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APS physics

More from the 2018 March Meeting
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PHYSICAL REVIEW ACCELERATORS AND BEAMS

Open-Access Pioneer and Community Organizer

By Frank Zimmermann

Since its start in 1998 *Physical Review Accelerators and Beams* (*PRAB*) has been an all-electronic journal, a daring novelty at the time and a testing ground for other *Physical Review* journals. Equally unheard of, thanks to external financial sponsorship, *PRAB* has been made available free of charge to both authors and readers around the world. As such, it is a pioneering "gold" open-access journal, far ahead of its time. Innovative and forward-looking, *PRAB* rapidly established its reputation as the world's premier journal in accelerators and beams.

Accelerators have been a part of one-third of all physics Nobel Prizes awarded since 1939 [1] as well as being engines of discovery for chemistry, biology, and medicine. While members of the accelerator community make essential contributions to a broad range of sciences, "their peers are other accelerator scientists and their professional interests are related to accelerators and beams" [2]. Almost all accelerator experts are working at the nexus of universities, research centers, and industry, giving rise to unique collaboration models and research methodologies.

To better serve and nurture this community, in 1997 the APS Division of Physics of Beams (DPB) recommended establishing a scholarly, peer-reviewed journal devoted to the science and technology of accelerators and beams. It would cover the full breadth of accelerators and beams, publish quickly, circulate widely, and have an international editorial board and pool of referees [2].

Martin Blume, APS Editor in Chief at that time, understood the intimate connection between technology and the resulting science, and, departing from *Physical Review* tradition, he was willing to champion a journal covering all of accelerator research [2].

As a result, *Physical Review Special Topics - Accelerators and Beams* (*PRST-AB*) was approved

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Astrophysicist Helms the NSF Mathematical and Physical Sciences Directorate

By Katherine Kornei

Anne Kinney

The new head of the National Science Foundation's Mathematical and Physical Sciences Directorate invokes Einstein when describing her job responsibilities. "The question I ask myself is if Einstein were proposing [for NSF funding], would he win?," says Anne Kinney. "We want to make sure the answer to that question is always yes."

In January, Kinney stepped up to lead one of the NSF's largest directorates, which includes five divisions: astronomy, chemistry, physics, materials science, and mathematics. She oversees how fundamental research in these areas is funded—over 40% of the federal support for basic research at academic institutions comes from the Mathematical and Physical Sciences Directorate. Kinney is quick to highlight NSF's previous and ongoing research success stories, for example its support of the Laser Interferometer Gravitational-Wave Observatory (LIGO). "That's a very proud example of what you want to make sure you're always supporting," Kinney says.

Kinney, who holds a doctorate in physics and astronomy from New York University, spent 14 years at the Space Telescope Science Institute where she was an Instrument Scientist working on the Faint Object Spectrograph aboard the *Hubble Space Telescope*. In 1999, Kinney joined NASA to lead

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Condensed Matter Physics Gets an AI Assist

By Sophia Chen

2018 APS March Meeting, Los Angeles—At the beginning of his equation-filled PowerPoint presentation, invited speaker Ehsan Khatami pulled up a picture of a puppy.

Gesturing toward the puppy's round, doleful eyes, the San Jose State University physicist explained how he'd used artificial intelligence—the same approach that lets Google's image recognition software distinguish between puppies and kittens—to identify phases in a quantum condensed matter model.

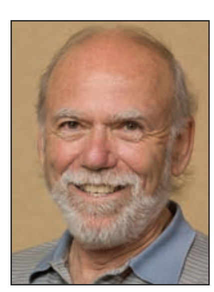
For a simple model of spins, a neural network can distinguish between a disordered state at high temperature (top) and an ordered state below the transition temperature (bottom).

Simulation of exotic phases and emergent phenomena is a hot topic in condensed matter physics research, but conventional computing methods are reaching their limits: As the number of particles in a model approaches values for actual materials, simulations require supercomputing facilities. "It becomes enormously expensive," says Khatami.

Khatami and other condensed matter researchers think that artificial intelligence—which includes techniques known as machine learning and neural networks—can be used alongside conventional computing algorithms for studying collections of electrons in a material. Machine learning algorithms can run on an ordinary desktop computer beefed up with additional graphical processing units—computer chips that are popularly used to display video game graphics

AI ASSIST continued on page 5

Kavli Symposium: LIGO, Quantum Computers, and More



Barry Barish

Shoucheng Zhang

Ivan Schuller

Manu Prakash

Amir Abo-Shaeer

By Leah Poffenberger

2018 APS March Meeting, Los Angeles—The Kavli Foundation Special Symposium brought five distinguished physicists together to share groundbreaking physics, out-of-the-box physics applications, and ideas for innovative science education.

Barry Barish (Caltech) reviewed the history of the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the latest discoveries in gravitational wave detection. Shoucheng Zhang (Stanford) and Ivan Schuller (University of California at San Diego) both gave presentations on the future of computing: Zhang on the discovery of a particle which could be critical to topological quantum computing, and Schuller on the development of computers that mimic the human brain. Creator of the Paperfuge—a simple toy repurposed as a medical centrifuge that requires no electricity—Manu Prakash (Stanford) spoke next on the application of physics to global health and education challenges in developing countries. To round out the evening, Dos Pueblos Engineering Academy founder Amir Abo-Shaeer shared his vision for reimagined science education to equip potential future physicists.

Barish, recipient of the 2017 Nobel Prize in Physics, kicked off the three-hour session with a discussion of gravitational wave detection, beginning with Einstein's 1916 prediction of their existence. Experimental verification took a further 100 years. As Barish described, gravitational waves remained elusive for a century because no instrument existed that was sensitive enough to detect the small stretching of space indicating passage of a wave until Advanced LIGO in 2014.

Barish became a principal investigator for LIGO in 1994, and the instrument began taking data in 1995 and ran for 11 years without detecting gravitational waves. The issue, Barish noted, was in the sensitivity of the instrument, which was constrained by seismic noise. To combat the constant shaking of Earth, Advanced LIGO was constructed using techniques found in everyday objects such as cars and noise-cancelling headphones. Armed with high-powered shock absorbers and active-seismic isolation techniques that measured ambient shaking and corrected for it, Advanced LIGO went online in September 2014. Within five days, it detected the first evidence of gravitational waves. Since then, it has seen four events caused by black hole mergers and one—most recently—from merging neutron stars. This neutron star merger was also observed by astronomers around the world, creating "what we now call multi-messenger astronomy," says Barish. It also solved a mystery: "It was

KAVLI continued on page 7

Revised 4/18/18

Spotlight on Development

The Millie Dresselhaus Fund

APS is pleased to announce the establishment of the *Millie Dresselhaus Fund for Science and Society* to honor the remarkable scientific career and inspiring community legacy of Mildred S. Dresselhaus. A campaign has been launched to endow this fund and we invite you to consider supporting this effort.

Mildred S. Dresselhaus

Millie, as she was known to everyone, made important contributions to science through her research on carbon, semimetals, and nanomaterials and other nanostructural systems. Her contributions have won significant accolades in and of themselves—but more than this, she was an inspiration and mentor to many young women and men as they developed into scientists and engineers.

The Millie Dresselhaus Fund for Science and Society will reflect the areas in which Millie excelled and left her mark. The goal is to raise a $600,000 endowment to support activities in the areas of science and society to honor her remarkable scientific career and inspiring legacy. This initiative is unlike any other at APS—not only will it recognize scientific contributions of one or two recipients per year, but its reach and impact will benefit thousands of aspiring women physicists each year. The Fund will support the following activities:

Science: $300,000 will fund awards to individuals who have excelled in science and who have made significant contributions to nanoscience and nanomaterials—areas pioneered by Millie. This APS prize will provide an annual $10,000 stipend, travel to an APS national meeting, and a certificate.

Society: $300,000 will be used to endow a named keynote address to be delivered to the more than 1,900 young women who attend Conferences for Undergraduate Women in Physics (CUWiP) each year. The fund will also provide travel grants for undergraduate women who lack sufficient resources to attend these conferences. In addition, there will be an "action fund" to provide minigrants to local Women-in-Physics groups throughout the country, to enable them to conduct activities aimed at encouraging young women to obtain a physics degree.

The APS Development Office, in partnership with the Executive Committees of the APS Divisions of Material Physics (DMP) and Condensed Matter Physics (DCMP), is currently recruiting volunteers to serve on the Millie Dresselhaus Fund Fundraising Committee. The objective of the Committee will be to identify and solicit major gift commitments that will help raise 60%-80% of the goal. This will position APS to launch the Campaign, and successfully raise the balance from the membership of DMP, DCMP and related units, as well as the broader physics community.

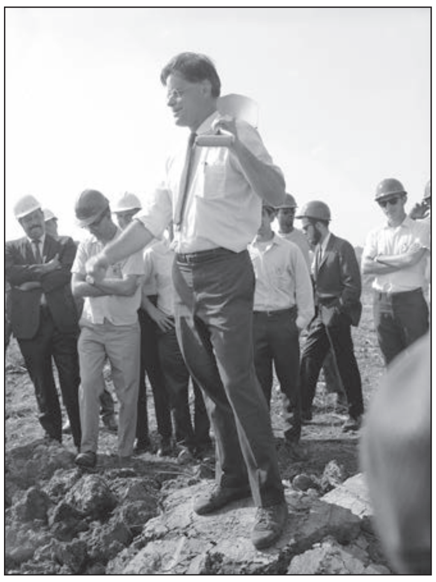
Gifts of any amount will be greatly appreciated and recognized on the Dresselhaus campaign website (go.aps.org/2G82o5C). For more information on ways to support *The Millie Dresselhaus Fund for Science and Society*, please contact Irene I. Lukoff, APS Director of Development at lukoff@aps.org or 301-209-3224.

This Month in Physics History

April 17, 1969: Robert R. Wilson's Congressional Testimony on Founding Fermilab

Over the last five decades or so, Fermilab scientists have made some of the most fundamental discoveries in particle physics, garnering numerous Nobel Prizes along the way. But the facility may never have been built had a handful of physicists—chief among them the lab's first director, Robert R. Wilson—not convinced the U.S. Congress of the project's value.

Born in Frontier, Wyoming, in 1914, Wilson had a lifelong love of the great outdoors, regaling physics colleagues with tales of his life as a cowboy in the Wild West. ("Most of them turned out to be true," physicist Dale Corson told the *New York Times* for Wilson's obituary in 2000.) He also had a mechanical bent, tinkering with pumps and vacuum tubes. As a physicist he naturally gravitated towards the fundamental building blocks of nature. At the time, "we only had electrons and protons, and you could put those together into atoms in various ways and make the whole universe," he recalled. "It was a very simple theory that even a dope could understand. I decided then that I wanted to go into physics."



Robert R. Wilson

By 1932 he was working in Ernest O. Lawrence's flagship cyclotron laboratory (a.k.a., the "Rad Lab") at the University of California, Berkeley and received his Ph.D. in 1940. He was infamously fired twice: once for losing a rubber seal right before a presentation to a potential donor, and once for accidentally melting a pair of pliers while welding. The lab still offered him his job back, but after his second firing, he decided to move to Princeton University instead. He left Princeton when J. Robert Oppenheimer invited him to join the then-fledgling Manhattan Project. Despite initial reluctance, he wound up being the youngest group leader in the experimental division when Enrico Fermi persuaded him to head the Cyclotron Group—by promising to meet with Wilson every week to talk about physics. "Sure, I sold out," Wilson later said. "Everyone has his price, and mine was a few moments each week with Fermi."

The sculpture "Broken Symmetry" at Fermilab

Wilson was among those who witnessed the Trinity Test, from a bunker 10,000 yards north of Ground Zero. Noticing that part of the mushroom cloud of radioactive debris had peeled off and was heading for the bunker, he ordered everyone in it, including soldiers—"using a vocabulary everyone could understand"—into trucks for evacuation. "As we left, that cloud of radioactive debris was right on top of us and it was spooky," he recalled. "We were lucky though. About 25 miles later it came down on a bunch of cattle and turned their hair white."

After the war ended, Wilson moved to the Laboratory of Nuclear Studies at Cornell and designed accelerators. On April 19, 1969, Wilson was among a number of scientists who testified in Washington, DC before the Joint Committee on Atomic Energy concerning a proposed multimillion-dollar particle accelerator to be built in Batavia, Illinois. Despite the key role physicists played in ending World War II, some members of Congress were skeptical of paying a hefty price tag for a machine that did not seem to directly benefit the U.S. national interest.

During Wilson's testimony, then-senator John Pastore bluntly asked, "Is there anything connected with the hopes of this accelerator that in any way involves the security of the country?"

"No, sir, I don't believe so," Wilson replied.

"It has no value in that respect?"

"It has only to do with the respect with which we regard one another, the dignity of man, our love of culture. It has to do with: Are we good painters, good sculptors, great poets? I mean all the things we really venerate in our country and are patriotic about. It has nothing to do directly with defending our country except to make it worth defending."

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Letters to the editor are welcomed from the membership. Letters must be signed and should include an address and daytime telephone number. APS reserves the right to select and to edit for length and clarity. All correspondence regarding *APS News* should be directed to: Editor, APS News, One Physics Ellipse, College Park, MD 20740-3844, Email: letters@aps.org.

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Education & Diversity Update

Nearly 100 physicists gathered February 9–10 for the annual conference of the Physics Teacher Education Coalition (phystec.org/conferences/2018/) to network and learn more about preparing future physics teachers. Several of them stayed for the next two days (February 10 & 11) for the triennial Building Thriving Undergraduate Physics Programs workshop (phystec.org/conferences/thriving18/index.cfm), where more than 100 faculty developed strategies to strengthen their undergraduate physics programs.

To help institutions prepare future physics teachers, the PhysTEC project has released a new rubric for characterizing teacher preparation programs in order to help faculty identify how their programs can grow and improve. The Physics Teacher Education Program Analysis Rubric (phystec.org/thriving/), along with its user-friendly supporting materials, can help program leaders emulate the thriving programs.

The Hunt For the Elusive Majorana Qubit

By Sophia Chen

2018 APS March Meeting, Los Angeles—It's a tale oft told in physics: researchers are, yet again, excited about a phenomenon that may or may not exist. This time, it's Majorana fermions—weird objects that act as their own antiparticles. Some condensed matter physicists think they've seen these elusive beasts, but others aren't so sure. Either way, Microsoft has put out a bounty for the Majoranas and hopes one day to harness them for quantum computing.

While particle physicists also study a version of the Majorana fermion (neutrinos might be of this ilk), the ones of interest to quantum computing are quasiparticles—many electrons acting collectively in materials to mimic particles. In 2012, researchers at the Delft University of Technology in the Netherlands first reported experimental evidence of the quasiparticle in a semiconductor nanowire attached to a superconductor. Subsequent measurements by several other research groups also match theoretical predictions, although it is still possible that the signals could come from some other interaction in the nanowire.

Because of these tantalizing experimental results, researchers think that someone will conclusively nail down the quasiparticle soon. "It looks like a dog, and it walks like a dog," says Mihir Pendharkar, a Microsoft-funded graduate student at the University of California, Santa Barbara (UCSB), who presented his research at the 2018 March Meeting. But still, he adds, it might not be a dog.

Quantum computing researchers want to use a specific kind of Majorana fermion, known as a Majorana zero mode, as a qubit. "In classical terms, a Majorana zero mode is like half an electron," says Pendharkar. Theory, along with supporting experiments, suggests that these half-electron quasiparticles can exist at the ends of one-dimensional semiconducting wires that are attached to a superconductor.

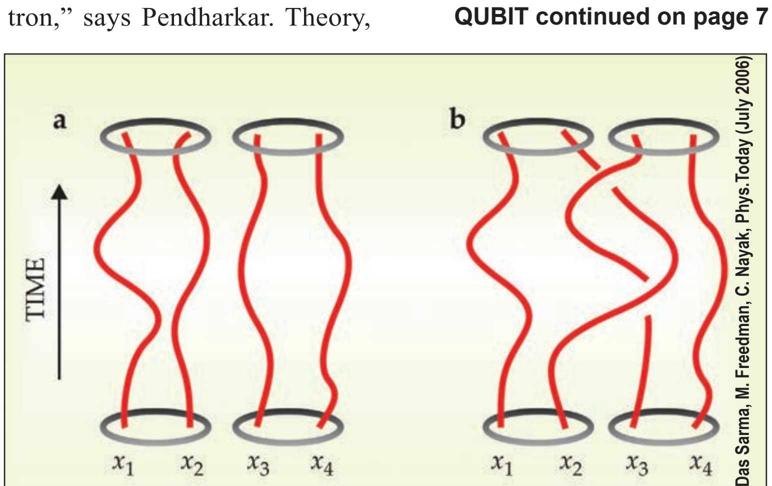
One predicted property of these quasiparticles is that they have a "memory" of how they've been moved around. For example, if you swap two quasiparticles' positions on a nanowire, "they would remember whether they had been moved clockwise or counterclockwise around each other," says Pendharkar.

You can store information in a pair of quasiparticles by exploiting this property, says Christina Knapp, a graduate student at UCSB who also presented in the same session. For example, in a simplistic encoding scheme, moving one quasiparticle clockwise with respect to the other could correspond to a 1, while moving counterclockwise could correspond to a 0. To read out the qubit, in principle, you would collide the two half-electron quasiparticles together on the nanowire and measure the outcome, which would yield a different signal depending on whether they were in a 0, 1, or a superposition state.

Researchers predict that these quasiparticles will be more robust at holding information than the qubits that Google and IBM are currently building. The latter are error-prone because of "local" noise, such as ambient electromagnetic fields. Consequently, thousands of superconducting qubits are required to lower the error rate enough to perform a logical operation. Google, the current record-holder, has put only 72 of these qubits together. This constrains researchers to design algorithms that are still useful despite inevitable errors.

Unlike Google's computer,

QUBIT continued on page 7



Trajectories of Majorana quasiparticles can be arranged to be topologically distinct and might form the basis for robust qubits in quantum computing.

Q&A with Danielle Bassett on the Physics of Brains

By Sophia Chen

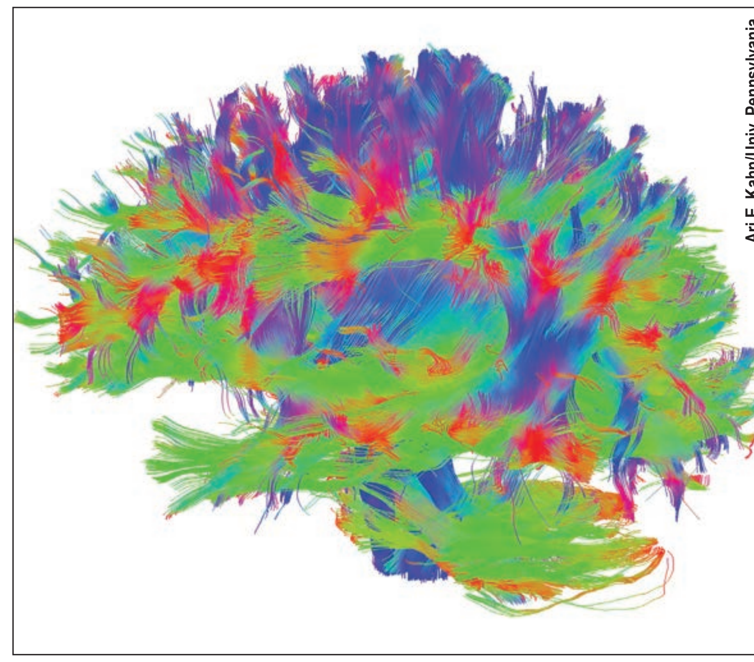
2018 APS March Meeting, Los Angeles—Human thought is capable of beauty and baseness, boredom and inspiration. And your brain, that creased chunk of meat in your head, produces all of it.

But how? What, physically, is thought?

Researchers are still a long way from answering that question. But Danielle Bassett, a physicist at the University of Pennsylvania, is developing tools that could eventually link the qualitative ideas of psychology to measurable signals in the brain.

Bassett, the animated recipient of a 2014 MacArthur Foundation Fellowship, uses the mathematical framework of network theory to study how different parts of the brain share information. With a team of neuroscientists, doctors, and engineers, she studies human brains with a magnetic resonance imaging scanner as the subjects complete cognitive tests—including one similar to the video game Guitar Hero. Then, she converts the data into an interconnected map that could easily also describe the interactions between friends on a social media website. Bassett and her colleagues look for patterns in the maps.

They've analyzed brain maps of schizophrenia patients, eight-year-old kids, and of course, University of Pennsylvania undergrads. She spoke with *APS News* following her invited talk at the 2018 APS March Meeting in Los Angeles.



The brain houses an intricate wiring network that serves as an information transmission highway system.

How long has this field been around?

I would say it really took off around 2010. The first paper technically came out 14 years ago, but it was sort of a trickle initially. My first paper in the field was in 2006. The first textbook, *Brain Network Analysis*, came out in 2016, and the first journal, *Network Neuroscience*, was [published] in 2016 as well. I still feel it's quite new.

How do you divide the brain into nodes in a network?

There are actually very strict boundaries between different sectors of the brain, and these broad anatomical boundaries are very consistent across humans. Different types of neurons exist in each spot, or different patterns of connections between neurons exist in each spot. So there's something different about the material in different parts of the brain. We study the entire brain and divide it up into about 200 pieces, and we look at the connections from one piece to another.

In your talk, you said that you classify these connections in two different categories. Can you explain?

One type is called a structural edge, where the neurons are structurally connected. In your brain, all neurons have a long tail called an axon, and these tend to line up together. When you have thousands of these tails lining up, you get something called a tract. We count how many of these tracts go from one piece of the brain to another piece.

The other type of connection is called a functional edge. Here, instead of asking whether two things are structurally connected, we're asking if they are sharing information with one another. So we measure the level of activity over time in two pieces of the brain and compare how similar they are. You can use something super simple, like calculating if they are linearly related to each other, or you can compare their spectra, or do other things that estimate causal relations. These relations are probably supported by structure, but you don't need to know the structure to estimate the relationship.

We measure these connections using a type of imaging called diffusion MRI, which basically tracks water molecules in the brain. Water molecules are constantly bouncing around in the brain, but they're constrained by these tracts. Either they're bouncing inside one of these tubes, or against it.

So you study how these networks change while someone is in the scanner.

We measure something called network flexibility, which is how these functional connections change in time. We also look at something called network control, which is how the structural connections change in time. We take data every thirty seconds for about an hour.

Also, the pattern of connection is not very consistent across humans, which is really interesting. The differences have been connected to everything from your IQ to your personality. There's a recent paper that showed that the pattern is sort of a fingerprint of you. It's different from anyone else's.

How noisy is your data?

The common sources of noise are actually cardiac or respiratory artifacts that cause the blood flow to change in your brain. Also motion—our biggest source of noise is a person moving in the scanner. We try to tell them to stay still. It actually complicates taking images with kids, because the younger they are, the more likely they're going to move.

You're interested in a psychological concept called "cognitive control," which is basically like self-control.

Cognitive control includes selecting and monitoring behavior, as well as attention and inhibition. It's really interesting because it's the most pervasively altered function in psychiatric disease, but we don't know why. You see it in people with autism, schizophrenia, bipolar disorder, major depression, and post-traumatic stress disorder. We want to know how much our measurements relate to cognitive control. Our results so far indicate that they are related, which is neat.

What kinds of technical limitations do you struggle against?

I'm really interested in human cognition because humans have capabilities that lots of animals don't—but that means we have to stick with imaging techniques that don't hurt the person. Right now, the imaging technique can only go down to about one cubic millimeter. Eventually, I would love to be able to go down to individual neurons. But it's really hard to identify where neurons are in the brain, even when you do it invasively. You certainly can't do it non-invasively.

Have you ever tested your own brain?

We do have a couple scans where I really needed preliminary data for a grant.

This interview has been edited and condensed for clarity.

Sophia Chen is a freelance writer based in Tucson, Arizona.

Letters

Members may submit letters to letters@aps.org. APS reserves the right to select letters and edit for length and clarity.

AIP and *The Physical Review*

APS is celebrating the 125th anniversary of the founding of *The Physical Review* with a number of publications and program events. Roberto Lalli's article (*APS News*, February 2018) on the early history of the journal, however, omits an influential series of events set in motion by the 1929 stock market crash that had significant impact on the fortunes of the APS journals and many other American physics journals.

In 1929 APS formed a "Committee on Applied Physics," initially to look at the role of industrial physicists and their participation in APS programs and meetings. The effects of the Great Depression on scholarly journals soon became a pressing committee topic. The Committee invited The Optical Society and the Acoustic Society of America to collaborate on addressing these economic challenges. Together with the American Association of Physics Teachers and the Society of Rheology, they formed the American Institute of Physics (AIP) in 1931 to consolidate their publishing operations. (AIP was largely financed by the Chemical Foundation until the new organization became self-sufficient. I encourage my fellow APS members to thank our chemistry colleagues for their community's role in our history.)

Lalli points out that *The Physical Review* editor at the time, Jack Tate, instituted voluntary page charges and page reductions to combat the significant budget pressures on the journal. This is true, but the economies of scale generated by the joint publishing operations of AIP had significant positive impact on publishing as well. This fascinating story is recounted by Henry Barton, AIP's first director, in the January 1956 issue of *Physics Today* [1] and in Tom Scheiding's article [2] published in 2013.

AIP served as the publisher of APS journals up until 2004 when APS began to manage its own publishing operations. APS and AIP continue to partner on scholarly publishing industry initiatives, such as co-founding the non-profit CHORUS in 2014 to provide public access to publications describing publicly funded research.

AIP now manages a $25M annual portfolio of outreach services on behalf of all 120,000 members of AIP's ten Member Societies. These programs include the Society of Physics Students, the Statistical Research Center's education and work force studies, the Center for History of Physics, the Niels Bohr Library & Archives, and publications such as *Physics Today,* the *GradSchoolShopper*, *FYI* science policy news, and *Inside Science* for science literacy.

APS initiated the formation of AIP when APS leadership was deeply concerned about our community's ability to disseminate research findings. Future challenges facing science can be addressed more effectively by societies working together. The lesson from our history in the 1930s validates this collaborative approach.

1. Barton,H. A. 1956. The story of the American Institute of Physics, *Physics Today* 9, 1, 56-66.
2. Scheiding, T. 2013. Building the scholarly infrastructure in physics in interwar America, *Studies in History and Philosophy of Modern Physics* 44, 450-463.

H. Frederick Dylla
Lewes, Delaware

The author was the Executive Director and CEO of AIP from 2007-2015, and currently serves on the Board of CHORUS as AIP Publishing's representative.

Silent Sky Sparks Discussion of Women in Physics

By Amanda Babcock

2018 APS March Meeting, Los Angeles—A popular event at nearly every March Meeting is the staged reading of a physics-oriented play. This year's selection was Lauren Gunderson's *Silent Sky*, which dramatizes the life of Henrietta Swan Leavitt from the beginning of her time at Harvard Observatory until her death. The cast from International City Theatre in Long Beach staged the production last year, and read the play at the March Meeting. *Silent Sky* captures the essence of being female and a scientist during a time when it was considered paradoxical to be both.

Tracey Roman

From left: Jennifer Parsons (Williamina), Leslie Stevens (Annie), Jennifer Cannon (Henrietta) and Eric Wentz (Peter) in International City Theatre's Silent Sky

In addition to Henrietta, her real life colleagues Williamina Fleming and Annie Jump Cannon play supportive and occasionally sassy roles. Fleming, a Scotswoman and former maid to observatory director Edward Pickering, is the original member of "Pickering's Harem," the casually sexist term used at the time for the women "computers" who analyzed photographic plates. Annie Jump Cannon, as Henrietta in the play points out, is known for the stellar spectra classification system she and Fleming worked to develop. Henrietta's star-struck reaction to meeting Cannon and Fleming is perhaps more fitting of a modern teen girl meeting her favorite pop star, but it gets the point across: these women should be respected.

The play opens with Henrietta arguing with fictional sister Margaret "Margie" Leavitt about taking the job at Harvard Observatory. She expresses her passion for astronomy and her need to understand "where we are" in the universe. Margie asserts she should be home with her family or starting one of her own. Her arguments reflect the attitudes of the time. Henrietta however is determined and eventually Margie relents and agrees to help her convince their father she should go.

The audience travels with Henrietta to Harvard and her first encounter with fictional astronomer Peter Shaw. It is his job to "make rounds" checking on the ladies' work and to orient the new computers to their positions. Shaw remarks in an offhand way that he considers the work tedious. An affronted Henrietta asks Shaw, "It's not—how best to make you uncomfortable—*passion*?"

"That's a bit excessive for physics," is Shaw's taken-aback reply.

Henrietta goes on to explain why passion is important. She points out that, unlike Shaw, she has had to work to earn her place every step of the way. Passion is the only way she can see to go after her dream. In a time when women did not become professionals, certainly did not become scientists, Henrietta's drive kept her on a path to becoming an astronomer. Her own passion is not misstated. An obituary for Leavitt published in *Popular Astronomy* in January 1922 describes her as unusually devoted to her work.

Shaw's character plays the dual

SILENT SKY continued on page 5

WILSON continued from page 2

Congress approved the funding, and Wilson took the lead on the design and construction of the facility. Under his guidance, the National Accelerator Laboratory (later renamed Fermilab) was completed on time and under budget. "No one was more aware of the technical subtlety of accelerators, no one more ingenious in practical designs, no one paid more attention to their aesthetic qualities," Wilson's former Cornell colleague Boyce McDaniel recalled. "He thought of accelerator builders as the contemporary equivalent of the builders of the great cathedrals in France and Italy."

It was aesthetics that drove Wilson to design Fermilab's main accelerator ring to be visible from the air, via a 20-foot-high berm running the entire length of the ring. Nor did he want the facility to look like a typically sterile government lab. So he restored part of the surrounding prairie, complete with a herd of bison. His own abstract sculptures—he studied sculpture in Italy during a 1961 sabbatical—are dotted all over the grounds, most notably "Broken Symmetry," an orange-and-black arch across one of the entrances.

Wilson is often called the "father of proton therapy," thanks to his 1946 paper on the radiological use of high-energy protons. The paper grew out of his wartime research into the effects of radiation damage on the human body; Wilson had been deeply affected by two Los Alamos scientists who died of acute radiation sickness after accidents while testing plutonium cores. For the treatment of cancer patients, most proton therapy facilities today follow the tenets and techniques he established.

Wilson suffered a stroke in 1999 and never fully recovered. He died on January 16, 2000, at the age of 85, and is buried at a 19th century cemetery on the Fermilab site.

Further Reading:

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Hoddeson, L. and Kolb, A. 2003. Vision to reality: from Robert R. Wilson's frontier to Leon Lederman's Fermilab, *Physics in Perspective* 5: 67-86.

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NSF continued from page 1

its Universe Division and manage a variety of current and planned space missions such as the *Spitzer Space Telescope* and the *James Webb Space Telescope*. Her work at NASA and a subsequent job at the W. M. Keck Observatory as chief scientist cemented her role in management, a field that combines her scientific background with her interest in policy. "I know how the federal budget works or doesn't work," she jokes.

Kinney is looking forward to helping to develop several "big ideas" for future NSF investments. One of these initiatives, Windows on the Universe: The Era of Multi-Messenger Astrophysics, is about combining different astronomical datasets—electromagnetic radiation, cosmic rays, neutrinos, and gravitational waves, for instance—to better understand the universe. Another initiative, Harnessing the Data Revolution, is focused on developing methods and infrastructure to effectively process, visualize, and store the enormous datasets that are now hallmarks of many fields of science.

Kinney also hopes to foster collaboration between NSF and other governmental agencies that fund basic research. "Different scientific agencies used to have 'an off-handed look' at each other," she says, "[but] I think that culture has really changed." NSF, NASA, and the Department of Energy are working together much more closely, Kinney notes. "That's a huge positive for science."

Leading the Mathematical and Physical Sciences Directorate is an enormous responsibility, Kinney admits. There's an "amazing history" of scientific results from NSF-funded research, says Kinney, and she's committed to continuing that tradition. "I will do my damnedest to make sure the very best science comes out of this institution."

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AI ASSIST continued from page 1

and are perfect for fast parallel computations.

In a machine learning algorithm, a neural network can be "trained" to recognize patterns: Show the algorithm as many photos of dogs and cats as possible, and it can learn to distinguish one animal from the other. In condensed matter physics, instead of sorting cats and dogs, you're sorting images of known electron configurations that are above and below some critical temperature, says Khatami.

Condensed matter physicists have only begun to use these artificial intelligence techniques in the past few years. Khatami was introduced to machine learning at the March Meeting just two years ago. "It was a Friday talk, and I had nothing better to do," Khatami told *APS News*. "I just dropped in, and I stepped out of the room completely fascinated by the idea of neural networks."

Khatami has since used neural networks to look for phase transitions in a 64-particle version of the Hubbard model, a quantum model of charged particles in a lattice. These particles—simplistic models of electrons—have spin and can move freely in the three-dimensional lattice. While still a simple model, it is complicated enough to predict certain phase transitions and difficult to simulate without supercomputers.

Based on the Hubbard model, Khatami produces a series of images, where each pixel represents a particle, and its color represents the particle spin direction. If all the spins are aligned, "the image is completely black or completely white," he says. But Hubbard model images usually aren't one color: Thanks to quantum noise, they ultimately resemble a poorly played game of Tetris.

Khatami trains the neural network with these images. Then he asks the algorithm to predict what the model will look like under a different set of conditions. His neural network predicts a type of spin ordering that is consistent with results found using a more traditional technique, he says.

Because the use of machine learning in condensed matter physics is so new, researchers are still doing proof-of-principle studies. "We've shown that we can reproduce results seen with other techniques with much less effort," says physicist Simon Trebst of the University of Cologne. Trebst, who presented an invited talk after Khatami, identified phase transitions in a system of several hundred fermions using a hybrid method that combines machine learning with a conventional numerical method, the Quantum Monte Carlo algorithm.

Machine learning could be useful in other areas of condensed matter research. Khatami thinks that experimentalists could use machine learning to look for patterns in electron microscopy or scanning tunneling microscopy images.

Trebst believes that combining machine learning with condensed matter experiments could help answer questions about the inner workings of the network itself. Right now, researchers know that the machine can find patterns, but they don't really understand how it finds them. Research suggests that some machine learning processes work like a mathematical technique used in both particle and condensed matter physics called "renormalization." This method systematically maps a microscopic picture onto a macroscopic one. Intuitions gained in condensed matter physics could help unlock how machines learn.

Machine predictions alone will not directly confirm new physics, says Trebst. The neural network is a mathematical algorithm only as good as the data it has been given, and the process it uses to identify and extrapolate patterns is still mysterious.

Instead, machine learning predictions can help guide condensed matter experiments that probe the interactions of hundreds, thousands, even 10^{23} electrons. These systems are difficult to simulate with normal computational methods, yielding approximate predictions that are difficult to test. Machine learning results can be used to help build consensus among these various predictions to steer the next steps. "These problems are so hard that any guidance is needed," says Trebst.

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International News

The Qatar Physics Society

By Ilham Y. Al-Qaradawi

In 2016, I had the honor of founding the first scientific society in Qatar, and one of the first societies focusing solely on physics in the Gulf region—the Qatar Physics Society (QPS). QPS was created with many goals in mind, but mainly to bring together physics professionals, students, and even those with merely an interest in the field, and offer events and programs to advance their knowledge, as well as enhance their skills.

As a fast-developing nation, Qatar's knowledge-based economy is a vital aspect of the country's plan for development. QPS has a role in this, by promoting scientific excellence, empowering members with knowledge of best practices and the latest news, and providing support and networking for physicists.

In the short time since the launch of QPS, the Society has made great strides towards its goals of promoting and advancing physics in Qatar and the region. In November 2017, QPS hosted the 9th International Conference on Isotopes in Doha, Qatar, for the first time in the Middle East region. The conference attracted 200 attendees from more than 30 countries around the globe, and this dynamic international environment allowed for a lively exchange and discussion of ideas in the isotopes field. The topics discussed ranged from the policy, economics, and global impact of isotope production and use, to isotopes in the environment; additionally, special panels were held, such as a plenary session to mark Marie Curie's 150^{th} birthday.

The QPS Particle Physics Masterclass

QPS organized its first high school event in 2018. The International Particle Physics Masterclass took place during the last week of February for the first time in Qatar. This event allowed high school students in Qatar to experience being a physicist for a day. The masterclass included hands-on experience for the students to discover the world of quarks and leptons with real data from CERN. The students analyzed live data from particle physics experiments. The students had the opportunity to unravel the mysteries of particle physics, as well as to gain insights about various areas and methods of basic research into the fundamentals of matter and forces, thus enabling students to perform measurements on real data from particle physics experiments themselves. In addition, the students were able to join a video conference to further discuss the results of the experiments with scientists at CERN and other groups of students in Helsinki, Brussels, Cyprus, and Trieste in Italy.

This exhilarating experience is one of many that the Qatar Physics Society (QPS) has planned for students, as well as teachers and physics professionals in Qatar. Events such as the Particle Physics Masterclass allow academics and non-academics alike to immerse themselves in the world of physics, which not only raises their awareness of the relevance of physics in our world today, but also expands their horizons.

The emergence of QPS plays a vital role in the educational as well as the scientific sectors in Qatar. These fields have been expanding both at the primary and higher education levels, from multiple American universities opening branch campuses in Qatar Foundation, to recently established STEM schools in Qatar. Education is now a priority in Qatar, as stated in the *Qatar National Vision of 2030* and the *Qatar National Research Strategy*, which both emphasize as well as highlight the importance of developing the aca-

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SILENT SKY continued from page 4

role of romantic interest and butt of the ladies' jokes throughout. His interactions with the women highlight the feminist themes of the play every time Fleming or Cannon poke fun at him. Was there a real romantic interest in Henrietta's life? Is it necessary to include one? Aside from the dramatic effect, Shaw seems out of place. Henrietta's work and accomplishments stand on their own.

The final scene of the play highlights a reality of the women computers. They performed complex calculations and recorded countless astronomical objects but were forbidden from touching the telescope. A brilliant flight of fancy sees the group breaking into the Harvard Observatory and Henrietta gazing through the telescope at her beloved stars.

Following the performance, physics professors Brian Schwartz from Brooklyn College and Smitha Vishveshwara from the University of Illinois at Champaign-Urbana moderated a discussion with the audience and the cast. The conversation centered on the use of art to convey science in popular culture. Though it was pointed out that the play takes liberties with some historical details, the cast explained their desire to represent the emotion and the personal drama of being a female scientist.

When asked if any of the cast members had taken an astronomy class prior to being cast in the play, two stated they had taken a freshman-level astronomy course but most had no exposure to the field. However, the play itself inspired the actors to research their characters, either the real people or similar historical figures of the time, and to draw on the details of their lives. Actress Jennifer Cannon (Henrietta Leavitt) noted Dava Sobel's *The Glass Universe* as an invaluable resource for understanding her character.

At one point the cast asked all the physicists in the room to raise their hands. The majority of the audience tentatively raised a hand to the delight of the cast. Jennifer Cannon declared, "We were so nervous!" Leslie Stevens (Annie Cannon) noted she had checked her notes on the Draper star catalog before the performance not wanting to accidentally misstate Cannon's achievements. This attention to detail is evident throughout, especially in the use of the photographic plate prop that effectively mimicked the real thing.

In the final monologue of the play, Henrietta somberly describes the historical events following her death. Among these include a detail from 1925 when she was sent a letter about a nomination for the Nobel Prize in Physics. Leavitt had died more than three years earlier and was no longer eligible. Historically, then-director of the observatory Harlow Shapley downplayed Henrietta's accomplishments.

Only much later were Leavitt, Fleming, and Cannon acknowledged for their groundbreaking work, relegated as they were to "the harem." Despite the lack of recognition in their lifetimes, their work has withstood the test of time. As Henrietta states and the cast members enthusiastically repeat, "The universe doesn't much care what we wear."

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demic attainment of students, particularly in math and science. Thus, QPS will help students explore the fields of math as well as science, and in particular physics, through this shared platform. This not only allows the students to increase their knowledge, but also ignites their curiosity about the field of physics and its relevance to our daily lives.

QPS aims to be the primary voice for physics in Qatar and the region, and so we work to promote and advance the knowledge of physics. QPS is changing the way physics is perceived through awareness campaigns, training, networking, exposure, and events. QPS involves physicists, students in schools and universities, physics and science educators, researchers, industry professionals working in areas related to physics, and decision-makers as well as the general public.

QPS aspires to engage in partnerships and collaborations with local and global scientific organizations and other physics societies worldwide for the benefit of humanity. To learn more about the Society, please visit the main website at QatarPhysics.org.

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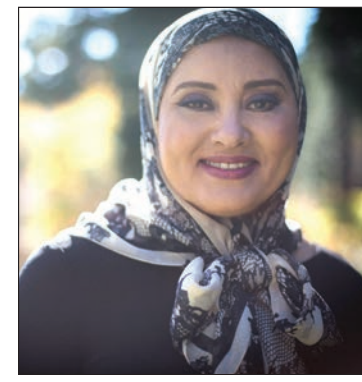

PRAB continued from page 1

by the APS Council in November 1997 and Robert H. Siemann of the Stanford Linear Accelerator Center, Stanford University, became the first editor. In 2016, the name was changed to *Physical Review Accelerators and Beams* to better integrate the journal into the *Physical Review* family.

The first *PRST-AB* article was published on 12 May 1998, and for more than a decade it was the fastest growing APS journal. At the same time, *PRST-AB* quickly became more international. At the start, 80% of the published articles originated in the Americas; this number decreased to 35% by 2017. Currently the European and Asian regions contribute 45% and 21%, respectively.

PRAB continues to be completely free of charge for both authors and readers. It is an arrangement called "diamond" open access, made possible through the generous support of its sponsors, who recognize the importance of publishing accelerator science and technology. Initially eight large U.S. national laboratories supported the journal financially. Since then many other laboratories and research institutions—in the Americas, in Europe, and more recently in Asia, especially Japan, Korea, and China, as well as various accelerator conference series—joined as sponsors. Two years ago, *PRAB* welcomed its first industrial sponsors—companies active in the fields of accelerator physics or accelerator technology. At present more than thirty-five institutes and six companies sponsor *PRAB*. A list of all sponsors is available at journals.aps.org/prab/sponsors.

With this support, day-to-day operations are coordinated by a Lead Editor, three Associate Editors, and a Journal Manager. The Editors are assisted by an Editorial Board—a valuable resource for discussions of policies and new initiatives. Board members also serve as referees in cases where there are contentions or questions on which the Editors need advice. These board members are well-respected accelerator scientists, who represent different research specialties, strike a balance between universities and large laboratories, and connect *PRAB* internationally. A list of present *PRAB* staff and Editorial Board members is posted at journals.aps.org/prab/staff#ed.

In a further innovation, the APS DPB and the European Physical Society Accelerators Group share responsibility for the health and vitality of the journal by advising on the membership of the Editorial Board, and by encouraging scholarly publication in accelerator science and technology.

In response to increasing interest and demand, as well as to better cover topics at the boundaries between disciplines, *PRAB* has recently introduced new dedicated topic sections (go.aps.org/2Gbs4dz). And like other APS journals, *PRAB* highlights important articles in the form of "Editors' Suggestions." A selected few have been covered by the APS commentary journal *Physics*. In addition, aesthetically attractive pictures, one per month, appear on the journal webpage with links to the corresponding articles.

Through special editions, invited contributions, articles related to the APS Robert R. Wilson Prize for Achievement in Accelerator Physics, editorial outreach, tutorials, and Editorial Board meetings during the International Particle Accelerator Conferences, *PRAB* has become an important "Community Organizer," thereby realizing one of the intentions of its founders. For the coming years, *PRAB* looks forward to further transforming scientific publication in the field of accelerators.

We welcome your feedback and suggestions (prab@aps.org).

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PRAB Lead Editor Frank Zimmermann is a Senior Scientist at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland, a Fellow of APS, and a Board Member of the Accelerator Group in the European Physical Society.

QUBIT continued from page 3

which stores information in a single localized object, a Majorana-based qubit would encode a single bit of information in multiple quasiparticles. According to theory, this type of quantum information should be much less likely to go bad. The quasiparticle still "remembers" whether it has been moved clockwise or counterclockwise with respect to its twin, even if you move it around on a nanowire. The information is also immune to local environmental noise.

The researchers liken these qubits to a knot on a shoestring, so that how the knot is tied indicates the information stored. "The knot doesn't really change if you tug at the part of the shoestring," says Knapp. "It doesn't care about little changes in the system."

To be clear, no one is tying physical knots in a nanowire—but you can mathematically visualize the timeline of these quasiparticles as you swap their positions as knots or braids. These knots are known as topologically protected states; hence, the proposed quantum computers built with Majorana fermions are known as topological quantum computers.

Theorists have already begun designing solid-state qubits using the hypothesized quasiparticle, although Pendharkar and his adviser, physicist Chris Palmstrøm of UCSB, say that it will likely be decades before anyone makes a topological qubit. "Right now, we don't even know if the fundamental thing actually exists," says Palmstrøm. To conclude once and for all that they've created Majorana zero modes, Pendharkar says, a research group must demonstrate that a pair of them yields the predicted properties when swapped.

However, Palmstrøm's group is already working to design a chip-based architecture for the expected qubits. They have designed a layered chip made primarily of indium-based materials containing sheets of electrons that interact only two-dimensionally. They can then etch those sheets into one-dimensional "wires" that they can couple to a superconductor to create the Majorana edge modes. Etching is a much more feasible—and scalable—manufacturing process than laying single nanowires in parallel, says Pendharkar.

Pendharkar and Palmstrøm are careful not to over-promise their device. After all, unlike Google, IBM, and Intel's quantum computers, theirs doesn't exist yet. "There are different bottlenecks for different technologies," says Palmstrøm. "We're at the bottleneck where we don't even know whether the technology works."

But other quantum computing architectures could hit a different bottleneck, Palmstrøm says: They'll be difficult to expand into the thousand and million qubit devices that will ultimately be broadly useful to society. Because a topological qubit doesn't need the same type of error correction as superconducting qubits, it should be easier to make a working thousand-qubit quantum computer out of topological qubits. A topological qubit should be a fundamentally better piece of hardware—they just have to figure out how to make it.

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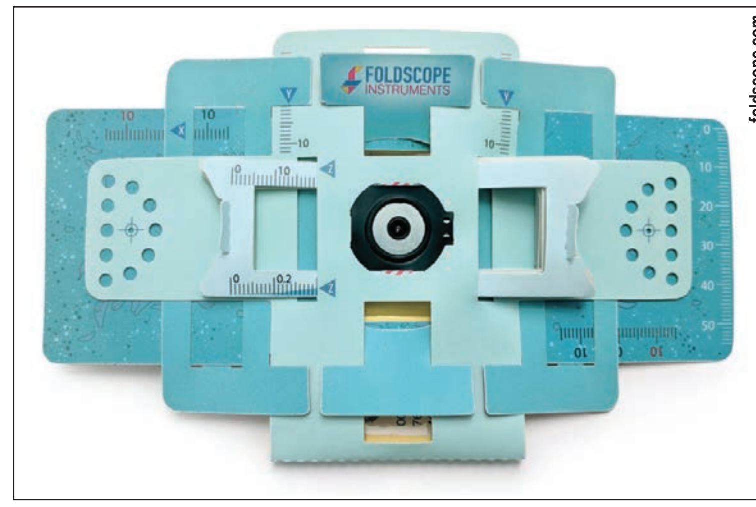
a puzzle forever where heavy elements like gold came from—but now we know they probably come from colliding neutron stars."

Like Barish, Zhang spoke on a breakthrough physicists have been chasing for decades: the discovery of the chiral Majorana fermion. Until recently, this particle that would act as its own antiparticle was pure conjecture, or as Zhang put it, "fictitious." Research at Stanford University using exotic materials resulted in the discovery that the Majorana fermion—first predicted by Ettore Majorana in 1937—exists. And its existence could be key to new breakthroughs in topological quantum computing.

Quantum computing is plagued by the instability of quantum bits, or qubits, which are easily perturbed, but the topological technique of quantum braiding (see illustration at the bottom of page 3) can create a more robust quantum computer. Chiral Majorana fermions may give way to a new quantum braiding technique: one qubit could be split into two Majorana fermions that would braid naturally as they move through space-time. "We are in an exciting moment," said Zhang. "Finally, I think topological quantum computing can be possible."

Schuller presented an alternative to quantum computing for the future: developing computers that work more like the human brain than machines. This idea of neuromorphic computers is fairly new and inspired by the potential end of rapid advances in traditional computation. If the limits of computing are reached, Schuller says there are three options: quantum computing, neuromorphic computing, or "just learning to live with this."

According to Schuller, the goal of neuromorphic computing is not to create a biological system, or recreate the human brain, but to learn from biology, much like airplanes were developed using the principles of flight observed in birds. The brain, for example, collocates memory and processing, bypassing a bottleneck in computing. It also functions with much lower energy consumption, a principle Schuller says may be used to complement current computational capabilities. As the global demand for computational power rises, more efficient power usage can help mitigate the energy consumption issue. As an emerging field, many fundamental questions exist surrounding neuromorphic computing which, according to Schuller, will require an interdisciplinary approach to seek out answers.



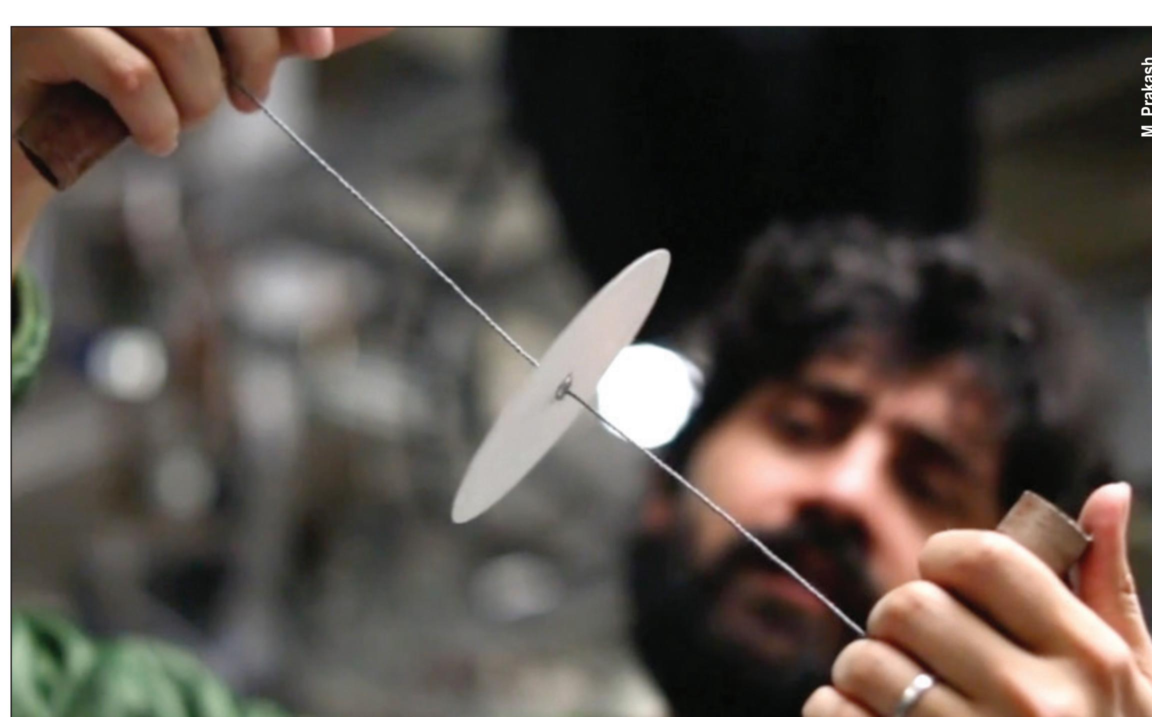
The Foldscope - an easy to assemble microscope.

Prakash moved the symposium away from the future of computing and transported the audience to areas of the world facing global health issues. Physics, as it turns out, can be applied to a number of practical problems such as disease diagnosis and global vector surveillance. Prakash shared his work in developing low-cost tools for "diagnostics under a tree," and making the experience of science accessible to communities across the globe. The Paperfuge and Foldscope, both produced in Prakash's lab, are examples of what he calls frugal science: a philosophy that inspires design of powerful scientific tools at an ultra-affordable price point.

At 20 cents a unit, the Paperfuge can be used in place of a centrifuge with just a few minutes of human power: modeled after classic spinning toys, the Paperfuge can reach 125,000 RPM and separate blood from plasma in less than two minutes. This low-cost tool, which replaces expensive centrifuges, can be used to diagnose anemia and malaria. The Foldscope is another inexpensive tool—costing about a dollar per unit—that can be used for both medical diagnostics and education. According to Prakash, the Foldscope has been deployed in over 130 countries. "The Foldscope has produced a massive global community engaged in curiosity-driven science," says Prakash.

Abo-Shaeer concluded the symposium with the story of his journey from struggling science student to founder of Dos Pueblos Engineering Academy. From his personal experiences, Abo-Shaeer has developed a charge for science academia: "It's time we begin thinking differently about how we measure talent," he says. Dos Pueblos Engineering Academy, which he founded in 2002, brings hands-on, project-based learning to high school students, abandoning traditional textbook-based physics courses. In the Academy's hands-on lab, students—50 percent of whom are female—have a chance to explore concepts of physics through experimentation and design, while gaining direct engineering experience.

As a college student, Abo-Shaeer's aptitude for physics and engineering was never fully realized in traditional courses, where he often felt out of place, working twice as hard as other students to achieve similar grades. Abo-Shaeer says he was "saved by the sun," after high marks on a solar-powered water heater transformed his college career and his feelings towards his own scientific skills. His mission at Dos Pueblos Engineering Academy is to bring similar experiences to his students, providing a space where any student can bloom into a scientist or engineer—and he asked that others do the same. "We need to work together to find an educational model in which every person can find their place in science, and contribute to the scientific community," says Abo-Shaeer.



Manu Prakash's centrifuge made from a spinning toy.

The Back Page

For SHE's a Jolly Good Fellow?

By Kerstin Nordstrom, Jacinta Conrad, Karen Daniels, and Jennifer Ross

In October, APS announced its 2017 Fellows. As mid-career women physicists who hope to one day be named Fellows, we despaired that several of our Units had no women Fellows in 2017. We asked each other: Was it a fluke? Was it true in other Units? For other underrepresented groups? We show that APS Units do award proportionally fewer Fellowships to women, and propose actions that we can take to work towards a less biased process for groups underrepresented in physics.

Our own Units were not unique: zero women were selected in 42 of 97 opportunities in the Units over the last three years. Small-number statistics are often faulted for a lack of representation of women: zero is a common outcome. And while regression to the mean yields symmetric distributions for large samples, small samples (such as Fellowship allocations) exhibit long-tailed, asymmetric distributions [1]. Accounting for the range of outcomes thus requires inspecting the *distributions* rather than the means.

For example, the Topical Group on Soft Matter (GSOFT) has about 23% women, and selected zero women for 5 Fellows slots in 2017 (Fig. 1a). In an unbiased selection [1], zero is a common outcome (27%). 73% of the time, however, there should be one or more women, with 33% of the outcomes corresponding to two or more women. Further, GSOFT has selected zero women several years in a row, which is statistically unlikely for repeated unbiased selections.

Because women are the largest underrepresented group within APS, constituting 14% of APS members in 2016 [2], a statistical analysis was possible. We hope that our findings spur similar analyses along other lines. For instance, we observed that Fellows with names of Chinese origin were also underrepresented.

We examined three years of data, excluding students and Fellows from our calculations. We include Divisions or Topical Groups, but not Forums [3]. For a given Unit and year, we compared the number of female Fellows to a null model: random sampling of the Unit population. We then analyzed each Unit's performance—over, under, or neutral— in selecting women (Fig. 1c), determined by median values and likelihoods generated by the model [4]. To be fair to Units with small allocations, we discuss only Units with five or more Fellow slots.

The ratio of under- to overperformance was 3:1 for Unit selections in 2017, prompting our concern. In contrast, 2015 and 2016 had roughly equal numbers of under- and overperformance. This makes the three-year total roughly equal, with a slight edge to underperformance.

While this may appear reassuring, we found other disturbing patterns in the data. Many (9 of 19) Units never overperformed in these three years. Half of the overperformance can be attributed to just three units—the Division of Astrophysics (DAP) [Fig. 1b], the Division of Physics of Beams (DPB), and the Division of Particles and Fields (DPF)—which overperformed in at least 2 of 3 years. In contrast, four units—the Division of Biophysics (DBIO), the Division of Nuclear Physics (DNP), the Division of Polymer Physics (DPOLY), and GSOFT—underperformed in at least 2 of 3 years. These include units with both higher (DBIO) and lower (DNP) percentages of women members: more women in the field does not necessarily lead to more or fewer women Fellows. Further, there appear to be overperformers who wash out the underperformers, but in an equitable system every Unit should strive to be fair to its own members.

Next, we compared distributions of selections of five and six Fellows across Units (2015-2017) to the null model for two scenarios (Fig. 1d,e) spanning best and worst-cases [5]. Although the small dataset is sensitive to noise, this exercise nonetheless reveals interesting features.

In selections of five Fellows (Fig. 1d), one data point corresponds to $N = 3$ women: the Topical Group on Magnetism (GMAG) 2016 selection. All other selections involve zero or one female Fellows; $N = 2$ is expected once or twice but does not appear. Based on GMAG's selection history and the estimated likelihood of the $N = 3$ selection, this may reflect a concerted effort to nominate women. Without this point, the data would show underrepresentation in the tail of the distribution ($N \geq 2$), and overrepresentation of $N = 1$.

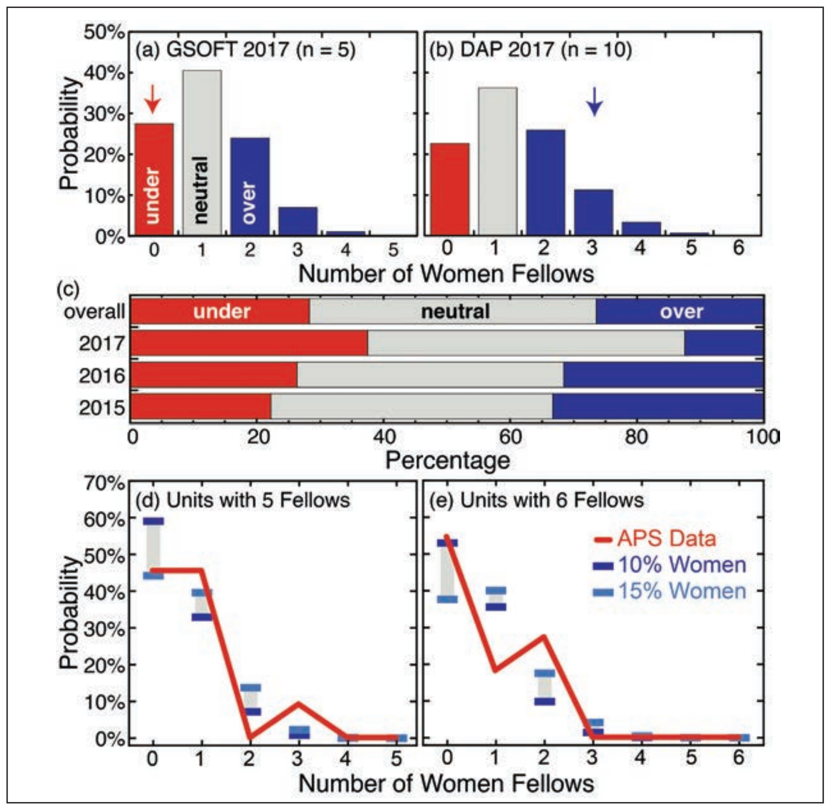


Figure 1: (a,b) Probability distributions of the number of women Fellows expected for (a) n = 5 selections from a population with 23% women (GSOFT 2017) and (b) n = 10 selections from a population with 13% women (DAP 2017). Arrows indicate the number of women Fellows selected by GSOFT and DAP in 2017. (c) Percentage of Units with at least five Fellow slots classified as under/over-performing. (d,e) Probability distributions of the number of women Fellows from each Unit with (d) five and (e) six Fellow slots. APS data (red) are compared to the expected number of women Fellows assuming the percentage of women members is 10% (dark blue) or 15% (light blue).

In selections of six Fellows (Fig. 1e), women are overrepresented at $N = 0$ and $N = 2$, underrepresented at $N = 1$, and $N = 3$ is expected to appear once in this sample but does not. This suggests that some Units may intentionally overcompensate, though this should not be viewed negatively: nominated candidates met qualifications for Fellowship, and APS has a mission to promote a diverse membership.

We conclude that, overall, there is a subtle but pervasive bias against women being selected as Fellows. Effort by one Unit may counteract the lack of effort of another, but does not fix the issue for women who aren't members of those Units. Through conversations with colleagues, we identified two types of biases at work:

Accumulation of individual biases: Units should both under- and over-perform, so why do we commonly observe underperformance? Nominators may not think of women or may not acknowledge their own potential for bias—no one is truly objective. Committees may stop after selecting one woman per year, without searching their networks for other qualified women. This might be surprising when mid-career women serve in the Unit leadership, indicating that high-level service [6] may not alone raise visibility.

Systemic biases: Cultural biases often lead women to be primary caregivers, and thus make career compromises such as reduced travel. This could make women less visible to their community, even with a strong publication record. Likewise, women may wait for the "right" year to apply for Fellowship: either willingly holding off to feel assured of success, or unwillingly, told to wait. Finally, support for women faculty often drops dramatically at mid-career [7], the key time for Fellowship nominations.

We therefore recommend actions by individuals, departments, Units, and APS elected leaders to counteract biases. These actions must be taken by allies to benefit members of underrepresented groups, as well as those at the intersection of different groups. This problem *cannot* be tackled only by underrepresented physicists, since it disproportionately adds to their workloads and would further contribute to the sense that they are outsiders.

Individual actions: Any active APS member can nominate! Sponsors should collect at least two letters of support from high-stature persons in the field who can compellingly champion the nominee's Fellowship. For those wishing to nominate a member for Fellowship, please visit go.aps.org/2IstEJF for guidelines. Potential Fellows must be APS members as of January 1 of the year prior to nomination; maintaining membership is important for those who wish to be considered.

Department actions: Departments should nominate their senior women for Fellowship. Many departments have awards committees to assemble nominations of mid-career faculty for Fellowship. Because departments are stakeholders in the success of their faculty, increased departmental involvement reduces the chance that less-visible nominees are overlooked. Ensuring that their senior women are recognized as Fellows sends a strong message that departments value and respect women.

Unit Fellowship Committee actions: Annually, each Fellowship Committee should discuss the APS guidelines for nominations, which advise on fair and rigorous practices. Committee members should not assume that they understand the requirements. Fair outcomes are more likely when guidelines are established prior to evaluation. One Committee member should be assigned to oversee the diversity aspects of the nomination process. This person should be respected, and should not necessarily be a member of an underrepresented group.

Unit leadership actions: Each Unit's leadership should view canvassing for candidates as part of its charge, yet Fellowship committees are often formed too late to contribute substantially. Early on, Unit leadership should act on carryover nominations and request a list of senior women physicists in the Unit who are not Fellows. Working from a list is less likely to amplify unconscious biases. Leaders should hold their Fellowship Committees accountable by training in best practices, examining the nominee list, and completing the final selection report required by APS. After the nomination season, each Unit should present the statistics of nominees to their members and Executive Committee. Units should manage the turnover in committee membership because a rotating chair may not have a chance to promote cases from prior years, and a junior chair may have difficulty in requiring actions by senior Fellows.

APS actions: APS leadership has a responsibility to act, and APS staff have been working to improve the diversity of nominees and recipients. Much effort has concentrated on junior members, rather than those who are post-tenure. APS should publicize summary statistics to help Units gauge their performance. The APS Committee on Fellowship could consider additional slots for Units that perform well by metrics like ours. Indeed, APS previously offered an additional Fellow slot to Units that put forward international candidates. We propose a similar mechanism to encourage women and minority Fellows.

The APS Council recently reduced the number of Fellow slots because previous allocations were based on the total membership (now almost 40% students). This will further strain the selection process and may be a reason that fewer women were 2017 Fellows. Taking the actions we recommend will help prevent underrepresented groups from being further marginalized. We hope that this will energize physicists at all levels to combat bias and recognize excellence through Fellowship across a diverse membership.

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References

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3. Forums account for only 10% of Fellows and are too different from Divisions and Groups to apply our analysis, though their gender breakdown is even more skewed against women.
4. For methodological details visit: tinyurl.com/apsfellows
5. go.aps.org/2HwgMRG. Women received 10% and 15% of PhDs in 1990 and 2003 (a rough approximation of a "mid-career" range).
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