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APS physics

APS Joins March for Science
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Highly Selective, Interdisciplinary, and Open Access for All

By the PRX editors

PHYSICAL REVIEW X

Seven years ago, *Physical Review X* (PRX) was launched by APS as its first open-access journal to offer high quality coverage of all areas of pure, applied, and interdisciplinary physics. In journal years, PRX is a toddler compared to the 125-year history of the Physical Review family [1], but it is running steadily and confidently. Indeed, it has gained a strong reputation for reliable quality, topical inclusiveness, high impact, and global readership. What has PRX done that has worked? And where is it going from here?

From the very beginning, the PRX editorial team, supported by its founding Editorial Board, has carried on the tradition of the Physical Review family: publishing important experimental, theoretical, and computational physics papers of different varieties. Among these are important discoveries or breakthroughs; significant advances in the state of the art; in-depth explorations of possibly risky concepts; and not least, original, substantive research at the boundaries between physics subfields and between physics and other scientific disciplines [2]. PRX has embraced them all in the open-access format.

How does PRX put this tradition into daily practice? When the selectivity is as high as PRX's, the final editorial decision to accept or decline a paper does not just depend on the paper's technical validity, but *necessarily* involves evaluating its *potential* for making significant and broad impact down the road. Yet, we all know that there are no clear-cut metrics or algorithms for this task. What to do then?

Foremost, we draw again on the Physical Review family tradition: PRX is for scientists, by scientists who are our authors at times and also our referees at other times. We rely on the advice of our expert referees and of PRX's distinguished and diverse Editorial Board. When we decline a paper without external review, the decision is often made in consultation with either an appointed member of the Editorial Board or an expert chosen from the appropriate community. When papers are sent out for external review, we

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Plenty of Plenaries: From Feynman to LIGO

By Leah Poffenberger

2018 APS April Meeting, Columbus, Ohio—The Kavli Foundation Keynote Plenary Session theme this year was "A Feynman Century," and it kicked off with a talk on the life of Richard Feynman (1918-1988) given by an expert: his younger sister, Joan.

Joan Feynman, an accomplished astrophysicist despite her mother's belief that "women's brains can't do science," credited her brother Richard as being her first teacher—and her first employer, paying her four cents a week to be his research assistant in his homemade electronics lab when she was five years old. She would go on to have a long career at the Jet Propulsion Laboratory and in the leadership of the American Geophysical Union (AGU), where she ensured women would be welcome at all AGU meetings. Feynman talked about her own research on climate change that tracked the importance of climate stabilization in the development of agriculture.

She concluded her talk with a remembrance of her brother's final moments after a ten-year battle with cancer. "Richard's last message to the world was 'this dying is boring, I wouldn't want to do it again,'" said Feynman. "He died with a sense of humor and telling the truth."

Christopher Monroe (University of Maryland) followed with a reflection on Richard Feynman's contributions to the field of quantum computing. "Feynman's work has weaved its way through the field of quantum information and computing," said Monroe. Feynman was one of the first to recognize a "completely new opportunity for design" in predicting the advent of nanotechnology.

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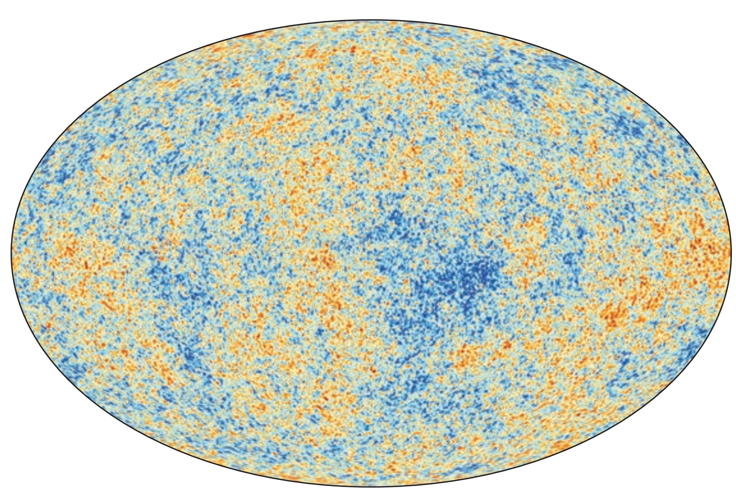
Hubble Trouble: A Crisis in Cosmology?

By Sophia Chen



Planck Collaboration

Analysis of the cosmic microwave background from the Planck satellite—one way to measure the Hubble constant

2018 APS April Meeting, Columbus, Ohio—In 2013, the European Space Agency's Planck Observatory released a map of the cosmic microwave background (CMB)—with the highest resolution to date.

That's when the trouble started.

Applying the standard model of cosmology—the Lambda Cold Dark Matter (λCDM) model—researchers used the CMB map to calculate the Hubble constant, a number that describes how quickly the universe is expanding. But that number disagreed with calculations based on telescope observations of supernovae and pulsating stars. Today, various CMB calculations of the Hubble constant differ from stellar and supernovae versions by more than 5 percent, equivalent to about three standard deviations. To a smaller degree, the Hubble constant differs between different CMB observations, too.

Unfortunately, no one knows where the discrepancies come from. Researchers affiliated with Planck have even re-analyzed data taken by the Supernova H0 for the Equation of State (SH0ES) collaboration without success. "There's a lot of back and forth with people checking analyses and results and consistency," says Bradford Benson of the University of Chicago. In an April Meeting session titled "Crisis in Cosmology," researchers recapped the latest ideas for resolving the discrepancy.

It's "tempting," says Stephen Feeney of the Flatiron Institute, to think that some part of the standard model of cosmology is wrong. The model describes how the universe evolved since the Big Bang. Given an expansion rate and a specified amount of matter and energy both dark and bright, it tells you how to calculate the Hubble constant using the temperature fluctuations in the CMB—the speckles of hot and cold on the map, which correspond to expansions and contractions of matter in the early universe. By changing the model, you can make the Hubble constant value match the supernova and star-derived values.

For example, adjusting the number of neutrinos in the λCDM model can help get rid of the discrepancy. "Even though neutrinos are light particles, since there are so many of them, they can affect the evolution of the universe," says Benson, who works on CMB observations at the South Pole Telescope. Perhaps, he says, more neutrino species exist than are now known. But according to Feeney, it's hard to physically justify these changes.

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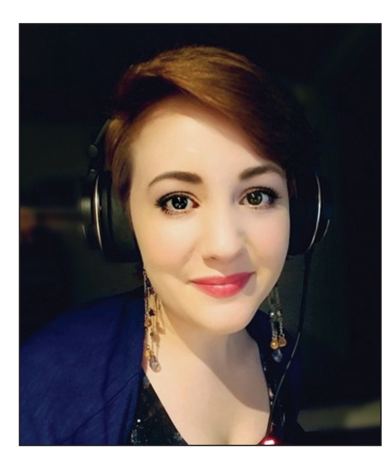
Profiles in Versatility

Removing Barriers in Science

By Alaina G. Levine

When Jesse Shanahan enters a conference venue, she doesn't just scroll through the scientific program for interesting talks and events. Her eye is focused on something bigger: the accessibility of the meeting for the entire scientific community. So where one might stroll into a hotel ballroom and sit down, Shanahan's gaze is fixed on gaps. Is there space for people who use wheelchairs? Are there enough benches throughout the venue for people to sit down? Are there quiet rooms for those who need a sensory break? Is the font on the nametags large enough to read without a scanning electron microscope? Do the nametags incorporate the person's preferred gender pronouns, as is starting to become the norm?

These are the questions that inspire Shanahan's work as an astrophysicist and accessibility consultant. Although early in her career and only 27 years old, she has already made a mark at the American Astronomical Society (AAS), where she co-founded the Working Group on Accessibility and Disability and currently serves on its Coordinating Committee. She currently does freelance accessibility and inclusion projects for AAS and schools and universities. For example, an instructor might want to know how to arrange a classroom and devise a curriculum to be more accessible and inclusive.



Jesse Shanahan

Shanahan's overarching goal is to remove barriers and "small reminders that 'this field isn't for you'," she says. And this mission is highly personal—as a graduate student in astronomy and physics, she faced hardship when she developed a disease that caused chronic pain and required her to use aids to walk. Suddenly, she couldn't access the observatory because she couldn't climb the stairs.

This was just one of several barriers she faced as she got used to living with her condition, and she noticed the lack of assistance, support, and resources for disabled scientists within the scientific enterprise. It lit a fire in her. "I am just really stubborn. If there is some kind of challenge, it makes me want it even more," she says. "I shouldn't have had to face those

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Revised 5/9/18

Programming a Quantum Computer

By Sophia Chen

2018 APS March Meeting, Los Angeles—Quantum computing could offer the world some new superpowers. But as the hype around the technology builds, some experts are trying to rein it in: discussing it in more practical terms, without invoking an abstract future with a quantum computer on every desk.

They are more upfront with caveats now. A quantum computer could break modern encryption methods—but only if it had millions of qubits. (The current record: 72 qubits, which Google announced during the meeting.) The hardware wranglers have steadily increased the number of qubits in a machine over the last two years—but quality matters more than quantity, and nobody has demonstrated how to correct qubit errors in an economically viable way. Even with these errors, they anticipate that these relatively few qubits will soon be able to execute an algorithm that a classical computer can't—a turning point called "quantum supremacy"—but the result will probably just be the solution to a useless, abstract math problem.

But nevertheless researchers are developing useful algorithms. At this year's March Meeting, several presenters described algorithms motivated by physics problems that could run on existing prototype computers at Google, Intel, and IBM. Many of these algorithms are simulations of well-studied quantum systems, but researchers could eventually extend computing techniques to study less-understood phenomena.

Sonika Johri of Intel is working on an algorithm for the company's 17-qubit quantum computer that simulates the so-called fractional quantum Hall effect. This effect occurs in two-dimensional electron gases under a strong magnetic field. The electrons in the gas behave collectively such that the ensemble appears to be composed of individual fractional charges, rather than whole electrons.

She aims to simulate a system where the ensemble appears to be composed of thirds of an electron, a phenomenon that has been indirectly observed in experiments. This state should be relatively insensitive to external noise, so it's a good candidate for quantum information storage. If Johri can make Intel's superconducting qubits mimic this state, it could potentially be used as quantum computer memory.

Jarrod McClean of Google is developing algorithms to run molecular simulations on a quantum computer. The computer would solve Schrödinger's equation for a molecule to calculate its allowed energy states. Or, simply put, "given where the nuclei are, how do I figure out where the electrons are going to be?" says McClean.

Quantum computers potentially offer the capability to simulate complicated molecules that classical computers can't. However, so far researchers have managed to tackle only small molecules with two to three atoms, which classical computers can still manage. The largest molecule modeled to date with a quantum computer is beryllium hydride (BeH_2), simulated on IBM's 7-qubit machine last September.

These simulations are reasonable near-term goals because the systems map naturally onto the quantum computing architecture. In McClean's simulations, for

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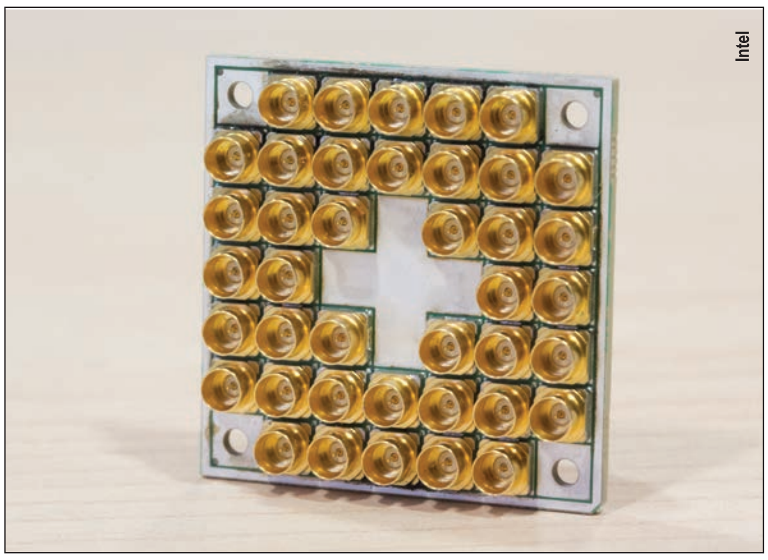


An Intel quantum computer prototype consisting of 17 qubits

This Month in Physics History

May 10, 1860: Discovery of Cesium

One of the best elements for atomic clocks is cesium, which was first discovered in 1860 by Robert Bunsen and Gustav Kirchhoff. However, it took another 20 years before another scientist successfully isolated the metal.

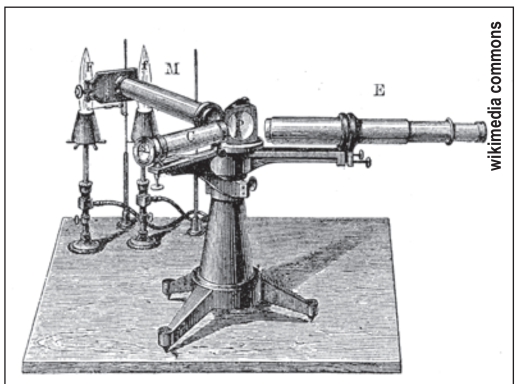
Born in Germany in 1811, Bunsen's father was a professor of modern languages at the University of Göttingen. Bunsen himself eventually earned his doctorate there. He spent the next three years traveling across Europe before becoming a lecturer at his alma mater. He held subsequent positions at the University of Marburg, Breslau (in Poland), and Heidelberg. Initially interested in organic chemistry, he lost an eye while working with an arsenic compound known as cacodyl cyanide, which exploded during an experiment. But his work did produce the most effective antidote for arsenic poisoning, iron oxide hydrate, which is still used today.

Bunsen is best known for his invention of the Bunsen burner in 1855 with his laboratory assistant Peter Desaga, a device which has been a staple in chemistry labs ever since. It proved instrumental to his studies of emission spectra from heated elements and arguably marked the beginning of spectroscopy as an invaluable tool in scientific research.

Kirchhoff was born in 1824 in Königsberg, Prussia (now Kalingrad) and moved to Berlin shortly after his marriage to the daughter of his mathematics professor. At just 26, he became a professor at the University of Breslau, where he first met Bunsen. Kirchhoff initially researched electrical circuits and thermal radiation; he coined the term "black body radiation" in 1862. (Kirchhoff's laws of electrical circuits and Kirchhoff's law of thermodynamics are both named in his honor.)

Bunsen convinced Kirchhoff to move to Heidelberg with him in 1854 so they could continue to collaborate on research proving that all pure elements emit a distinct spectrum. Scientists had previously observed what we now know as emission spectra in the 1750s, when Thomas Melvill noticed (while observing them with a prism) that the flames from lamps burning alcohol infused with dissolved salts emitted more yellow light than the rest of the light spectrum. Several years later, Andreas Sigismund Marggraf claimed he could tell the difference between sodium and potassium compounds via a similar method. Sodium produced more yellow flame, while potassium emitted violet flames.

Gustav Kirchoff and Robert Bunsen



Spectroscope used to detect spectral lines of elements in a flame

In 1822 John Herschel noticed emission spectra lines while passing light from different colors of flame through a prism, and four years later, photographer William Fox Talbot noted, "A glance at the prismatic spectrum of a flame may show it to contain substances which it would otherwise require a laborious chemical analysis to detect." Talbot later used it to distinguish between lithium and strontium compounds, both of which emit red flames, but with different spectra. But impurities in the samples available at the time made it difficult to prove, since multiple spectra would be produced simultaneously.

So there had never been a careful, systemic approach to such studies before Bunsen and Kirchhoff teamed up in 1859. Bunsen came up with the idea of using filters to block intense colors (like the yellow of sodium compounds), to better detect less intense colors of light emitted by other elements, such as the violet hues of potassium. Kirchhoff then suggested improving on this method by adapting the Herschel/Talbot method of passing the light through a prism. Together they devised an instrument based on this principle: the spectroscope.

On May 10, 1860, while analyzing the spectral emissions from spring waters known to be rich in lithium compounds, Bunsen spotted a new sky-blue signature in the spectra in addition to the expected light from sodium, lithium, and potassium. He and Kirchhoff realized it belonged to a new element, which he dubbed cesium (Latin for "sky blue"). It was just a trace amount, so he hired a chemical factory to isolate the cesium by evaporating 12,000 gallons of spring water. This gave him a large enough sample to determine its properties: an atomic mass of 128.4 (today we know it is 132.9). But despite his skill with the method, he failed to isolate pure metal-

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Making Room in Physics for Everyone

By Leah Poffenberger

2018 APS April Meeting, Columbus, Ohio—Creating a diverse and inclusive workplace is crucial to ensuring physics is explored by the brightest minds, regardless of gender, race, or LGBTQ (lesbian, gay, bisexual, transgender, or queer) identity.

The 2018 APS April Meeting offered several events and sessions on diversity, including a panel discussion on "Best Practices for Establishing a Diverse and Inclusive Workplace," sponsored by the APS Committee on Minorities. Each panelist lent unique perspectives and experiences to the questions that arise around creating a diverse and inclusive environment.

"Creating diversity is about getting people in the door, and inclusivity is about keeping people in the room," said Jesús Pando, a member of the Committee on Minorities who moderated the discussion. Pando was joined by Arlene Maclin, a distinguished black female physicist and Howard University professor; Ansel Neunzert, a transgender graduate student at the University of Michigan; and Willie Rockward, current president of the National Society of Black Physicists.

This diverse panel discussed many ways to improve inclusivity in physics academia, such as mentorship, faculty demographics reflecting student demographics, and re-evaluation of who gets to participate in science. Questions provided by Pando and the audience facilitated a lively three-hour session that gave voice to the experiences of underrepresented groups in physics.

"There's untapped potential in physics," said Rockward. "We need everybody to solve the big problems."

One of the ways to ensure talented individuals have the chance to work on these problems is mentorship, especially for students who may be from underrepresented groups. Often, the need for mentorship arises in commonplace circumstances, as in Neunzert's case on their first day teaching in front of a classroom after transitioning. "I didn't know what to wear," says Neunzert. "Someone giving me advice on what to wear or how to present myself would've gone a long way to making me feel more comfortable."

Maclin has experienced the impact of mentorship on student success from both sides of the

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lic cesium with electrolysis. The result was always a kind of blue "melt." This substance "neither under the naked eye nor under the microscope" showed any trace of metallic substance, so they decided it must be a chloride. (It was more likely a colloidal mix of the metal and cesium chloride.)

The following year, Bunsen and Kirchhoff observed the presence of yet another alkali metal with a dark red spectrum—hence its name, rubidium (from the Latin for "dark red"). And this time Bunsen did successfully isolate the element, making his inability to isolate cesium all the more frustrating. It was Swedish chemist Carl Theodor Setterberg who finally did so, using a mixture of cesium-based salts derived from waste material after extracting lithium from lepidolite ore. Still, Bunsen and Kirchhoff were the first recipients of the Davy Medal "for their researches and discoveries in spectrum analysis."

Bunsen retired from the university at 78 and spent his remaining years studying geology and mineralogy, dying ten years later in Heidelberg. As for Kirchhoff, he still collaborated with Bunsen, but he was far more interested in using emission spectra to study the night sky, identifying some 30 elements present in the Sun. He and Bunsen also explained certain dark lines in the solar spectrum (now known as Fraunhofer lines). Given his disability—he often used crutches or was confined to a wheelchair—over the years he found it increasingly difficult to conduct experiments, so he found himself gravitating toward more theoretical work, eventually accepting the chair of mathematics at the University of Berlin in 1875. Kirchhoff died in 1887 and is buried in Schoenberg, Berlin, just a few miles from the graves of the Brothers Grimm.

Further Reading:

Crew, H. 1899. Robert Wilhelm Bunsen. *The Astrophysical Journal* 10. 301-305.

Kirchhoff, G. and Bunsen, R. 1861. Chemische Analyse durch Spectralbeobachtungen. *Annalen der Physik und Chemie* 189. 337-381.

Weeks, M. E. 1932. The discovery of the elements, XIII: Some spectroscopic discoveries, *Journal of Chemical Education* 9. 1413-1434.

Correction

"This Month in Physics History" (*APS News*, April 2018) mistakenly stated that Fermilab scientists garnered "numerous Nobel prizes." In fact, the only Fermilab laureate is Leon Lederman, for his work with Melvin Schwartz at the University of Chicago. Regarding the same article: As much as the Editor would like to claim that the photo of the Fermilab sculpture "Broken Symmetry" was a subtle April Fool's Day joke, the joke was on him. His photo research turned up a beautiful image of the sculpture, but one that had been photoshopped to humorous effect. The correct photo is available at vms.fnal.gov/stillphotos/2008/0300/08-0325-01D.jpg

The Road to a Goldwater Scholarship

By Leah Poffenberger

Remarkable achievements rarely happen overnight—and becoming a Goldwater Scholar is certainly remarkable.

The Goldwater Scholarship is awarded each year to just over two hundred college sophomores and juniors at institutions across the United States. The scholarship, which was created in 1986 in honor of the late Arizona Senator Barry Goldwater, is considered one of the most prestigious scholarships available to undergraduate students studying natural science, engineering, or mathematics.

This year, 211 students—33 of whom are majoring in physics fields—were selected from more than 1200 applications based on their academic achievements and commitment to research. Along with the honor of becoming a Goldwater Scholar, winners will receive either a one- or two-year scholarship, depending on whether they are sophomores or juniors, of up to $7,500 per year. Scholarship recipients in physics were also awarded a one-year membership in APS. An additional 281 students received an Honorable Mention.

Even just becoming an applicant for the Goldwater Scholarship—let alone a winner or an honorable mention—is the mark of an exceptional student: To apply, a student must be nominated by a Goldwater Campus Representative. Scoring such a nomination requires students to participate in, or display interest in, meaningful scientific research.

The process of becoming a Goldwater Scholar is lengthy: It doesn't begin with the application, nor does it happen without help. Three 2018 Goldwater Scholars shared their path to the scholarship with *APS News* and reflected on the relationships that helped them get there.

Liam Lambert, a student at Roanoke College in Virginia, is no stranger to the Goldwater Scholarship: Last year, as a sophomore, he received an Honorable Mention. Since very few sophomores win the Goldwater Scholarship each year, Lambert was undeterred from applying again, this time with even better results.

The difference for Lambert this year wasn't just five more months of research experience between March (when Goldwater Scholars are announced) and September (when applications open). The key was figuring out how to best tell his research story, something several campus advisors helped him do.

Lambert's research experience at Roanoke began thanks to a professor he befriended who connected him with Rama Balasubramanian. Balasubramanian would become one of Lambert's research advisors, and she also serves as the Goldwater Scholarship Campus Representative for Roanoke College. She suggested Lambert should apply for the scholarship after his first semester of research.

"Liam is incredibly motivated to understand every aspect of his research and seeks to find answers, however big or small," says Balasubramanian. "I noticed this unique quality when he joined my lab in his first year. Now, he is a seasoned research student in our department, and I am confident he will make big strides in his future career. "

In this year's application essay—the three-page cornerstone of the Goldwater Scholarship application—Lambert focused on how his research has progressed. His first research project involved working with nanoparticles used to create carbon nanotubes, which developed into an engineering project that more fully lined up with his interests: building a device to measure the size of these nanoparticles.

"Never be afraid to tell a professor what type of research project you want to work on," says Lambert.

He also expects his research to continue evolving: Lambert intends to conduct research on microscopic flows of fluid over surfaces in the future.

"The research you do in college doesn't have to be what you want to do later," says Lambert. "It's just important to show an appreciation for research and all that comes with it."

Lambert attributes some of his success, both in research and in achieving the Goldwater Scholarship, to attending a smaller college, which has allowed him to develop one-on-one relationships with faculty. And he encourages other students to start this process early.

"If you're interested in research, get connected early," Lambert says. "You don't have to wait to start school—you can talk to professors about research during college visits."

Mika Sarkin Jain, a junior studying physics at Stanford University, has an impressive range of research interests, from soft matter physics to optics to fluid mechanics—especially where these physics fields intersect with biomedicine. He learned about the Goldwater Scholarship from an advisor he was speaking to about research funding who suggested he apply.

"That's a big part of this story: nothing happens in isolation," he says.

But Jain's journey to the Goldwater Scholarship began long before he started working on new diagnostic imaging techniques or mathematically modeling brain malformations.

"As a child, I asked a lot of questions—What are magnets? What is light? How does the human body work?" says Jain. "I guess I never outgrew these kinds of questions, and Stanford was the perfect place to ask them."

Jain's innate curiosity spurred him to seek out new ideas and research projects early on in his college career.

"I started reading papers and bringing research ideas to professors," says Jain. "I'm incredibly grateful to those professors, postdocs, and others who have made all of this possible."

When applying for the Goldwater Scholarship, students are asked to list one or more research mentors. Jain listed six, who he says all played a huge role in his research and in developing his goals outside of the classroom.

Jain offered two pieces of advice for students who would follow his path into research and science: form relationships with faculty, and take advantage of available non-science classes.

"My ideas haven't always come to me when I'm thinking about science," says Jain. "Fermenting different topics in my mind, like art and language, has sparked ideas

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challenges. If I really want something I don't care if something gets in the way, especially if I see those barriers should not exist in the first place."

Although she is passionate about ensuring access to science for all, she didn't start her career as an astrophysicist. In fact, she didn't emerge into science until well into her undergraduate years at the University of Virginia, where she at first wavered between majoring in physics, or linguistics and anthropology. She ultimately chose linguistics because the class sizes were smaller, something she was used to from her high school. But she didn't drop her love for physics and mathematics, and throughout her college years, served as a math tutor and explored the subjects on her own time.

Shanahan studied linguistics in Tunisia during the Arab Spring in 2011, but turned to physics. "I had always been dancing around physics and math, and I said why don't I see if this is something I like. So I picked up an astrobiology class and I was hooked." She was convinced that she had found her field.

While finishing her linguistics work, she popped her head into physics professors' offices during a conference at Rice University. "I can't believe people talked to me," she says. "I was this random linguistics student asking them about what can I do to make this switch." And while several people gave her a doomsday career scenario, David Alexander, a solar astrophysicist, spent an hour speaking with her. He put her in touch with people at George Mason University (GMU) near where she was based in Virginia, and soon after, Shanahan started doing volunteer research in GMU's department of astronomy. "I did the opposite of the conventional astronomy student," she notes with a chuckle. "I started out in research."

With the support of her faculty mentors at GMU, she was able to apply for and get accepted to a graduate astrophysics program at Wesleyan, which "was like a bridge program and designed for students like me who might not be competitive in other programs."

But it was while she was at Wesleyan that Shanahan found an especially important calling. She received a diagnosis of a genetic connective tissue disease. The disease and the treatments impacted her ability to move and suddenly she found herself facing barriers that she hadn't even realized existed. "I couldn't access the observatory without pain and trouble. With stairs, there was always a risk of a fall," she says. "At Wesleyan, there were varying layers of support and this was a whole level of obstacles I never realized. I didn't know my rights. I didn't know the barriers that people with disability face."

"My doctor told me the consistent high pressure, stress and lack of sleep was irreparably damaging my health. Eventually the demands of the program became so great I felt I had to choose between my health and career, and I chose my health," she explains. "Not every department is like this. But sometimes the nature of academia is that people who have these illnesses and disability often face these choices. I didn't know about this. I was not used to such severe consequences to my health. It started with survival and I didn't have a choice—it's either this or I give up and can't do my research."

Shanahan remained at Wesleyan for 2 years, but when she left she wasn't ready to give up astrophysics. But she sensed there were definitely others in the same situation and perhaps had it even worse. As a scholar and an observer, she was keen to uncover solutions. "I did use this [revelation] to motivate me. People with disabilities don't have a choice —I had to advocate for myself. The more I learned that this is endemic and widespread and systematic it lit my fire about how little work was being done here. I realized … then I wanted to keep fighting for it."

And fight she did. In 2015, she was serving on a panel on Inclusive Astronomy, an AAS-sponsored conference about how to tackle these issues. Meg Urry, professor of astronomy and physics at Yale, who was President of AAS at the time, reached out to Shanahan about organizing accessibility for an AAS conference.

While this experience pushed her towards accessibility consulting as a profession, she didn't give up on her dream of a being in astrophysics. Through networking, she found her way to Chris Lintott, a professor of astrophysics at the University of Oxford, who engaged Shanahan in a project called the Galaxy Zoo, which invited the public to help identify galaxies. "He was the one who said I don't have to make a choice between my health and career," she says. "I learned from him things can be different. Academia doesn't have to be this cutthroat environment. You don't have to let it affect or injure your health. It made me realize there is a way back in."

Since the beginning of 2017, Shanahan has been conducting research and pursuing data science projects for the Galaxy Zoo, and she also does freelance science writing, tutoring, outreach, and disability consulting work.

"In the last year I have realized there is a place for me in astrophysics," she says. "Prior to that, I thought it was a dream—like becoming an astronaut—that this was pretty impossible but I will keep trying anyway. But there is a place for me as an astronomer, and not just a disability activist with a disability. I have my ambition back and my drive back."

Shanahan is still early in her career and still thinking about what to do next. But she is certain that she wants to remain in science and expand her impact on both science and scientists. "Maybe it's not a Nobel Prize—maybe it's just getting the font changed on a nametag. … But that's far more meaningful to me than any research paper or publication," she says. "If I can make a change that is lasting and helps people then I consider myself successful."

Alaina Levine is Contributing Correspondent for APS News. *Full Disclosure: The author is a paid speaker for the AAS.*

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ask referees to back up their judgment with both technically rigorous and factual arguments and well-argued viewpoints or perspectives. We also listen to authors' substantive, meaningful rebuttals and may modify our views of their papers based on those. When the referees' opinions are conflicting, we try to communicate with them to resolve the conflict as much as possible before asking authors to address the disparate opinions or suggestions. And we build on our collective experience to moderate a collegial and productive dialogue between authors and reviewers.

We also recognize we must continuously deepen and expand our editorial competence, including our knowledge of physics and of the current research landscape. We survey the literature; we regularly discuss manuscripts together and use the distilled experience going forward. We go to conferences large and small to learn more and to talk to researchers about both science and the editorial process. We hope these efforts improve our choices of referees, our understanding of their reports and author replies, and our editorial judgment.

This integrated approach has drawn encouraging feedback. Authors have taken the trouble to let us know that our process has significantly improved their papers; referees have expressed their appreciation for our personal communications with them, not only about review processes, but also about the science involved. Perhaps even more gratifying, some authors whose papers were declined for publication in PRX have acknowledged the attention and care we have given to their papers.

Although PRX is now a confident top player in physics publishing, it still has room to grow, in quality, in topical coverage, and in reputation. We know we must continue to follow the fundamental principles that have guided our editorial work so far. We will also continue, and improve on, our established editorial practices. The foremost challenge will be to do so, as submissions continue to increase and the topical coverage continues to broaden, without compromising the quality of our editorial work and in turn, the quality of the journal.

To this end, we are working on improving editorial efficiency in our areas of strength and bolstering our coverage of new topics; we are continuously striving to improve our ability to distill and recognize signals for potential impact. Given the broad readership of our journal, we will also ask and assist authors to make their papers, especially highly technical ones, more informative, more engaging, and more readable for non-specialists by leveraging the no-length-limit feature of PRX articles and the journal's open access. With the same strong commitment to the journal as the founding Editorial Board, our recently renewed Board is fully engaged in guiding and supporting these editorial efforts.

Since May 2011, many of you from different communities in physics and even in other disciplines have sent PRX your outstanding papers, have served as our reliable and trusted advisers, and have encouraged us when we have done well and have also offered us constructive, sometimes thought-provoking, criticisms when we have made missteps. Without your constant support there would not have been PRX as it is today: Thank you!

We see PRX's mission as your mission: emphasizing scholarly quality, substance, and long-term impact to bring the scientific signal above the noise We count on your continued engagement in the joint endeavor to cement—in the best publishing traditions of the Physical Review family—PRX's reputation as a journal you are proud to publish in and you are eager to read.

1. Phys. Rev. X 8, 010001 (2018).
2. Phys. Rev. X 7, 010001 (2017).

The PRX Editors: M. Cristina Marchetti is the William R. Kenan, Jr. Professor and Distinguished Professor of Physics at Syracuse University in Syracuse, New York, and Jean-Michel Raimond is Professor of Physics at Sorbonne Université, Paris; they are the Lead Editors of PRX. Ling Miao has been Managing Editor of the journal since its founding. Dario Corradini, Victor Vakaryuk, Alessandro Villar, and Yiming Xu are Associate Editors.

APS Joins the March for Science

By Leah Poffenberger

In 2017, one million science supporters joined together in the March for Science, an unprecedented movement to stand up for science in public policy. This year, on April 14, science marched on at over 200 satellite locations.

Like last year, this year's main March for Science took place in Washington DC, drawing crowds of scientists and science enthusiasts, armed with eye-catching signs and a passion for science advocacy. More than 250 science organizations, including APS, joined the March for Science, helping to make the event possible.

APS and the Optical Society (OSA) partnered for an open house at the OSA headquarters in downtown DC the morning of the March to present a physics-demo pre-show that drew in a small but enthusiastic crowd. APS and OSA also joined forces for the March for Science teach-in program on the National Mall, hosting physics demos and an always popular talk on *The Physics of Superheroes* by Jim Kakalios.

"It's great to get out and meet local people who are excited about science," said Stephen Skolnick, a member of the APS outreach team. "It's great that they're seeing the need for scientific thinking in our daily lives."

The teach-in tent also pulled in people who hadn't planned on joining the March for Science: Attendees of concurrent events happening near the National Mall were intrigued by science demos. "We ended up doing outreach where it wasn't totally expected," said Skolnick. "We got to see wonder on kids' faces—that's what we're hoping to do."

James Kakalios entertains the March for Science crowd with a talk on the physics of superheroes.

In addition to the pre-march teach-in, the March for Science hosted a rally before the march began that included a variety of speakers, from Rush Holt, CEO of the American Association for the Advancement of Science, to 8-year-old Flint resident Mari Copeny, who talked about the contaminated water in her city.

This year's March drew a smaller turnout than last year, likely due to the high number of marches and events in the past year, but the fact that the March happened still had an effect. "A diminished number of people isn't a sign they don't care about science," said James Roche, APS outreach programs manager. "We just have to keep knocking on the door."

To continue voicing support for science, the week after the March for Science was a dedicated week of action to encourage March attendees to contact their representatives. "Even just leaving a message for a [member of Congress] can have a concrete effect," said Skolnick.

Education & Diversity Update

The 2018 APS Bridge Program & National Mentoring Community (NMC) Conference will focus on strengthening mentor relationships, building firm foundations to create a successful Bridge student experience, and providing knowledge through discussions. Registration will open Summer 2018. For more information please visit aps.org/programs/minorities/nmc/conference/

Become an NMC Mentor today! The NMC facilitates and supports mentoring relationships between African American, Hispanic American, and Native American undergraduate physics students and local physics mentors. You don't have to be mentoring anyone at the moment to register. If you're already mentoring a qualifying undergrad, invite them to join the program too. Membership in the NMC is free for both mentors and mentees. You can register at aps.org/programs/minorities/nmc/.

The NMC provides monthly talking points to facilitate a deeper mentor-mentee relationship, professional development opportunities, and access to an emergency fund (aps.org/programs/minorities/nmc/nmcbeam.cfm) for students with unexpected financial challenges.

Are you an industry physicist? Stay tuned. We will soon be launching the NMC Constellation Mentoring initiative for non-faculty physicists interested in being part of an undergraduate's journey to becoming a physicist.

PLENARIES continued from page 1

Monroe quoted Feynman on the use of quantum computers: "Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum, and by golly it's a wonderful problem because it doesn't look so easy." Monroe pointed out two quantum technologies that may finally be built into systems: superconducting circuits and trapped atomic ions. "There have been huge investments into these technologies," said Monroe. "People are starting to make bets here."

Feynman's legacy in quantum field theory was the focus of the talk by **Roxanne Springer** (Duke University). "Feynman's scientific method is now what we would consider a growth mindset," said Springer. "This is how we discover new physics and enable physics students to thrive." The core components of Feynman's scientific method included questioning authority and conventional wisdom; working out problems on his own to make sure he understood them; and finding joy that comes from meeting challenges in physics. At the end of Springer's talk, Joan Feynman added: "My brother didn't just question authority—he completely ignored it."

Nuclear Security, Pulsars, and Neutron Star Mergers

A second plenary session "From Nuclear Security to Neutron Star Mergers" featured three speakers, all women.

Njema Frazier (Department of Energy) spoke about "Physics and the Government: Navigating Science Policy and Nuclear Security," and emphasized the interconnectivity of science and natural security. Frazier noted the importance of basic research in nuclear science to better understand the behavior of the components of nuclear weapons. Such research contributes to long-term scientific understanding, new tools, and sustainability of "stockpile stewardship." The stockpile of nuclear expertise is also crucial to meeting the policy needs of the U.S., and Frazier spoke on DOE efforts to replenish a shrinking number of nuclear experts. "Bringing in a new workforce has been challenging," said Frazier. "But we're working with partners to look at the largest possible pool of talent."

Next, **Anne Archibald** (Netherlands Institute of Radio Astronomy) discussed a triple star system and its use for testing Einstein's general theory of relativity. The system has a unique configuration with a radio pulsar (a type of neutron star) and two white dwarf stars in tight orbits. Microsecond changes in the detected pulse rate enable the measurement of the orbital parameters. "Using this system, we have a test of general relativity that improves on all other tests," says Archibald.

Marcelle Soares-Santos (Brandeis University) described research on a neutron star system—perhaps one of the most famous pairs of neutron stars, whose collision was captured in August 2017 by the Laser Interferometer Gravitational-Wave Observatory, better known as LIGO. This discovery galvanized the astrophysics community as it opened up the field of multi-messenger astronomy. "This is the first neutron star merger that we have detected, and it has already delivered a lot on its promises," said Soares-Santos. An electromagnetic counterpart of these waves and bursts was located by several independent research teams. Once the source was located, it opened up observations at other wavelengths to better understand the neutron star merger.

Honoring excellence

The third plenary session offered a chance to hear from recent award winners in physics. **Eugene Parker,** who received the 2018 APS Medal for Exceptional Achievement in Research, spoke about the Sun's magnetic fields, a topic that is rich in research possibilities. Parker discussed what happens when strong opposing magnetic fields are pressed together, leading to the phenomenon of reconnection. This violent cutting and rejoining of magnetic field lines is thought to be the source of energy for events like solar flares. There are aspects of this, Parker indicated, that remain unsolved and will need numerical methods and supercomputers to tackle.

At the meeting, Nobel laureate **Rainer Weiss** (Massachusetts Institute of Technology) spoke on LIGO twice. The first event was a well-attended public lecture with an inquisitive audience. Weiss explained one of the first experiments to show that gravitational waves existed by analyzing the slowing of a pulsar many years before LIGO. "This research [conducted by Russell Hulse and Joseph Taylor Jr.] was really the first evidence of gravitational waves," says Weiss.

In his plenary talk, Weiss explained that before LIGO, other experiments, including one created by Joseph Weber, looked for gravitational waves, but LIGO was the first to reach a high enough sensitivity for direct detection. However, getting to this sensitivity was a challenge for LIGO that required contributions from many groups and continued support from the National Science Foundation.

Nobel winner **Barry Barish** (California Institute of Technology) discussed how LIGO later became Advanced LIGO after various upgrades, most importantly to combat vibrations at Earth's surface, thereby enabling detection of gravitational waves. Barish began working on LIGO in 1994, when the NSF funded construction of the LIGO Laboratory, which would be jointly operated by Caltech and MIT. In his time working with LIGO, Barish has overseen the improvement in LIGO's sensitivity. "The NSF was a tremendous hero in this," Barish said, acknowledging their continued support for an experiment that ran for 11 years without achieving the goal of gravitational wave detection.

LIGO continues to advance. "We're still a factor of two or three away from where Advanced LIGO can be," said Barish. An improved version of LIGO, while not yet funded, is known as A+ and could open up more possibilities in gravitational wave detection and allow LIGO to study more gravitational wave sources, even looking back into the very early universe.

Note: An expanded version of this article is available on aps.org/apsnews.

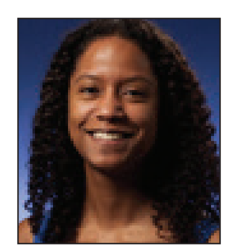

Joan Feynman


Christopher Monroe

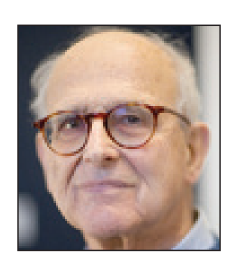

Roxanne Springer

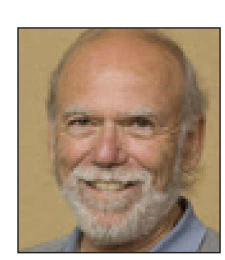

Njema Frazier


Anne Archibald


Marcelle Soares-Santos


Eugene Parker


Rainer Weiss


Barry Barish

QUANTUM continued on page 2

example, each qubit could represent a possible electron site in a lattice. If an electron occupies the site, for example, the qubit would read 1; if the site is vacant, 0; if the electron is partly there, partly not—then the qubit would be in a superposition of 1 and 0. The quantum computer would then apply a series of microwave pulses to the qubits to mimic the interactions between the molecule's constituent particles.

Algorithm developers like Johri and McClean don't usually interact directly with hardware. Instead, they work on theoretical proofs and protocols at different levels of abstraction. This might include estimating how long the computer will take to solve a problem, writing "pseudocode" (a sort of high-level model of a programming language that is not hardware-specific) or writing an actual sequence of operations performed by logic "gates" on the qubits.

For example, when developing a chemistry simulation, McClean has to translate Schrödinger's equation into a representation that maps onto the qubits. He also streamlines the gate sequences. "If you imagine physically laying out the qubits, one in the top right corner might not easily talk to the bottom left, depending on how they're set up," says McClean. "I try to compact these gate sequences so they're as short and efficient as possible."

Stephen Jordan of Microsoft presented work on algorithms for simulating quantum field theory on quantum computers. He and his collaborators designed pseudocode to simulate two simple quantum field theories: one that described purely bosons, and another that described purely fermions, and estimated how long different versions of the algorithm would take to run. One motivation for this work, Jordan says, is to simulate the entire Standard Model on a quantum computer, or to simulate a scattering experiment or collisions in a particle collider.

Although quantum computing companies are competing with each other, algorithm development culture is relatively open. McClean says that his group at Google behaves in a more "academic" fashion: for example, collaborating with researchers from both academia and other companies, McClean's group has recently released an open source library called OpenFermion for simulating quantum chemistry problems. Before Jordan joined Microsoft, for example, he made sure the company would let him still publish his research.

But the potential of these near-term algorithms is still unclear. A big challenge facing the field is error correction. State-of-the-art qubits are prone to errors less than 1% of the time, but the errors multiply quickly. While algorithm developers have come up with methods to correct qubit errors, they haven't yet demonstrated these techniques in full on actual hardware.

To compensate for these errors, McClean's group will likely use a quantum-classical hybrid algorithm called the variational quantum eigensolver. This algorithm involves an iterative process where different steps of the simulation are fed back and forth between a quantum computer and a classical one. Hybrid approaches can also speed up total computation time.

"The big question is, can we do practical problems without error correction?" says McClean. Small-scale algorithm demonstrations suggest yes. The near-term strategy, he says, is to try the same approaches on progressively larger quantum computers—until they fail. Then, they will develop new methods—and repeat the process.

The author is a freelance writer based in Tucson, Arizona.

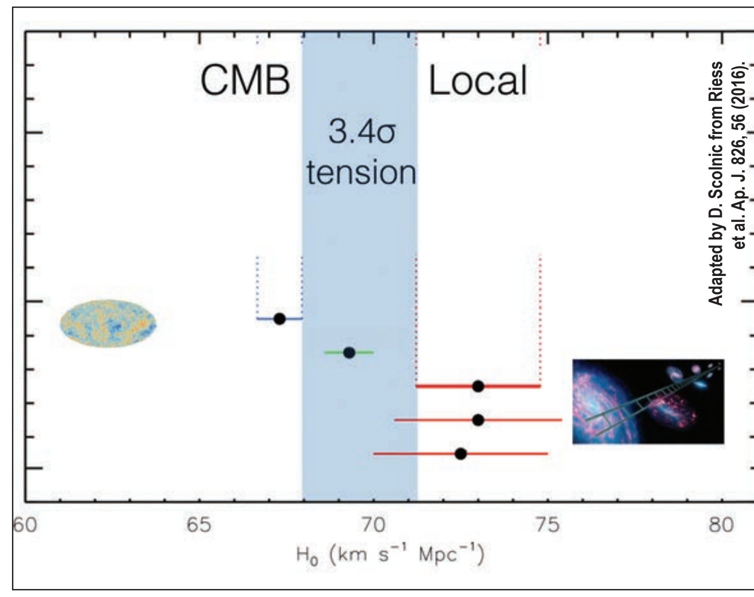
HUBBLE continued from page 1

However, the problem could be much more mundane. "Though it's not a very exciting hypothesis, one of the main ones is that there's systematic uncertainty in one or more of the measurements," says David Jones of the University of California, Santa Cruz, who is part of SH0ES.

But no source of uncertainty really stands out. "It could be a problem with the way you're taking the measurement; it could be a problem with the way you're interpreting the data; it could be that you're assuming too much about the things you're looking at," says Feeney. "All of these things have been tested, and there's not a convincing explanation."

One source of uncertainty comes from celestial distance measurements, which are required to calculate the Hubble constant when using stars or supernovae. To measure distance, cosmologists look for objects whose absolute brightness is known, so-called "standard candles" such as Cepheid stars, which pulsate at a frequency related to their brightness, or Type 1a supernovae, exploding stars of a consistent brightness. By comparing an object's absolute brightness to its observed brightness, they can calculate how far away it is. They hope to reduce the distance uncertainty, in part, by using new data from the Gaia space observatory, which will measure distances to Cepheids using geometrical methods.

They also want to improve their distance measurements by developing new celestial yardsticks based on gravitational waves produced in neutron star collisions, the first of which the Laser Interferometer Gravitational-Wave Observatory observed last October. If they measure the gravitational wave along with an accompanying electromagnetic signal, they can calculate the distance from Earth to the neutron stars. These measurements can be used to confirm the accuracy of the standard candles. "They've got nothing to do with Cepheids, or supernovae, or the CMB," says Feeney. "They're kind of an independent arbiter."



Estimates of the Hubble constant based on measurements of the cosmic microwave background (CMB) differ significantly from those based on a distance ladder built from "standard candles" like Type 1A supernovae (Local).

Researchers also need to understand the structure of the CMB in more detail. For example, many massive objects are positioned between Earth and the CMB, which create distortions—so-called gravitational lensing—on CMB maps. They don't understand these distortions well, which could mean they have misinterpreted past measurements, according to Feeney.

Solving the Hubble puzzle would mean cosmologists could calculate one fundamental value from two independent phenomena that bookend the history of the universe. "In a time sense, you're comparing one end of the universe to other," says Jones. The CMB, the oldest observable light in the universe, doesn't have much in common with a single supernova or Cepheid star.

According to Benson, cosmologists deserve some credit already, despite the discrepancy. For a value calculated from such unrelated astrophysical phenomena, the numbers are astonishingly close. "We're saying this is a 'crisis in cosmology,' but you can turn that on its head," he says. "The fact that the numbers agree at a five percent level is pretty remarkable."

The author is a freelance science writer in Tucson, Arizona.

2018 History of Physics Essay Contest

The Forum for History of Physics (FHP) of the American Physical Society is proud to announce the 2018 History of Physics Essay Contest.

The contest is designed to promote interest in the history of physics among those not, or not yet, professionally engaged in the subject. Entries can address the work of individual physicists, teams of physicists, physics discoveries, or other appropriate topics. Entries should be 1500-2000 words, and while scholarly should be accessible to a general scientific audience.

The contest is intended for undergraduate and graduate students, but open to anyone without a PhD in either physics or history. Entries with multiple authors will not be accepted. Entries will be judged on originality, clarity, and potential to contribute to the field. Previously published work, or excerpts thereof, will not be accepted. The winning essay will be published as a Back Page in *APS News*, and its author will receive a cash award of $1000, plus support for travel to an APS annual meeting to deliver a talk based on the essay. The judges may also designate one or more runners-up, with a cash award of $500 each.

Entries will be judged by members of the FHP Executive Committee and are due by September 1, 2018. They should be submitted to fhp@aps.org, with "Essay Contest" in the subject line. Entrants should supply their names, institutional affiliations (if any), mail and email addresses, and phone numbers. Winners will be announced by December 1, 2018.

News from the APS Office of Government Affairs

FY 18 Funding Bill a Win for Science

By Tawanda W. Johnson, APS Press Secretary

The diligent work of APS members, coupled with support from the APS Office of Government Affairs (APS OGA), contributed to a tremendous win for science agencies in the fiscal year (FY) 2018 omnibus bill. From writing op-eds and meeting with staff at their congressional offices to sending letters and making phone calls, APS members made a strong and persuasive case for the federal support of science.

The funding bill, signed into law on March 23 by President Trump, calls for between 5 percent and 16 percent growth in the research sections of agencies that APS OGA advocates for: the U.S. Department of Energy's Office of Science (DOE SC), National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and the Department of Education.

For DOE SC, the bill increases the agency's budget to $6.3 billion or 16 percent over FY 2017. DOE SC funds research in areas such as basic energy sciences, high energy physics and nuclear physics.

NSF's research and related activities account—which funds extramural research grants—increased by 5 percent to $6.33 billion.

The NIST science account, which includes funding for research user facilities, received a 5 percent boost to $725 million.

In the Department of Education, the bill funds sections II A and IV of the Every Student Succeeds Act (ESSA) for teacher preparation and afterschool programs. The sections had been zeroed out or deeply cut in the president's budget request. Under the FY 2018 omnibus, the sections are being funded at their FY 2017 level.

"APS members played a critical role in ensuring that the federal government maintains a strong investment in science and that the U.S. can remain a global leader in STEM," said Francis Slakey, chief government affairs officer at APS OGA. "Numerous professional societies made the case for science, but APS took a grassroots approach that focused on the local benefits of the federal investment."

APS OGA's partnerships with APS members on numerous statewide and Unit-specific campaigns contributed to the big win for research funding. For example, campaigns for the Division of Nuclear Physics and Division of Particles and Fields, which involved members of the Topical Group on Hadronic Physics, urged support for federal science funding. Moreover, the Forum on Physics and Society advocated for Congress to increase budgetary caps on the federal budget. APS OGA also partnered with the Society of Physics Students to stress the importance of federal funding that enables undergraduate research, including the Research Experiences for Undergraduates program at NSF.

In addition, the Forum on Education (FEd) addressed science education funding, specifically for teacher preparation and afterschool programs. The FEd campaign also amplified an op-ed published in the *St. Louis Dispatch* by Karen King, assistant teaching professor in the Department of Physics and Astronomy at the University of Missouri. APS member Eric Brewe, a professor at Drexel University, along with APS President Roger Falcone and APS Past President Laura Greene also played integral roles in underscoring the importance of sections of ESSA through meetings on Capitol Hill.

Greg Mack, manager of grassroots advocacy for APS OGA, said the department's online Advocacy Dashboard was instrumental in enabling APS members to advocate on the budget and other issues.

"Through the Advocacy Dashboard, APS members had year-round access to letters, tweets and phone scripts that were updated to keep pace with changing developments on budget," he said. "I'm excited by the thousands of APS members who took action, and I look forward to keeping up the momentum for fiscal year 2019."

Mark Elsesser, manager of science policy for APS OGA, said he, too, looks forward to building on the FY 2018 results after APS members helped to overcome three major hurdles during the appropriations process.

"The first key win was Congress rejecting the proposed deep cuts to science in the president's budget request. The next step was successfully advocating for Congress to raise the budget caps. Finally, we had to persuade Congress to prioritize science in the omnibus bill and provide robust funding to the science agencies that are important to our members," he recalled.

Elsesser added, "It was great to see congressional leaders—on both sides of the political aisle—respond to our requests and recognize the value of science. These funding increases send a clear signal to the world that the U.S. plans to remain a global leader in science and technology."

DIVERSITY continued from page 3

table, having been both mentor and mentee. "I met a female physicist for the first time when I was a sophomore in college, and she became a lifelong mentor," said Maclin. "She taught me the importance of what a mentor is."

For Maclin, this means acting as an advisor, and exemplifying what she calls "sponsorship"—speaking up on behalf of students in order to ensure their success. She often does this by pushing for research and internship opportunities for her freshman students. "Getting students into internships early helps keep students in STEM," says Maclin. "National labs are open to freshmen, but research universities need to get on board."

Rockward, too, employs a model of mentorship that involves championing his students. As the Chair of the physics department at Morehouse College, a historically black, all-male university, Rockward mentors students often from different backgrounds and facing different challenges than the majority of students at a predominantly white college. As a black male physicist, Rockward understands the challenges many of his students may face, and works to make sure their future research advisors will do the same. "I get calls all the time from people asking me to send them my brightest students," says Rockward. "But I can't just turn over my students to someone who won't be their advocate."

Rockward's concerns stem from what happens when his students move on to attend research institutions where they likely won't be represented in the makeup of the faculty. A physics department that includes diverse faculty opens up mentorship opportunities and combats social isolation that often plagues minority students. "Faculty should reflect the demographics of a university but this still isn't happening," says Maclin. "Some women are still the only [female] physicists at major research institutions."

Maclin's statement was confirmed by a question from a member of the audience—an undergraduate student who attends a university with a physics department in which half the students but none of the faculty are female. She wanted to know how to bring up this issue and, hopefully, change it. "Team up with other female students and form male allies," said Maclin. "Start from the bottom to work on these issues."

Creating a faculty environment that mirrors student demographics can be difficult in the case of less visible groups like the LGBTQ community. Pando pointed out that physics departments often don't collect data on such groups and therefore might overlook needs of LGBTQ student groups, and the responsibility to raise these issues often falls on the shoulders of people within those groups. "Be prepared to be labeled 'the person that…' and have the stamina to keep fighting," added Neunzert. "For every visible person, many more invisible people will hit the same barriers."

Many barriers for success for students from underrepresented groups in physics come from, as Pando put it, "the criteria about who gets to participate." In academia, this can be an issue, even for faculty: "It's a thorny point that women professors are often given more negative evaluations," said Pando. Changing the fixed ideas on who is able to be a physicist will likely come with increased support for students from underrepresented groups who succeed in the classroom. The panelists agreed this requires action from allies who may be outside of such groups. "Our hope is that we can move towards inclusion being everyone's issue," said Neunzert.

SCHOLARSHIP continued from page 3

that drove my research."

Renata Koontz almost didn't submit her application for the Goldwater Scholarship, and she had no expectations of winning. Now, she'll receive funding that will help her purchase a new computer to further her research in computational cosmology.

Koontz, a student at the University of California: Riverside, knew she wanted to do some kind of physics research—at first she was interested in gravity, but then started reading about dark matter, which is now the focus of one of her research interests. She also knew she didn't want to do "pen and paper work"—her words for theoretical physics—and her institution has few experimental physicists. For Koontz, computational physics was the perfect middle ground.

Her freshman year, Koontz was introduced to Hai-Bo Yu, a theoretical physicist whose work applied to astrophysics. He needed a student who knew how to program to analyze simulations—and Koontz was just the student for the job.

"Renata approached me as a freshman about research. I was worried the learning curve would be too high but I found a project for her," said Yu. "After a year she wanted something more challenging and began working on simulations of the universe—she learned the coding to do this pretty much alone and produced amazing results."

When a classmate told Koontz about the Goldwater Scholarship, urging her to apply, she was hesitant.

"I told him I don't know if I can do that," says Koontz. "But then I was approached by the Goldwater Campus representative and she convinced me it was a good fit."

Koontz thought about the application as a trial run for grants she'd have to apply for in the future, and just the process of writing her essay helped her prepare for the future.

"It helped me come up with a vision for my short-term goals—like what I would do if I won the scholarship—and helped clarify my vision for long term," says Koontz. "I learned you don't have to know exactly what you want to do, but you have to be able to envision short- and long-term goals."

Another faculty member, Flip Tanedo, was also integral to Koontz's Goldwater Scholar success.

"Dr. Flip gave me insight into how to communicate about my research better," says Koontz. "He gave me a lot of support and confidence in the application process."

Koontz urges other would-be Goldwater Scholars not to worry about perfection. "Don't worry about being prepared for research—just jump in and give it a try," she says. "Also don't worry about being a perfect applicant—I didn't have any expectations, but I still won!"

The Back Page

Labs are Necessary, and We Need to Invest in Them

By Marcos D. Caballero, Dimitri R. Dounas-Frazer, Heather J. Lewandowski, and MacKenzie R. Stetzer

Theoretical models are often useful in explaining or predicting natural phenomena, but at its core, physics is an experimental science. For example, recent experimental work conducted by the LIGO team validated Einstein's century-old prediction of gravitational waves, providing the most recent large-scale confirmation of the theory of general relativity. Furthermore, this experimental work has opened up the field of gravitational astronomy, allowing us to make observations at previously inaccessible length and energy scales. This, in turn, will help us to develop theories and conduct new experiments to explain the origins of our universe.

For physics students, laboratory work is an authentic way to develop an understanding of the experimental nature of physics. Experimentation provides opportunities to engage in the central practices of physics: designing and conducting experiments, analyzing and interpreting data, revising and troubleshooting models and apparatus, and communicating results to others. An education in physics where experimental work is absent is difficult to imagine. However, despite an ambitious national call to facilitate access to undergraduate research experiences for all undergraduate physics students, comparatively few are able to participate.

Laboratory courses that foster collaboration and deep understanding of experimental physics need more support.

Many students face barriers to becoming involved in undergraduate research; such barriers may include work and family obligations, geographical constraints, or mismatches between students' preparation and programmatic selection criteria. In addition, introductory physics students and students majoring in fields other than physics are not typically recruited to participate in undergraduate physics research. In light of these constraints, laboratory courses are critical to engage all physics students with the central practices of physics.

At all levels, laboratory courses can be great learning environments. They have low student-to-teacher ratios; they actively engage students with collaborative hands-on work; and they have the potential to support student-defined investigations. In introductory laboratory courses, students are exposed to the process and nature of scientific work, how evidence for theories and hypotheses can be collected, how arguments can be constructed through modeling and analysis, and how their arguments can be presented to others. As students move through the undergraduate physics curriculum, they encounter advanced laboratory courses, where we believe our majors should learn to be physicists. In addition to learning to use specific techniques and equipment, advanced laboratory courses often aim to develop students' troubleshooting, modeling, computation, and scientific communication skills as well as their ability to learn independently. Advanced laboratory courses play a crucial role in preparing our majors to succeed in graduate study and non-academic work alike.

From our perspective, laboratory courses are a core component of undergraduate physics education. At the same time, there is a vigorous national discussion about the state of laboratory instruction. A *Physics Today* article from 2017 [1] argued that "physics laboratory instruction in the U.S. is in disarray," citing aging equipment, stagnant experiments, a lack of financial resources and professional incentives to support comprehensive laboratory upgrades, and the complete disappearance of upper-division laboratories at many institutions.

In order to fulfill the educational potential of laboratory courses, we must address concerns about the quality and cost of apparatus, who is included and supported in laboratory instruction (and in what ways), and the apparent discrepancies between experimental physics learning goals and the ways in which laboratory courses are often designed and implemented. Organizations such as the Advanced Laboratory Physics Association (ALPhA) are working hard to improve the state of such courses by providing a variety of resources for laboratory instructors: a laboratory-oriented conference, targeted professional development opportunities, and access to equipment.

At the introductory level, instructors often argue that a primary goal of these laboratory courses is strengthening student understanding of the physics concepts covered in the lecture component of the course. Research conducted at three institutions by Holmes, Wieman, and collaborators [2], however, did not see a statistically significant impact of laboratory instruction on student performance on exam questions related to physics concepts covered during lecture. Moreover, related research by Wilcox and Lewandowski has shown that laboratory courses focused primarily on the development of physics concepts lead to students shifting away from expert-like beliefs about the nature of experimental physics (as measured by the Colorado Learning Attitudes about Science Survey for Experimental Physics, or E-CLASS) [3]. Thus, these findings suggest that many existing introductory laboratory sequences designed to reinforce physics concepts are not effective in achieving that goal. However, researchers and research-based curriculum developers are finding that laboratory instruction can be very effective in attending to learning goals associated with the practices of experimental physics [4].

At all levels, the goals for laboratory instruction must be clearly defined and aligned with the opportunities for learning in such an environment. Indeed, in 2014 a subcommittee of the American Association of Physics Teachers (AAPT) Committee on Laboratories prepared the *AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum* after examining the current state of undergraduate laboratory instruction and reflecting on the skills and practices that are integral to experimental physics [5]. There, the authors identified and articulated learning outcomes for the undergraduate laboratory curriculum in six broad areas: constructing knowledge, modeling, designing experiments, developing technical and practical laboratory skills, analyzing and visualizing data, and communicating physics. None of the outcomes target student conceptual understanding of physics content. Rather, the recommendations focus on the development of skills and competencies needed for successfully engaging in experimental physics.

Despite the tremendous value of lab courses, some physics departments have been under pressure to justify their expense, especially given equipment costs and small class sizes. Sometimes this culminates in a call to replace laboratory courses with computer-based simulations or lecture demonstrations, or even to eliminate them completely. Although lab costs are different from those associated with other courses, and equipment costs are likely higher, the type of learning that occurs in labs is unique and cannot be replicated in other learning environments. Therefore, we argue that it is unproductive to debate whether labs are "worth the expense." Instead, we must continue working together to improve laboratory courses within existing budgetary constraints.

We imagine a promising future for physics labs. In this future, students collaborate equitably with each other and their instructors to design and conduct experiments. All lab activities would align with clearly articulated learning goals and research-based assessments—and all of this takes place in an accessible, inclusive learning environment.

Realizing this vision will require continued investment of resources from funding agencies, professional societies, colleges and universities, educators, and education researchers. Four major areas of investment are:

1. **Collaborations between researchers and instructors.** Our vision for the future is inspired by existing successful teaching approaches. Partnerships between education researchers and lab instructors are an excellent way to learn and communicate which teaching practices work well for particular student populations and learning goals (e.g., see Ref. [6]). It is especially important to identify and study effective labs at two-year colleges and non-selective four-year colleges because these contexts are underrepresented in the physics education literature.
2. **Research-based assessments.** The physics education research community has a long track record of creating effective tools for assessing understanding of physics concepts, beliefs about the nature of physics, and other aspects of learning. However, few assessment instruments are tailored to the skills-oriented learning outcomes of undergraduate labs. Moreover, a need exists for tools that allow assessment of the process of science. The dearth of appropriate instruments makes it difficult for researchers or instructors to know which skills-based learning outcomes (e.g., experimental design, data analysis and visualization, and troubleshooting) are being met and which need to be better supported. Future development of skills- or process-based assessment instruments will facilitate the design, evaluation, and improvement of effective labs.
3. **Accessible and inclusive learning environments.** Labs use specialized equipment and software, and they often involve frequent peer-peer or student-instructor interactions. Therefore, labs may give rise to a unique combination of stereotypes, discriminatory behaviors, and mobility or sensory barriers that unfairly prevent full participation for some learners. Improved accessibility and inclusivity can be supported by research and development of labs that minimize barriers to students and educators from marginalized groups (e.g., people of color, people with disabilities, people who are lesbian, gay, bisexual, transgender, intersex, queer, or Two Spirit [LGBTIQ2S], women, and people from the intersections of these groups).
4. **Professional development opportunities.** Since 2010, ALPhA has developed and expanded a Laboratory Immersions program to support the dissemination of creative upper-division lab activities and enhance the confidence of lab instructors. More recently, the AAPT New Faculty Workshop has included a unit focused on introductory labs. Lab instructors and teaching assistants will benefit from further professional development opportunities focused on research-based pedagogies designed to develop students' lab skills while fostering accessible and inclusive environments.

Currently, physics laboratory courses are receiving attention from professional organizations and a growing number of education researchers as the physics community works toward more fully understanding and articulating the role of laboratory courses in the undergraduate physics curriculum. Looking to the future, we are excited by the prospect of synergistic efforts that share a common commitment to investing in and improving laboratory instruction for all students.

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