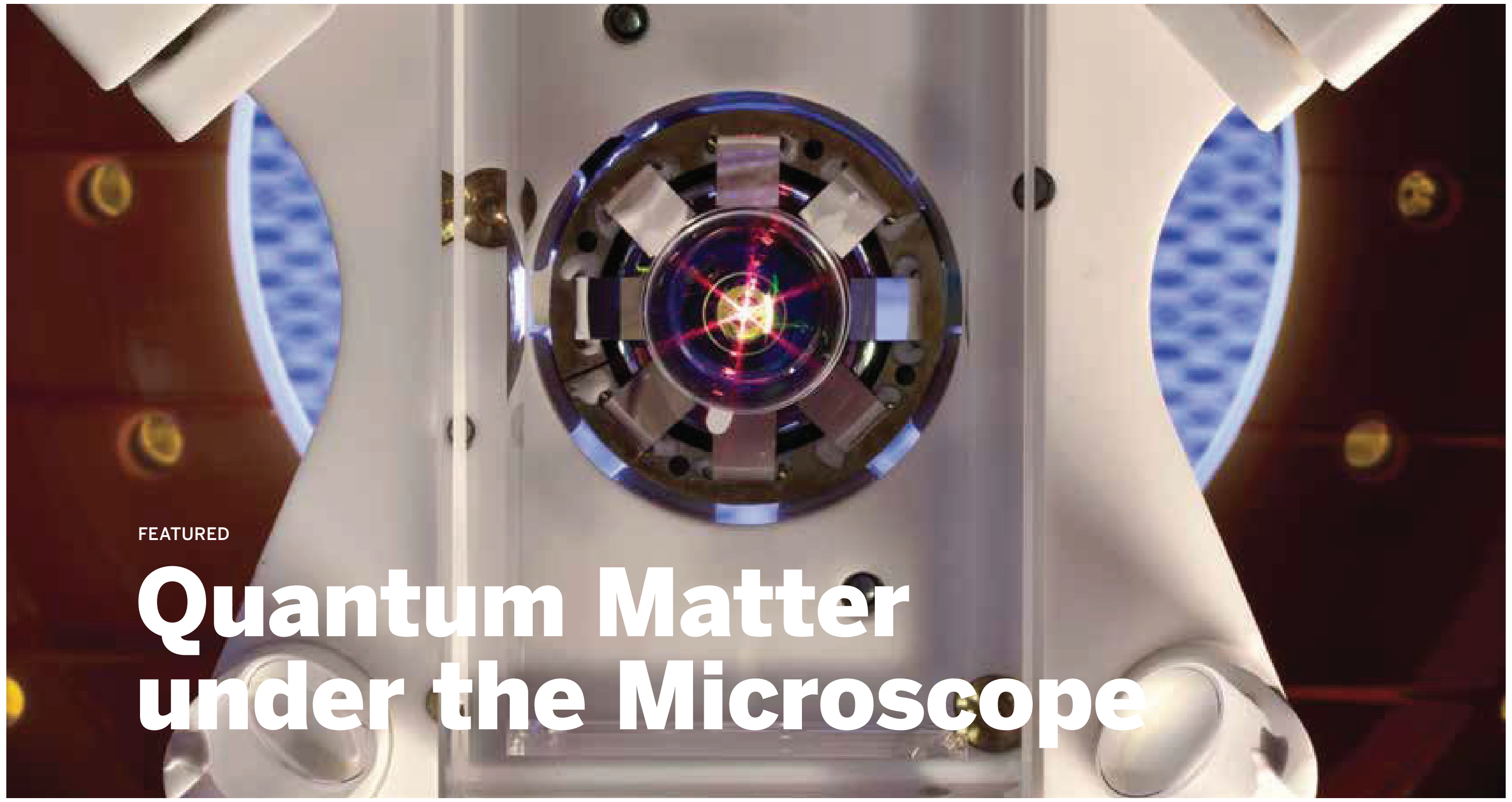
We took our inspiration from the idea of a "black-box" experimental theater. Unlike a traditional theater with a fixed stage and rows of seats, a black-box theater is just a big empty black room. A theater director is compelled to ask: Where should the audience be? Should they sit, or stand, or move around? Will they surround the actors, or will the actors surround the audience, or will they intermix? These kinds of questions don't even arise in a traditional theater.

Since the fall of 2012, SciBox has been in nearly constant use. The new Physics 15 labs meet here: students can seamlessly move between lab benches, discussion tables, chalkboards, and presentation screens. For Astronomy 16, Professor John Asher Johnson brings in half a dozen whiteboards (on wheels) and has students scattered around the room, working in small groups at the boards. In a General Education course, "What is Life? From Quarks to Consciousness," Dr. Andrew Berry and I integrate lecture, lab, and discussion sections, all in a single 90-minute class period, rearranging the tables and chairs as needed. We have even had student theater groups use the room: They come in late at night, move the furniture out of the way, rehearse, and then put everything back for our classes the next morning.

Since the fall of 2012, SciBox has been in nearly constant use. The new Physics 15 labs meet here: students can seamlessly move between lab benches, discussion tables, chalkboards, and presentation screens.

So we wanted a "black-box" classroom that could inspire innovation both in teaching and in learning. With a generous grant from the Harvard Initiative for Learning and Teaching (HILT), and additional support from the Faculty of Arts and Sciences, we tore down (asbestos-laden) walls that had previously divided our teaching lab spaces on the third floor of the Science Center and created a new, 2500-square foot open space. This space, dubbed "SciBox," has three rules: First, it must remain unfinished, with mostly unpainted walls and exposed utilities in the ceiling. Students should feel free to build things, including drilling into the walls or ceilings. Picture, for example, a warehouse or garage where entrepreneurs might start a new tech company. Second, everything on the floor must be on wheels, including the lab benches. Nothing is fixed or permanent. Third, and most important, anyone can use the space for anything, with priority given to activities that actually take advantage of the flexible nature of the classroom.

With the success of the original SciBox, we have created two similar spaces—two other SciBoxes—on the first floor of the Science Center. Now all of our introductory labs are taught in these flexible spaces, and we have had visitors from across Harvard and from other institutions who want to adopt similar designs for their classrooms. The idea of a totally flexible classroom isn't new: As a recent participant in a teaching conference pointed out, this is how kindergarten rooms have been designed for years. But by creating this space at Harvard, we have inspired our teachers and students to think differently about what it means both to teach physics and to learn physics.



FEATURED

Quantum Matter under the Microscope

by Philipp Preiss and
Prof. Markus Greiner

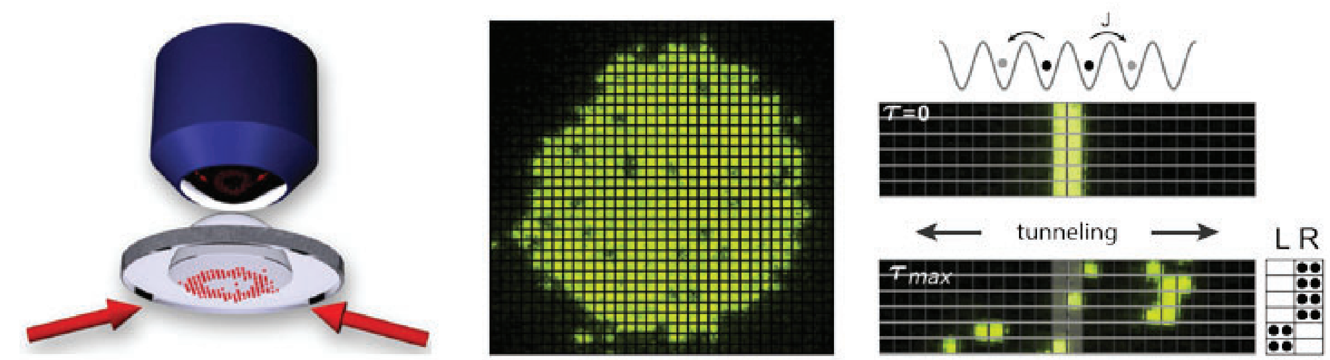
New methods for experiments with ultracold atoms in optical lattices enable the characterization and manipulation of complex quantum systems on the level of individual particles. Achieving such an exquisite level of control allows researchers in the Greiner group to engineer novel quantum states of matter and explore the fundamentals of quantum mechanics.

Above: Photo by Florian Huber.

Experiments with ultracold atoms in optical lattices are tackling some of the most pressing questions in physics: the emergent phases and collective behavior of quantum mechanical systems with many strongly interacting constituents. Such phases, which are notoriously difficult to treat theoretically due to the breakdown of classical numerical simulations for large quantum systems, can now be realized directly in experiments. Using the highly specialized tools and techniques from atomic physics research, physicists build correlated quantum systems in a particle-by-particle manner and even engineer novel, "synthetic" quantum matter with unusual properties not found in nature.

The creation of quantum, many-body systems with neutral atoms has established a new connection between atomic physics and condensed-matter physics: Theoretical tools originally developed for solid state systems are now used to understand the properties of ultracold atomic systems. Conversely, experiments with optical lattices can implement condensed-matter Hamiltonians with new features and tunable parameters. This continuous exchange has brought two fields of research together, leading to extremely fruitful experimental and theoretical efforts.

Markus Greiner's group has pioneered quantum gas microscopy that enables high-resolution readout and manipulation of cold atomic gases in optical lattices. Using a special microscope setup pioneered in our lab, we can directly image individual atoms in their many-body environment. Recently, our group has developed novel methods based on holographic beam shaping and adaptive optics to create arbitrary potential landscapes and even to manipulate single atoms in the optical lattice.



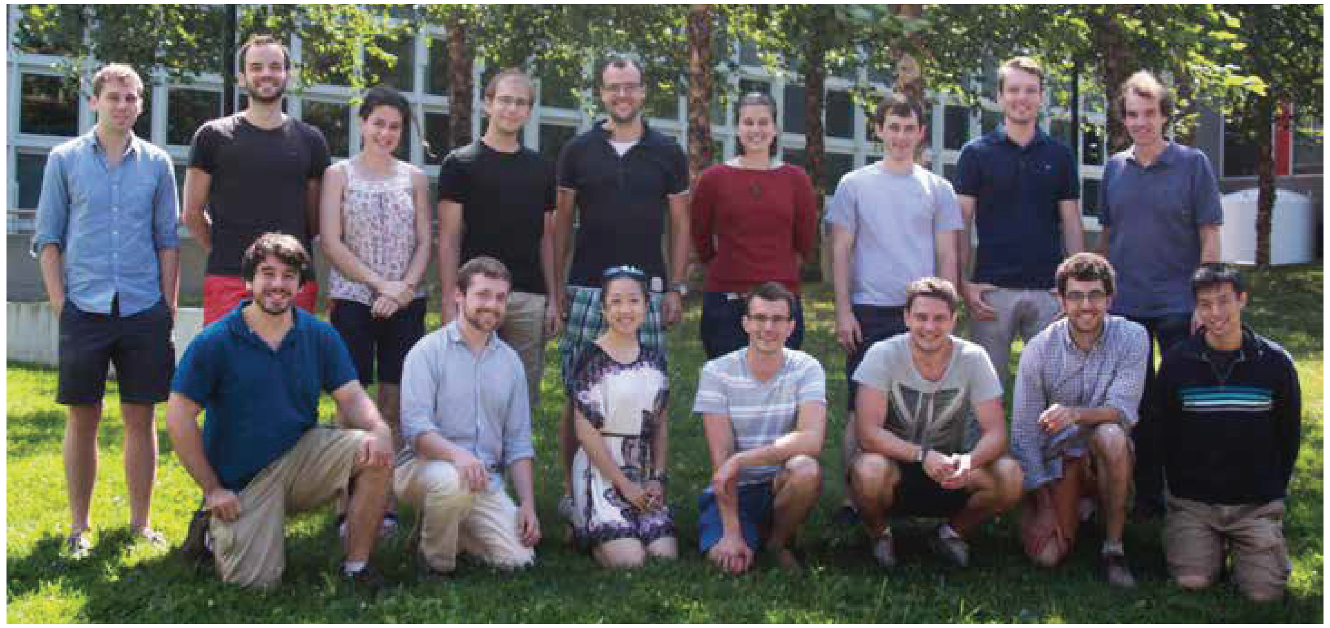
A quantum gas microscope (left) images a cloud of ultracold atoms in an optical lattice, directly revealing many-body ordering in raw images (middle). Here, strongly interacting particles form a Mott insulator with exactly one atom per lattice site, creating a low-entropy starting point for many other experiments. Single-site addressing techniques can be used to control the dynamics of individual particles as in two-particle quantum walks (right), where bosonic interference is observed on the fundamental level of two particles.

This leads to the unprecedented situation in which a system of many interacting particles can be controlled and imaged on the level of individual quanta. Attaining ultimate control over many particles combines the wealth of many-body quantum mechanics with the high level of control of quantum information processing devices, thereby providing a unique platform to explore the fundamentals of many-body quantum mechanics.

To enter the world of quantum mechanics, where coherent motion dominates over thermal fluctuations, atomic gases have to be cooled to the lowest temperatures ever achieved: Our experiments are performed at temperatures on the nanokelvin scale, one billionth of a degree above absolute zero. Clouds of about 10^5 atoms at these ultra-low temperatures can be produced by laser and evaporative cooling. Throughout the experiment the atoms are held in magnetic or purely optical traps in an ultrahigh vacuum to keep these fragile quantum states isolated from the environment. Meeting the requirements for successful cooling and trapping of atoms is a formidable challenge, which requires control over frequency-stabilized lasers, high-power electronics, vacuum technology, and control electronics. Teams of three to four graduate students and postdocs run the experiments to ensure that scientific ideas and technical developments come together to open new research directions.

With all these tools in hand, there are many ways to get creative and elicit interesting quantum states: Cold atoms in a lattice can be shaken, stirred, exposed to disorder, coupled to different internal states, or driven to excited manifolds—and often these tools can be combined to yield surprising new results. We were very excited to find that applying a strong gradient to Mott insulating states can realize a spin model, where the position of each atom encodes a spin state. Based on theoretical work by Subir Sachdev and collaborators, we were able to observe a quantum phase transition within this spin model: As an external field is tuned, quantum fluctuations, which persist even at zero temperature, drive the system from one spin phase to another through highly correlated states at the phase transition point.

One of the most exciting aspects of quantum gas microscopes is their ability to manipulate individual atoms in the lattice. This technique lets us assemble the building blocks of quantum systems one particle at a time, and allows us to play a "quantum Lego" game: We place atoms in the optical lattice in an interesting configuration, and then let them evolve and interact with each other as we track their motion under the microscope. This gives rise to some very curious scenarios: For example, two non-interacting bosons placed next to each other will "bunch up" and be detected close to each other with much higher probability than can be explained classically. This interference effect, a unique signature of the quantum statistics of the particles, can be observed very cleanly in the quantum walks of two particles. Interestingly, when the particles are allowed to interact with each other, this behavior is completely reversed, and the particles avoid each other over long distances.



Back row (L to R): Aaron Krahn, Robert Schittko, Anne Hébert, Anton Mazurenko, Daniel Greif, Susannah Dickerson, Matthew Rispoli, Greg Phelps, Markus Greiner. Front row (L to R): Casey McKenna, Max Parsons, Christie Chiu, Philipp Preiss, Alexander Lukin, Adam Kaufmann, Eric Tai.

While we can learn a great deal from such small, well-controlled systems, the really interesting and counterintuitive features of quantum mechanics emerge when many particles are allowed to interact. Through their coherent motion, such many-body systems can become entangled: parts of a quantum mechanical system can be perfectly correlated over arbitrarily large distances, appearing to interact via "spooky action at a distance"—type phenomena. In many-body systems, entanglement gives rise to highly unusual and fragile states of matter—a feature that makes it the main resource required for quantum information processing and quantum communication.

By exploiting the ability to control the dynamics of individual particles, we are working toward a very general scheme to measure the amount of entanglement in many-body systems: Entanglement and quantum correlations can be associated with a type of entropy, resulting in the paradoxical, and classically impossible, situation whereby part of a system carries more entropy than the system as a whole. Allowing two copies of the same quantum mechanical state to interfere can enable direct measurements of this entropy in a one-dimensional bosonic system and its constituent parts, allowing us to place bounds on the entanglement in different many-body phases. Such measurements can address important questions regarding the interplay of entanglement and particle number fluctuations, with interesting connections to fields as far removed as cosmology. This continuous interaction between theory and experiment, sparked by the implementation of new observables and tools, is one of the major appeals of studying many-body systems in optical lattices.

In the coming years, novel experimental systems will take center stage in research with ultracold atoms. A major breakthrough has recently been achieved by our team working on a Fermi gas microscope. While lithium's small mass and its atomic structure make it very challenging to image, the team has now reached single-atom resolution in a two-dimensional lattice geometry and is excited to start experimenting with strongly interacting Fermi systems. Such experiments are closely linked to current research in condensed-matter: Fermionic atoms in an optical lattice directly mimic the physics of electrons in a solid moving through a crystal lattice formed by ionic cores. The new experiment in our group will study microscopic observables and correlation functions in the Fermi-Hubbard model and explore the formation of magnetic order at extremely low entropies.

Entirely new Hamiltonians can be implemented with particles that interact over long distances. Promising candidates include atoms with large magnetic moments and dipole-dipole interactions, such as the Erbium atoms being used in a current experiment in our group. The availability of such techniques will open new frontiers for ultracold atoms, including the quantum simulation of models from high energy physics, and establish connections to even more diverse fields of research.

Markus Greiner's Research is Ultra Cool

by Steve Nadis

When atoms in a gas are refrigerated to extreme temperatures —about one hundred billionth of a degree above absolute zero—the results can be pretty darn cool. "Cold for a gas means slow, and slow means long de Broglie wavelengths," explains Physics Professor Markus Greiner, whose research centers on this frigid realm. "Matter waves become very large, and particles get spread out over large regions and overlap." While one might expect that things get duller at super cold temperatures, with all activity presumably grinding to a halt, the opposite is true, according to Greiner. "Instead, quantum mechanics takes over with all of its amazing consequences."

Greiner has developed an array of new instruments, and devised innovative experimental approaches, to study the "complex states of matter" that he and his colleagues can create in his lab. One of his specialties is to trap frozen atoms in a so-called optical lattice, which he describes as "an artificial crystal created by light." The light pattern changes in a periodic fashion, and atoms get stuck, momentarily, at places where the light intensity reaches a maximum or minimum. But when the atoms move, they move quantum mechanically. They can be delocalized over many lattice sites, and they feel all other atoms. This interplay of motion and interaction gives rise to a broad range of new states of matter that were never observed before.

The next step is to take pictures of individual atoms with a "quantum gas microscope"—a device Greiner also invented. In principle, he says, it works like a typical light microscope. One trick is to use fluorescent light scattering to detect atoms floating in a vacuum. The hard part, he notes, is that the atoms will try to fly away as you're trying to image them. "The technical challenge is keeping them localized long enough to capture enough photons so that we know where they are," Greiner says. "We're basically trying to stop time long enough to get a snapshot." But once the atoms start fluorescing photons, they give away their position. "They are no longer quantum mechanically delocalized, and the atomic matter waves collapse to the sites we find them in. The resulting patterns we observe can then afford us deep insights into the world of quantum matter."

He developed the first version of this apparatus as part of his PhD work as a graduate student (between 2000 and 2003) at the University of Munich. His 2002 report on the subject for *Nature* is one of the most cited papers in physics over the past 15 years. Greiner won the I.I. Rabi Prize and the MacArthur Award for these and related accomplishments, starting a new field in the process—one in which he remains a leader.

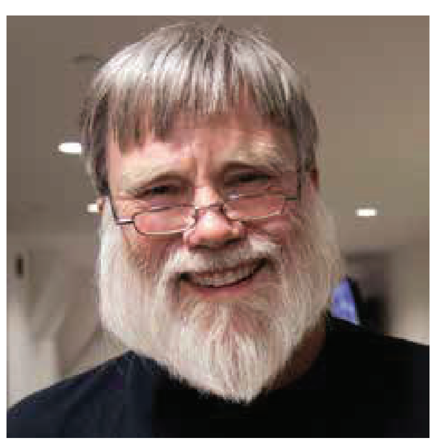
"Quantum gas microscopy has become widespread worldwide. Within the last few months alone eight new quantum gas microscopes have been completed," he says, "That is fantastic, because I want other people to use this technology." His goal, all along, has been to encourage experimentation in this area—and thereby create a dynamic, interactive environment—rather than try to stifle it. That philosophy has paid off. He and his fellow practitioners have conjured up a range of novel materials, affording insights into quantum physics and other areas. Applications in quantum computers, high-temperature superconductors, and materials science in general may be just around the corner.

In some ways, the origins of this work can be traced back to his high school days, when Greiner started experimenting with light waves and holograms and seeing how two different waves interfere with each other, either constructively or destructively. "I later learned that quantum mechanics is just the same," he says. "Matter waves also interfere constructively and destructively. We normally don't see those effects, but you can see them through the study of optics."

That's why Greiner has established a teaching lab in optics that all Harvard physics majors must take. "Building intuition in wave optics can give you intuition about quantum mechanical systems too," he says. As he sees it, learning is about understanding—not about memorizing formulas. His approach to teaching is, therefore, as hands-on as possible, always trying to encourage his students' creativity and playfulness. "It's not all about grades," Greiner stresses. In the long run, finding interesting problems to work on is probably the most important thing for anyone hoping to do research. "And if you're lucky enough to focus on things you're really fascinated in and really enjoy, it doesn't feel like work at all."

PROGRAMS

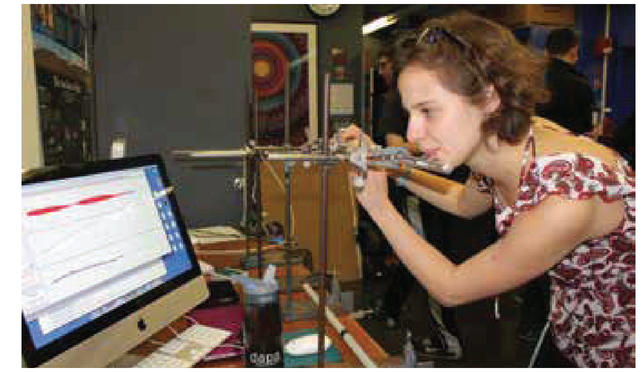
Undergraduate Program



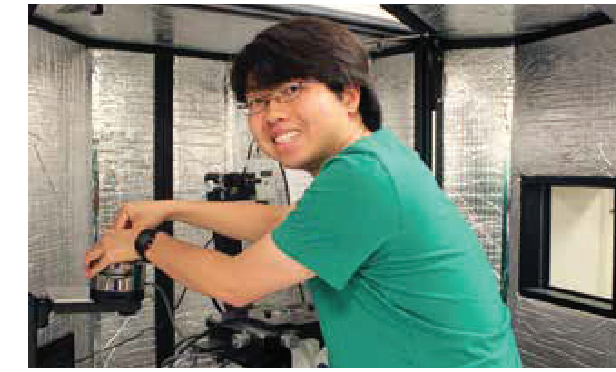
Professor of Physics and Director of Undergraduate Studies, Howard Georgi
Photo by Jon Chase / Harvard University.

Words From the Director

"As Cambridge emerged from the deep freeze last spring, our undergrad concentrators in physics and in chemistry and physics came together twice—first to educate interested freshmen about the concentrations and then a couple of weeks later, on Visitas weekend, to give prefrosh the real scoop. It is always wonderful to see this terrific group of young science students share their enthusiasm for physics."



Undergraduate concentrator: Julia Grotto, FAS'17



Undergraduate concentrator: Andrew Lin, FAS'17

NEW CONCENTRATORS

The Physics Department welcomed a new group of 47 sophomores who signed up for the Physics and Chem/Phys concentrations this past year, many of them pursuing joint concentrations or secondaries in other fields. In addition to subjects like Astrophysics, Mathematics, and Computer Science, these fields include Sociology, Literature, and English.

PRIZES & AWARDS

Emma Dowd, AB '15 received a National Science Foundation Fellowship and will be studying physics at Berkeley. John Sturm, AB '15 will be studying Economics at Cambridge as Harvard's annual Paul Williams Fellow. John was also last year's recipient of the Physics Department's Sanderson Award, which is presented to the graduating Physics concentrator with the highest grade average in concentration courses.

STUDENTS' RESEARCH

This summer, the number of Physics and Chem/Phys concentrators who stayed on campus to undertake full-time research hit an all-time high of 40. These students worked in physics, chemistry, engineering, and related fields. Year after year, the funding for physics undergraduate summer research is made possible, in no small part, due to the generous gifts of James Niederer, AM 1955, PhD 1960, who established the Haase Family Fund, and the family and friends who established a fund in memory of Stephen Brook Fels, AB 1962, AM 1963, PhD 1968.

Andrew Lin, a rising junior, pursued exciting research last summer. Continuing work he had done during the past year in the laboratory of Professor Robert Westervelt, Lin focused specifically on condensed-matter physics and quantum nanomaterials. Working under the supervision of Dr. Sagar Bhandari, Andrew's project centered on the fabrication of graphene-on-boron nitride heterostructures for analysis via scanning-probe microscopy. A two-dimensional hexagonal lattice of carbon atoms, graphene has made waves in the world of physics due to properties such as its uniquely tunable band-gap and high electron mobility. Characteristics like that make graphene ideal for studying the fundamental physics of electron motion in two-dimensional electron gas layers (2DEGs). This research could ultimately lead to tremendous advances in computing technology: graphene is touted as a future successor to the silicon-based, complementary metal-oxide semiconductor (CMOS) systems used in present day computing. Graphene acquires special significance in medical research as well, with potential applications for nanoscale power sources, biosensors, and circuits in truly nanoscale medicine. In this way, the opportunity to work with the Westervelt Group has played a central role in solidifying Andrew's interest in continuing with research in a medical post-graduate program.

CAREER PATHS

This past year's graduating class consisted of 48 Physics and Chem/Phys concentrators. Fourteen of these students headed off to graduate school at ten different institutions to study Physics, Astrophysics, Applied Math, Chemistry, Biochemistry, and Economics. Others are now attending medical school, and still others have joined the workforce in software, consulting, aerospace, finance, teaching, and various startups.

FUN STUFF

The Society of Physics Students was active again last year with many events, including numerous physics-minded movie nights on the big screen in Jefferson 250, the annual pumpkin drop, a hugely successful liquid nitrogen ice cream party during the Visitas weekend, a Harvard/Yale SPS board game mixer, as well as a Women in Math and Physics board game event co-sponsored with the Harvard Undergraduate Mathematics Association. Plans for this year include a graduate mentor program and the reintroduction of the Physics Table—a regular dinner at which students present talks on physics topics they find interesting.

PROGRAMS

Graduate Program

by Dr. Jacob Barandes

THE PHD CLASS ENTERING IN 2015

The new students entering the Physics PhD program in Fall 2015 were remarkable for their geographic diversity, hailing from the American states of Alaska, California, Connecticut, Florida, Illinois, Indiana, Massachusetts, North Carolina, New Jersey, New York, Texas, Virginia, Washington, and Wisconsin. Incoming students born outside the United States came from Canada, China, Germany, India, Italy, Norway, Romania, Serbia and Montenegro, South Korea, Syria, and Taiwan.

THE PHYSICS GRADUATE STUDENT COUNCIL

Created by Physics PhD students in the spring of 2009, the Physics Graduate Student Council has continued to be an integral part of the Physics Department. The council provides a forum for graduate students to propose new initiatives and discuss issues of common concern. It organizes social events like the popular biweekly Friday afternoon social hour and monthly movie nights.

The council also administers annual surveys to graduate students on advising and the school's overall climate. The council's current president is Jae Hyeon Lee, and its other members (in alphabetical order) are Erin Dahlstrom, Nick Langellier, Olivia Miller, Joe Olson, Anna Patej, and Arthur Safira.

NEW INITIATIVES

To help new graduate students learn more about research going on in the department and make connections with more senior graduate students in a variety of labs, the Physics Graduate Student Council put together a new annual poster session on January 26 in the department's library. The council held a second poster session on March 31 during the open house for prospective PhD students.

Following another proposal by the Physics Graduate Student Council, the department also organized its first annual graduate student panel on research and the qualifying exam. Held on February 23 and moderated by Dr. Jacob Barandes, Associate Director of Graduate Studies, the panel's members (in alphabetical order) were graduate students Ruffin Evans, David Farhi, Elizabeth Jerison, Sarah Kostinski, Tomo Lazovich, and Alex Lupsasca. The panelists—who were all in either their fourth or fifth year of the PhD program and represented fields including biophysics, atomic physics, quantum gravity, applied math, and particle physics—talked about their experiences getting into research, finding advisors, and taking the qualifying exam. They also fielded questions from the first- and second-year graduate students in the audience.

Opposite: Incoming Graduate Students Fall 2015;

Right: Students at annual Open House.

2015 CONFERENCE OF THE NATIONAL SOCIETY OF BLACK PHYSICISTS (NSBP)

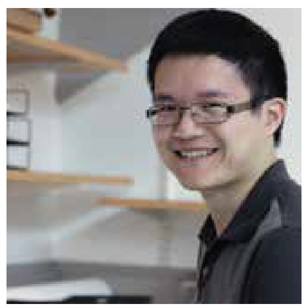
The departments of Physics and Applied Physics, joint co-sponsors of this year's conference of the National Society of Black Physicists (NSBP), were represented at this event by several faculty members, staff members, and students. In attendance this year from Harvard's Physics department were Prof. Vinothan Manoharan (Director of Graduate Studies), Dr. Jacob Barandes (Associate Director of Graduate Studies), Lisa Cacciabaudo (Graduate Program Administrator), Carol Davis (Undergraduate Program Coordinator), as well as PhD students Patrick Jefferson (quantum gravity), and Rodrick Kuate Defo (computational physics), and undergraduate sophomore Olumakinde Ogunnaike (physics-math joint concentrator). Representing Harvard's Applied Physics department were Dr. Kathryn Hollar (Director of Educational Programs), Gloria Anglon (Assistant Director of Diversity and Student Engagement), as well as PhD students Sorell Massenburg (soft-matter physics) and Suhare Adam (material science).

2015 NORTHEASTERN SATELLITE CONFERENCE FOR UNDERGRADUATE WOMEN IN PHYSICS (CUWIP)

The annual Conference for Undergraduate Women in Physics (CUWiP) consists of several satellite conferences, all run simultaneously in different regions of the country. The department was represented at the 2015 northeastern satellite conference on January 18 by Dr. Jacob Barandes (Associate Director of Graduate Studies) and Lisa Cacciabaudo (Graduate Program Administrator), as well as by PhD students Ellen Klein (soft-matter physics) and Elise Novitski (atomic and low-energy particle 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.



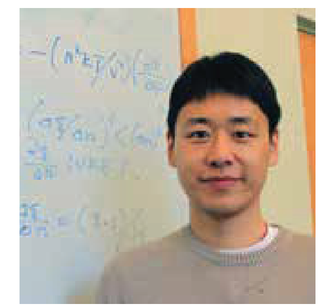
Dennis Huang

2015 GOLDHABER PRIZE WINNER

Dennis Huang received his BSc in Physics and Mathematics at the University of British Columbia in Canada, where he was awarded the Governor General's Silver Medal in Science. His first exposure to condensed-matter experiments came about in his sophomore summer, when he spent hours using a microscope to search for 2D graphene flakes in Prof. Joshua Folk's lab. He went on to further work fabricating gated graphene devices and investigating quantum transport in these systems at cryogenic temperatures.

At Harvard, Dennis has continued his research in condensed-matter physics in Prof. Jennifer Hoffman's lab, but this time in the context of a 2D high-temperature superconductor: single-unit-cell FeSe, grown on SrTiO3. He spent the first part of his PhD setting up a combined molecular beam epitaxy (MBE) and scanning tunneling microscope (STM) system, housed in a floating room for vibration isolation in the basement of LISE. He distinctly remembers the slightly overwhelming experience of standing in an empty room in January 2013 and progressing toward the development of a fully-assembled system eight months later (although it took another ten months before he had a fully-functional system). Currently, Dennis uses spectroscopic STM imaging of defect-induced quasiparticle interference in FeSe/SrTiO3 in order to uncover its electronic structure and superconducting pairing mechanism. He is also performing *ab initio* simulations of atomic defects in FeSe under the guidance of Prof. Efthimios Kaxiras in order to complement the STM data.

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.



Bo Liu

2015 GOLDHABER PRIZE WINNER

Bo Liu finished his PhD in January 2015, with a PhD secondary field in Computational Science and Engineering, and was the winner of the IACS scholarship for computational research. Bo finished his undergraduate study at the University of Science and Technology of China in June 2010, majoring in Applied Physics (condensed-matter physics), where he was twice awarded the National Scholarship for academic excellence.

Bo entered Harvard's PhD program in the fall of 2010 and joined Prof. Eric Heller's group to pursue theoretical and computational research.

Bo's PhD research focused on scattering theory in two-dimensional electron systems and plasmonic systems. He worked on explaining an experimentally observed stability of electron transport in two dimensions with classical chaotic dynamics. He also solved an inverse scattering problem in which a prespecified light-scattering wave pattern can be achieved by manipulating the positions of a collection of metallic nanoparticles.

Goldhaber Prize

Siyuan Sun

2015 GOLDHABER PRIZE WINNER

Siyuan Sun wanted to be a physicist ever since he heard about special relativity in high school. As a freshman at Duke University, he began working for Prof. Ashutosh Kotwal on the Tevatron, which was then the most powerful particle collider at Fermilab.

Now in Harvard's PhD program, Sun works at the Large Hadron Collider with Prof. Melissa Franklin. Last year, Sun was part of the team that measured the width of the Higgs mass distribution at ATLAS. In his current project, he is working to improve reconstructions of physical processes in which large numbers of particles are undetectable by the detector. He is also involved in monitoring and maintaining the ATLAS detector itself.

Shu-Heng Shao

2015 GOLDHABER PRIZE WINNER

Shao was an undergraduate student at National Taiwan University in Taipei, Taiwan, where he studied theoretical physics. Shao's general research interests include quantum field theory, string theory, supersymmetry, and mathematical physics. At Harvard, Shao works with Prof. Xi Yin on various aspects of holographic dualities, and, in particular, the AdS/CFT correspondence, which includes supersymmetric matrix quantum mechanics and little string theory. Shao has also had the opportunity to work with Mboyo Esole and Prof. Shing-Tung Yau in the Math and Physics Departments on the relation between geometric singularities and phase transitions in quantum field theory. In another collaboration with Junior Fellow Clay Córdova, he studied the problem of counting ground states in supersymmetric quantum mechanics, which has broad applications on the counting of BPS states in four-dimensional supersymmetric quantum field theories.

GSAS Merit Fellowship

Ruffin Evans

2015 GSAS MERIT FELLOWSHIP WINNER

Ruffin Evans is a fourth-year PhD candidate in the research group of Prof. Mikhail Lukin. A native of Charlottesville, Virginia, Ruffin graduated from the University of Virginia with degrees in both Physics and Chemistry. As an undergraduate, Ruffin was recognized as the top student in his graduating class and also received awards for best undergraduate research in both chemistry and physics. Ruffin obtained support for this research through a Goldwater Scholarship, a prestigious national award for STEM undergraduates.

At Harvard, Ruffin's research focuses on integrating color centers in diamond with nanophotonic optical cavities. These nanostructures increase the interaction between light and individual color centers, allowing the light to be efficiently controlled on the single-photon level. This work has applications in classical and quantum information technology, where the realization of low-power optical nonlinearities remains an outstanding challenge. Ruffin's research was previously supported by the National Science Foundation through the Graduate Research Fellowship Program.

Tomo Lazovich

2015 GSAS MERIT FELLOWSHIP WINNER

Tomo Lazovich did his undergraduate work at Harvard. He first worked with Prof. Melissa Franklin on the CDF experiment at the Tevatron collider at Fermilab, where he developed new online tools for monitoring the detector. Later, he worked with Prof. Franklin and Prof. Joao Guimaraes da Costa on the ATLAS experiment at the Large Hadron Collider (LHC) at CERN. He helped to commission the operations of the muon system with cosmic rays and wrote a senior thesis on the identification and rejection of the cosmic-ray muon background in ATLAS. His thesis won Harvard's Hoopes Prize.

Continuing in the graduate program, Tomo stayed on the ATLAS experiment with Prof. Guimaraes da Costa. He analyzed data taken in 2011 and 2012 from the LHC to search for the signature related to the production of the Higgs boson, the last missing piece of the Standard Model—the theory describing all of the known fundamental particles and their interactions. In July 2012, the ATLAS and CMS experiments jointly announced the discovery of the Higgs. Tomo went on to analyze that particle's properties in the two-W boson decay channel with the full dataset from Run 1 of the LHC. Now that "Run 2" at the LHC is underway, Tomo has been using the newly discovered Higgs to search for unknown physics beyond the Standard Model. In particular, he is searching for heavy particles that decay into two Higgs bosons, which subsequently decay into two bottom quarks each. This research holds the potential to shed light on some of the unanswered questions in particle physics and will also help us learn more about the nature of the Higgs particle itself.

Chin Lin Wong PhD '14 and Marsella Jorgolli PhD '15

Graduate Student Awards and Fellowships*

American Association of University Women (AAUW) Dissertation Completion Fellowship

Elizabeth Jerison

Amherst College Graduate Fellowship

Daniel Ang

Department of Energy Computational Science Graduate Fellowship (DOE CSGF)

Julian Kates-Harbeck

Goldhaber Prize

Dennis Huang

Bo Liu

Shu-Heng Shao

Siyuan Sun

GSAS Merit Fellowship

Ruffin Evans

Tomo Lazovich

Hertz Foundation Fellowship

Sabrina Pasterski

National Defense Science and Engineering Graduate (NDSEG) Fellowship

Laurel Anderson

Aaron Kabcenell

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

Solomon Barkley

Scott Collier

Alexandra Thomson

National Science Foundation Graduate Research Fellowship Program (NSF GRFP)

Ellen Klein

Sabrina Pasterski

Abigail Plummer

Emma Rosenfeld

Julia Steinberg

Elana Urbach

Smith Family Graduate Science and Engineering Fellowship

Sam Dillavou

TUSA Fellowship

Yu-Ting Chen

*Includes awards from 2014-2015.

Recent Graduates

David Isaiah Benjamin

Thesis: Impurity Physics in Resonant X-Ray Scattering and Ultracold Atomic Gases

Advisor: Eugene Demler

Gilad Ben-Shach

Thesis: Theoretical Considerations for Experiments to Create and Detect Localised Majorana Modes in Electronic Systems

Advisors: Bertrand Halperin (chair); Amir Yacoby (co-chair)

Willy Chang

Thesis: Superconducting Proximity Effect in InAs Nanowires

Advisors: Charles Marcus (Univ. of Copenhagen chair); Amir Yacoby (Harvard chair)

Hyeyoun Chung

Thesis: Exploring Black Hole Dynamics

Advisor: Lisa Randall

Jean Anne Currivan Incorvia

Thesis: Nanoscale Magnetic Materials for Energy-Efficient Spin Based Transistors

Advisors: Marc Baldo (MIT chair); Robert Westervelt (Harvard chair)

Ilya Eric Alexander Feige

Thesis: Factorization and Precision Calculations in Particle Physics

Advisor: Matthew Schwartz

Alex Frenzel

Thesis: Terahertz Electrodynamics of Dirac Fermions in Graphene

Advisors: Nuh Gedik (MIT chair); Jenny Hoffman (Harvard chair)

Andrew Higginbotham

Thesis: Quantum Dots for Conventional and Topological Qubits

Advisors: Charles Marcus (Univ. of Copenhagen chair); Robert Westervelt (Harvard chair)

Chia Wei Hsu

Thesis: Novel Trapping and Scattering of Light in Resonant Nanophotonic Structures

Advisors: Marin Soljačić (MIT chair); Adam Cohen (Harvard chair)

Marsela Jorgolli

Thesis: Integrated Nanoscale Tools for Interrogating Living Cells

Advisor: Hongkun Park

Rita Rani Kalra

Thesis: An Improved Antihydrogen Trap

Advisor: Gerald Gabrielse

Shimon Jacob Kolkowitz

Thesis: Nanoscale Sensing With Individual Nitrogen-Vacancy Centers in Diamond

Advisor: Mikhail Lukin

Maxim Olegovich Lavrentovich

Thesis: Diffusion, Absorbing States, and Nonequilibrium Phase Transitions in Range Expansions and Evolution

Advisor: David Nelson

Bo Liu

Thesis: Selected Topics in Scattering Theory: From Chaos to Resonance

Advisor: Eric Heller

Guglielmo Paul Lockhart

Thesis: Self-Dual Strings of Six-Dimensional SCFTs

Advisor: Cumrun Vafa

Sofia Magkiriadou

Thesis: Structural Color from Colloidal Glasses

Advisor: Vinny Manoharan

James W. McIver

Thesis: Nonlinear Optical and Optoelectronic Studies of Topological Insulator Surfaces

Advisors: Nuh Gedik (MIT chair); Jenny Hoffman (Harvard chair)

Aaron Michael Meisner

Thesis: Full-sky, High-resolution Maps of Interstellar Dust

Advisor: Douglas Finkbeiner

Kevin Michael Mercurio

Thesis: A Search for the Higgs Boson Produced in Association with a Vector Boson Using the ATLAS Detector at the LHC

Advisor: John Huth

Andrzej Kazimierz Nowojewski

Thesis: Pathogen Avoidance by Caenorhabditis Elegans is a Pheromone-Mediated Collective Behavior

Advisor: Erel Levine

Julia Hege Piskorski

Thesis: Cooling, Collisions and Non-Sticking of Polyatomic Molecules in a Cryogenic Buffer Gas Cell

Advisor: John Doyle

Aqil Sajjad

Thesis: An Effective Theory on the Light Shell

Advisor: Howard Georgi

Nicholas Benjamin Schade

Thesis: Self-Assembly of Plasmonic Nanoclusters for Optical Metafluids

Advisor: Vinny Manoharan

Michael Dean Shulman

Thesis: Entanglement and Metrology with Singlet-Triplet Qubits

Advisor: Amir Yacoby

William R. Spearman

Thesis: Measurement of the Mass and Width of the Higgs Boson in the H to ZZ to 4l Decay Channel Using Per-event Response Information

Advisor: Joao Guimaraes da Costa

Jeffrey Douglas Thompson

Thesis: A Quantum Interface between Single Atoms and Nanophotonic Structures

Advisor: Mikhail Lukin

Tout Taotao Wang

Thesis: Small Diatomic Alkali Molecules at Ultracold Temperatures

Advisors: Wolfgang Ketterle (MIT chair); John Doyle (Harvard chair)

Chin Lin Wong

Thesis: Beam Characterization and Systematics of the Bicep2 and Keck Array Cosmic Microwave Background Polarization Experiments

Advisor: John Kovac

Andy Yen

Thesis: Search for Weak Gaugino Production in Final States with One Lepton, Two b-jets Consistent with a Higgs Boson, and Missing Transverse Momentum with the ATLAS detector

Advisor: John Huth

PROGRAMS

Research Scholars

by Bonnie Currier, Research Scholar Coordinator

Following last year's highly successful gathering, the Harvard Physics Department's research scholars came together on September 17, 2015 for the third annual Post-Doc/Research Scholar Retreat. Nearly 60 scholars enjoyed this day-long event at the historic MIT Endicott House in Dedham, MA, a magnificent rural setting for reflection and discussion. The day began with the lively challenge of having to give one-minute introductions about group collaborations. A diverse range of individual and collaborative projects were exhibited in the poster session. Scholars had time for recreation and a fun, science-based trivia game.

Invited speakers were Mr. Dennis Overbye, Deputy Science Editor, *The New York Times*, and Dr. Simona Rolli, Program Manager at the U.S. Department of Energy, Office of Science, and Office of High Energy Physics. Harvard's very own Roy J. Glauber, Mallinckrodt Research Professor of Physics, was the keynote speaker.

This event was organized by post-docs from our research scholar cohort, who also serve on our research scholar advisory committee, in conjunction with the Department's Research Scholar Coordinator.

THE HBS MOUNT EVEREST SIMULATION

Last January, thirty of our Research Scholars organized into teams of five to tackle a virtual Mount Everest. Led by Willy Shih, Robert and Jane Cizik Professor of Management and Practice at the Harvard Business School, this team-based simulation led the scholars through a "six-day" climb in two hours, during which participants worked together, overcoming many obstacles in order to reach the "summit." Those who took part in this effort found their leadership, decision making, and team building skills challenged at practically every step of their virtual ascent, but almost all found the experience rewarding.

THE HARVARD PHYSICS MENTOR NETWORK

A new initiative within the Physics Department aims to make the task of finding a professional career a better experience for graduate students and research scholars—a category that includes Post-Docs, Research Associates, Junior Fellows, Visiting Scholars, Associates, Affiliates, and Fellows.

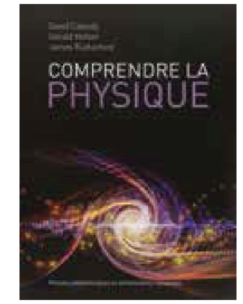
Graduate students and scholars can take part in this initiative in at least two ways. First, the department is creating a list of physics alumni who have offered to answer questions about what work is like in particular industries and in different countries, suggesting steps someone might take to prepare for a career in a given field. To contact any of these individuals, please get in touch with Bonnie Currier (bcurrier@fas.harvard.edu). Although these people have generously volunteered to help, please be respectful of their (limited) time. And please consider becoming a mentor yourself when you move on to new positions. For those alumni who want to be added to the volunteer list, please provide your current email address, appointment title, institution (university, industry, etc.), research field(s)/subfield(s), and the date of your PhD. That's all we need. Thank you!

The second way to tap into this initiative is through the Official Group for the Harvard Physics Community at LinkedIn (https://www.linkedin.com/groups?gid=4740923). Be sure to identify yourself as a Physics Graduate Student or Research Scholar in your profile. You can remain in this group as an alumnus.

We hope you'll find these resources and networking opportunities helpful. We would, of course, appreciate any feedback on how the Department of Physics can best support your career development.

Comprendre la physique

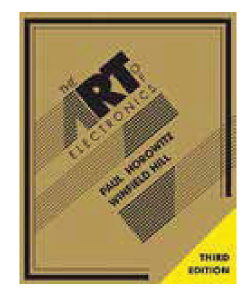
David Cassidy, Gerald Holton, and James Rutherford, 2014
Presses polytechniques et universitaires romandes



This book—the first French translation of *Understanding Physics* —provides a thorough grounding in contemporary physics, placing the subject into its social and historical context. Based largely on the highly respected Project Physics Course developed by two of the authors, it incorporates the results of recent pedagogical research. The text introduces some basic phenomena in the physical world and the concepts developed to explain them. It shows that science is a rational human endeavor with a long and continuing tradition involving many different cultures and people. The treatment emphasizes not only what we know but also how we know it, why we believe it, and what effects this knowledge can have.

The Art of Electronics

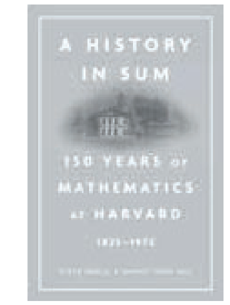
Third Edition
Paul Horowitz and Winfield Hill
Cambridge University Press, 2015



At long last, here is the thoroughly revised and updated third edition of the *The Art of Electronics*—widely accepted as the single most authoritative book on electronic circuit design. In addition to enhanced, up-to-date coverage of many topics, the latest edition contains much new material, including 90 oscilloscope screenshots illustrating the behavior of working circuits, 1,500 figures, and 80 tables. The current version of this book retains the feeling of informality and easy access that helped make earlier editions so popular. It is an indispensable reference for anyone, student or researcher, professional or amateur, who works with electronic circuits.

A History in Sum: 150 Years of Mathematics at Harvard (1825-1975)

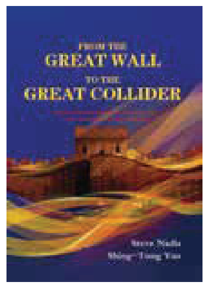
Steve Nadis and Shing-Tung Yau
Harvard University Press, 2013



In the twentieth century, American mathematicians began to make critical advances in a field previously dominated by Europeans. Harvard's mathematics department was at the center of these developments. *A History in Sum* is an inviting account of the pioneers who trailblazed a distinctly American tradition of mathematics. The heady mathematical concepts that emerged, and the men and women who shaped them, are described here in lively, accessible prose. "There is perhaps no better book for immersion into the curious and compelling history of mathematical thought," wrote Brian Greene, a Professor of Physics and Mathematics at Columbia University.

From The Great Wall To The Great Collider: China and the Quest to Uncover the Inner Workings of the Universe

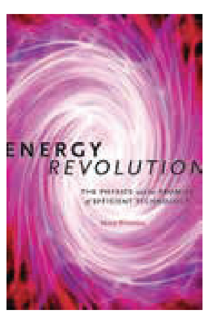
Steve Nadis and Shing-Tung Yau
International Press, 2015



The 2012 discovery of the Higgs boson was a sensational triumph—capping off a 48-year-long search that completed the so-called "Standard Model" of particle physics. While the celebrations were still underway, researchers in China were laying the groundwork for a giant accelerator—up to 100 kilometers in circumference—that would transport physics into a previously inaccessible, high-energy realm where a host of new particles, and perhaps a sweeping new symmetry, might be found. This book describes the ambitious, international effort to build a "Great Collider," which could provide a fuller understanding of our universe's origins and its most basic constituents.

The Energy Revolution: The Physics and the Promise of Efficient Technology

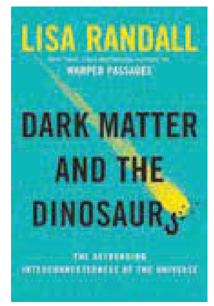
Mara Prentiss
Harvard University Press, 2015



Energy can be neither created nor destroyed—but it can be wasted. The United States wastes two-thirds of its energy, including 80 percent of the energy used in transportation. So the nation has a tremendous opportunity to develop a sensible policy, based on benefits and costs, which advances efficient energy use and a reliance on renewable sources. *Energy Revolution* presents the science, as well as the political and technical information, needed to support a bold claim: Wind and solar power could generate 100 percent of the United States' average total energy demand for the foreseeable future, even without waste reduction.

Dark Matter and the Dinosaurs: The Astounding Interconnectedness of the Universe

Lisa Randall
Ecco, 2015



In this fascinating exploration of our cosmic environment, Lisa Randall, a particle physicist and New York Times bestselling author, uses her research into dark matter to illuminate startling connections between the furthest reaches of space and life on Earth. Randall suggests that the comet—which crashed into the Earth 66 million years ago, killing off the dinosaurs—might have been dislodged from its orbit in the Solar System by passing through a disk of dark matter embedded in the Milky Way. Her book thus raises an astonishing (although admittedly speculative) proposition: Dark matter could have played a role in wiping out the dinosaurs.

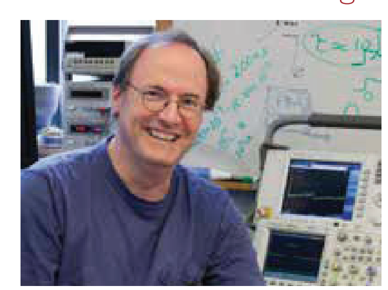
Celebrating Staff

Honoring More Than 125 Years in Physics

Carol Davis, Jan Ragusa, Dayle Maynard, and Barbara Drauschke

It was another banner year for the Department of Physics staff, highlighted by a combined celebration of four milestone birthdays, as shown. Seasoned veterans Barbara Drauschke, Carol Davis, Dayle Maynard, and Jan Ragusa all turned 65 in 2015, hosting a fun-filled party, complete with historic photos and a generous feast, that only they could muster. These women have served the Department with distinction for a collective total of 126 years and 135 years for the University at large. We are so grateful for their service and excited about the next chapter in their careers. The historic knowledge they carry is remarkable, from first-hand reflections of dictating correspondence for Professor Norman Ramsey and Professor Francis Pipkin to the early days of mathematical physics, when Professor Jaffe was delighted to learn that Ms. Drauschke knew how to type mathematical equations, and Professor Gabrielse had yet to have three children. We owe an incredible debt to these dedicated women, and the Department has been forever transformed by their diligence and longstanding commitment.

World-Class Circuit Designer



Jim MacArthur

Following some 15 years of circuit design experience at high-end manufacturers like HP, Data General, and Lexicon, Jim MacArthur founded our Electronic Instrument Design Lab (EIDL), which is now in its 15th year. He educates graduate students in all aspects of circuit design, as well as devising state-of-the-art instruments for laboratory research. MacArthur's devices have populated laboratories both at Harvard and at more than 25 institutions in the US and abroad (including MIT, Princeton, Stanford, and Yale, and universities in Australia, Canada, Denmark, Germany, Israel, Japan, Netherlands, Switzerland, and the UK).

Jim's output is prodigious—more than a thousand laboratory instruments (many of which seriously push the limits of performance achievable with contemporary technology), spread over some thirty research groups in Physics and SEAS. In the words of several of his professorial clients: "The electronics shop has enabled precision measurements that were previously beyond our reach." "On so many occasions we have collaborated with Jim to build custom-made instrumentation that has made our work possible. There really isn't anything that Jim can't do." "In my opinion, Jim MacArthur ranks among the very best things at Harvard. He brings to our group unique capabilities and is simply irreplaceable. He is profoundly important, both in terms of research and education of my students. The electronics shop remains one of my FAVORITE things at Harvard. Jim is excellent, knowledgeable, fair, friendly, accessible. A perfect 10." And (somewhat more succinctly): "We are fortunate to have this world-class circuit designer as our academic colleague."

Circuit-design education is a major part of EIDL's charter, and the graduate students fairly gush with enthusiasm: "My experience with EIDL has been nothing short of awesome. Jim is fantastic, and has served extraordinarily well in the dual roles of teacher and engineer... What is particularly remarkable is not only that he can answer any question I have with an expert answer, nuanced with subtleties about particular parts, but that he is so willing to be helpful and put up with my own incompetence."

Jim derives great satisfaction from connecting diverse research groups. "I think that one of most important functions of the e-shop is that it is a mechanism of collaboration between research groups, not just in the department, but throughout Harvard, and for that matter, the world," he says. "When students ask about the best capacitor for cryogenic applications, I direct them—sometime I almost have to frog-march them—to the Gabrielse lab, which has filled a notebook of data on cryogenic capacitor performance." And he goes on: "One of the fun parts of this job is finding an instrumentation solution that solves several problems in several different labs, and then using that instrument as a way to force a certain amount of communication between the groups. An example is the nitrogen-vacancy-centers research done in the Lukin, Yacoby, Loncar, and Walsworth groups, as well as in the instructional lab in the Science Center, and labs at Wellesley, Columbia, Howard University, Lincoln Labs, and several local start-ups. They all need variations on the same basic instrument, an agile synthesizer around 2.87 GHz."

Jim enjoys his role at Harvard, remarking that, coming after his earlier experiences, "designing things that professionals use to do their job better" is, in some sense, a "capstone job." Perhaps that explains why those of us in the buildings on weekends often see Jim in his lab, finishing up instruments for his many scientific clients.

HARVARD UNIVERSITY
Department of Physics

17 Oxford Street
Cambridge, MA 02138

Departmental Events

Physics Monday Colloquium

Our weekly colloquia with a single invited speaker is held at 4:15PM in Jefferson 250, preceded by an all-community tea at 3:30PM in the Jefferson Research Library.

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:
https://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:
https://www.physics.harvard.edu/events/gencal

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