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APS physics

Investing in Global Science
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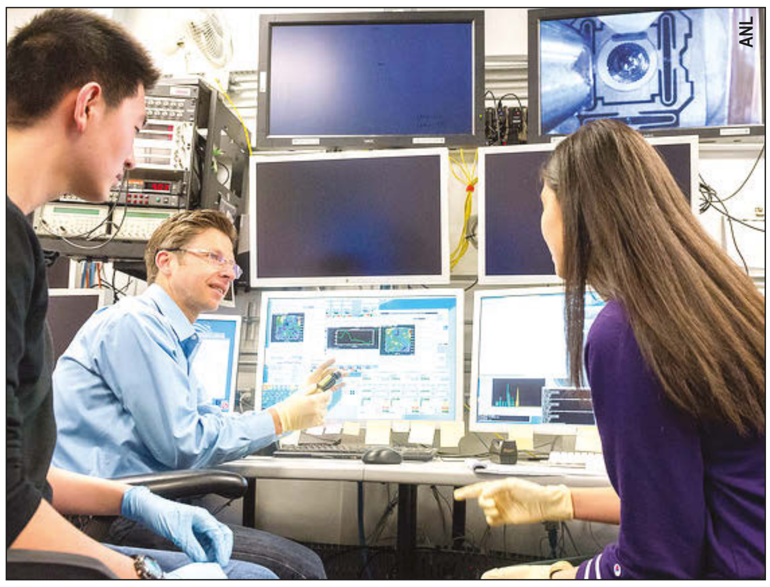
Unveiling the Past with Nuclear Physics

By Rachel Gaal

Historians might give an arm and a leg to travel back in time, but scientists have come up with ingenious ways to piece together the past here in the present. From the makeup of Egyptian funerary masks, to the authenticity of Van Gogh's murals, and the structure of the Florence Cathedral, the 2017 APS March and April meetings both featured research from around the world that painted a better picture of how historical artifacts were crafted.

A Second Look at What's Underneath

An anthropologist turned restoration expert, Brandi Lee MacDonald of the University of Missouri—Columbia, has been working with a collection of paintings from McMaster University in Canada for over five years. "This is a side project that just snowballed into this long-term project that's still ongoing," MacDonald announced at the APS April Meeting this past January in Washington, D.C. "Right now [the collection] is being shown across Canada. At the end of this summer I'll be able to access it for research again."



Volker Rose of Argonne National Laboratory works with students from Naperville Central High School at Argonne's Advanced Photon Source.

Nine oil paintings, dating back to the 1400s, were chosen by MacDonald and her team to apply analytical methods from physics to answer pivotal art historical questions for the curators at McMaster. "It took a year or two to develop the trust of the curators to start saying, 'Hey, you know that five million dollar painting you guys have? Can I put it in the core of a nuclear reactor?'," joked MacDonald.

With a suite of techniques in nuclear imaging, the researchers could find out what the paintings were made of, based on their chemical fingerprints. Using a handheld X-ray Fluorescence (XRF) device that can detect the chemical compo-

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Mining Computer Simulations For New Materials

By Sophia Chen

2017 APS March Meeting — Materials scientists are like chefs. "You shake and you bake, and your materials come out," says Wenhao Sun of Lawrence Berkeley National Laboratory (LBNL). But historically, they take forever to serve dinner. A researcher developing a semiconductor for a solar cell might spend three years tweaking different chemical compositions before even settling on a recipe.

Over the past decade, to speed up this process, materials scientists have begun to rely on computational methods to predict a material's properties in advance. Researchers discussed progress in the field at this year's March Meeting, which included 13 sessions on the theme of "Computational Discovery and Design of New Materials."

"There are so many sessions this year, and so many young people attending these sessions," says Turab Lookman of Los Alamos National Laboratory. "It's very exciting."

Lookman credits the explosion of activity in part to the Materials Genome Initiative, a government-led consortium that began in 2011 under President Obama. On average, it takes 30 years for a new material to be discovered in the lab and deployed in a commercial product. The initiative's goal is to cut this time in half. Federal agencies such as the National Science Foundation, the departments of Energy and Defense, and NASA participate by calling for proposals specifically related to materials design.

"Designing" materials is relatively new territory. Conventionally, scientists happen upon the material first and figure out its useful properties afterward. Take silicon, for example, which took over 40 years of tinkering and basic research to evolve from a mystery crystal at the heart of a radio into a transistor. The goal now is to move away from intuition-driven trial and error experiments.

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How African-American Women Succeed in Physics

By Sophia Chen

2017 APS March Meeting —Physicists all know the story about how the Catholic Church excommunicated Galileo for saying that Earth revolves around the Sun. Or how Einstein campaigned for building the atomic bomb after escaping Nazi Germany. This year, audiences learned about Katherine Johnson, an African-American NASA mathematician, in the Oscar-nominated film, *Hidden Figures*. She worked to send John Glenn to space in an era when NASA's bathrooms were still segregated.

But less-publicized experiments and equations have stories too. At this year's APS March Meeting, Felicia Mensah, the associate dean at Teacher's College, Columbia University, presented the stories of six contemporary African-American woman physicists. A biologist by training, Mensah trains K-12 science teachers and researches how to improve science curricula. Her former graduate student, Katemari Rosa—now a professor of physics education


Felicia Mensah

at Brazil's Universidade Federal de Campina Grande—interviewed these six women in person. They analyzed the many hours of interviews and published the results last August in *Physical Review Physics Education Research.*

The six women, anonymous in the paper, all have Ph.D.s in physics or a related field such as materials science. Two are assistant professors—one at a private liberal arts college, the other at a public historically black college. Three work for the government,

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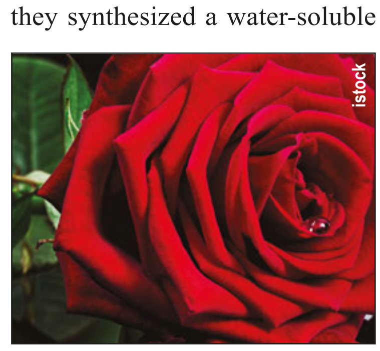
Research News: Editors' Choice

physics.aps.org

A Monthly Recap of Papers Selected by the Physics Editors

"Flower Power" Technology

Wouldn't it be groovy if flowers were symbols of peace, love—and electronics? The idea of electronic plants, or e-plants, has germinated before, but to no avail: electronic circuits were unable to integrate organically into the plant using its natural structure. Researchers may now have found a solution, literally. As Stavrinidou et al. report in the *Proceedings of the National Academy of Sciences* (DOI: 10.1073/pnas.1616456114), they synthesized a water-soluble



Wired plants

polymer solution that successfully transports electronic material throughout a plant, providing an opportunity for harnessing the power of plants in the future. Borrowing a trick from the way a plant soaks up water, the researchers placed a freshly cut rose in the solution for 24 hours. The small molecular size of the polymers (called oligomers) allowed the plant to completely transport the particles throughout its vascular system, including into the spongy "skin" area of the leaves known as the apoplast. The oligomers, which are ordered in a wire-like path within the plant's veins, were then tested for their electrical properties. The team concluded that the polymerized solution could retain a high conductivity over the extended length of the stem, mimicking an electrical circuit within the plant. The team hopes their solution can flower into a new electronic circuitry within plants for "power plant" technology.

The Mysterious Magnetism of White Dwarfs

The compact corpses of certain stars, called white dwarfs, are known to be the evolutionary endpoint for many luminous celestial bodies. But astronomers have yet to uncover the reason for their magnetic fields. One research team decided to investigate—and related it to our Jovian neighbor. Isern et al., writing in *Astrophysical Journal Letters* (DOI: 10.3847/2041-8213/aa5eae), analyzed and compared the convective motion in white dwarfs to the same process that generates intense magnetic fields on the surface of Jupiter, known as a dynamo. As white dwarfs evolve and cool to lower temperatures, they end up with two main constituent elements, carbon and oxygen, which crystallize to form a carbon-rich mantle on top of a solid core of denser oxygen. The team calculated the properties of white dwarfs within 65 light years from the sun, and they found that the stars with high magnetic fields would have more convective activity within the carbon mantle, leading to higher dynamo energy. While their calculations only sample single white dwarfs, the team has made progress in ruling out other long-standing hypotheses, such as binary mergers or amplification of progenitor magnetic fields.

White dwarf dynamo

Gluons Give Protons a Spin

The case of the proton's missing spin has come closer to being resolved, as theoretical computations find that force-carrying particles called gluons provide about half of the proton's spin. Originally, physicists assumed that the intrinsic spin angular momentum of the proton—which is equal to ½ in units of Planck's constant—was the result of adding together the spins of the three quarks that make up

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News from the APS Office of Public Affairs

Scott Franklin and Mina Hanna Named Five Sigma Physicists for Outstanding Advocacy

By Tawanda W. Johnson

APS recognized Scott Franklin and Mina Hanna with its inaugural Five Sigma Physicist Award for their outstanding science policy advocacy during the past year.

"I am thrilled and honored to be named a Five Sigma Physicist. The APS Office of Public Affairs (OPA) staff has been fantastic, walking me to congressional offices and providing me with talking points and materials. I could not have done it without APS," said Franklin, professor of physics and astronomy and director of the Center for Advancing STEM Teaching, Learning, and Evaluation at the Rochester Institute of Technology.

Franklin decided to get involved with science policy advocacy eight years ago. He explains, "I was attending an American Association of Physics Teachers national meeting, and the case was made that physicists could have an impact," recalled Franklin. "I also discovered that not many physicists were involved in advocacy, so I viewed it as a great opportunity."

Franklin then connected with APS OPA to gain tips on how to have an effective meeting with his member of Congress.

"The biggest thing I've learned about advocacy is that communicating on Capitol Hill is really different from communicating in academia. Scientists are used to laying out a long chain of reason and logic that leads to a conclusion. But that's not how you communicate on Capitol Hill. You start with your 'ask' and allow the representative or staffer to determine what angle is most useful to them," explained Franklin.

Franklin was chosen for the Five Sigma Physicist Award because he established a good working relationship with U.S. Rep. Louise Slaughter's office; consistently worked with OPA on meetings in Washington, D.C.; and participated in an advocacy campaign to visit the local offices of U.S. Sen. Kirsten Gillibrand and Slaughter.

Hanna became involved in advocacy after meeting with Greg Mack, APS government relations specialist, during the 2016 APS April Meeting in Salt Lake City, Utah. (Read more about Hanna in a previous edition of *APS News* at aps.org/publications/apsnews/201702/advocacy.cfm)

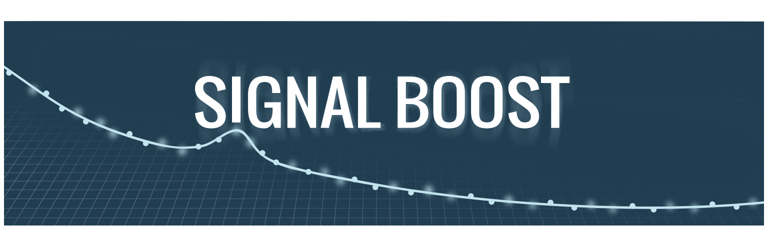
Hanna was selected for the award for writing an op-ed in the *Houston Chronicle* about the importance of funding scientific research, and for holding a meeting about the related issues with a staffer who works for U.S. Rep. Lamar Smith on Capitol Hill.

"I'm very enthusiastic and beyond grateful for APS and OPA for this recognition," said Hanna, a physicist, senior applications consultant at Synopsys, Inc. and chief operating officer at Wholesplit, LLC, both in Austin, Texas.

"We are proud to have Scott and Mina as Five Sigma Physicists," said Francis Slakey, interim director of OPA. "They recognize how crucial it is to the future of science for researchers to meet with congressional staff."

Added Greg Mack, "Five Sigma Physicists help make the needs of the physics community stand out from other interests. Scott and Mina are great examples of how APS members can work with the APS OPA to develop into effective science policy advocates to achieve this goal."

To learn more about the OPA grassroots program, contact Greg Mack at mack@aps.org.



Signal Boost is a monthly email video newsletter alerting APS members to policy issues and identifying opportunities to get involved. Past issues are available at go.aps.org/2nr298D. To receive Signal Boost and learn more about grassroots activities, contact Greg Mack at mack@aps.org or visit the sign-up page at go.aps.org/2nqGtJP.

This Month in Physics History

April 1914: James Franck Studies Atoms with Electron Collisions

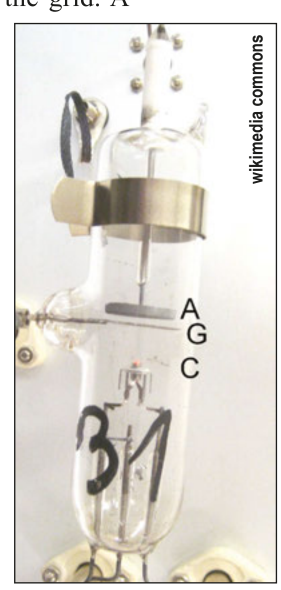
By Richard Williams

In 1882, James Franck was born in Hamburg, Germany, the descendant of Jews who had immigrated from Portugal generations earlier. He received his Ph.D. from the University of Berlin in 1906, and remained there until 1918. In 1914 he did his most celebrated work there on the scattering of electrons by mercury atoms. His joint papers with Gustav Hertz "entered their names on the rolls of the history of physics" [1]. His contributions to the understanding of physics; his stances taken, at personal peril, on moral issues; and his positions taken at the intersection of science and politics—these together made him one of the few scientists to be recognized so broadly [2]. He was truly a man for all seasons.

(From left) Nobel laureates Niels Bohr, James Franck, Albert Einstein, and Isidor Rabi.

The first Franck-Hertz experiment [3, 4] established the existence of discrete energy levels in mercury atoms. It was a joint effort by Franck and Gustav Hertz, the nephew of Heinrich Rudolph Hertz, whose experiments revealed the existence of the electromagnetic waves that had earlier been proposed theoretically by James Clerk Maxwell. The Franck-Hertz apparatus used a straight wire cathode, heated electrically to produce electrons by thermionic emission. It was immersed in an atmosphere of mercury vapor at a temperature around 120 °C with a vapor pressure of around one mm. Electrons emitted by the cathode were collected by a platinum anode after passing a mesh screen, or grid.

A voltage V, applied between cathode and grid, accelerated electrons toward the grid. A small retarding voltage between the anode and grid prevented electrons with very low energy from being collected. As Franck and Hertz increased V, the current collected by the platinum cylinder anode increased as well. This meant that the electrons passed through the mercury vapor almost without energy loss. Given the dimensions of the cell and the collision cross-section for electrons with the mercury atoms, the electrons would have several hundred collisions with the atoms on passing from the cathode to the platinum net. Thus, the collisions were elastic, with little energy loss by the electrons to the atoms. A crude analogy would be to compare the electron to a bullet passing through a gas, suffering many elastic collisions with minimal energy loss or deflection.



Mercury-vapor vacuum tube in teaching labs to replicate the Franck-Hertz experiment: anode (A), screen or grid (G), cathode (C).

But when V reached ~ 4.9 eV, suddenly the current fell nearly to zero. This meant that, at 4.9 eV, an electron lost nearly all its energy in a collision and could no longer overcome the retarding voltage and reach the anode. At first, Franck and Hertz believed that this was due to ionization of the mercury atoms by collision with electrons, but they soon understood that this energy loss was due to the existence of a discrete energy level between the ground state and the ionization level of the mercury atom. This was the first experimental demonstration, outside of spectroscopy, of the discrete atomic energy levels hypothesized in Bohr's theory of the hydrogen atom, published shortly before.

In the physics community, the effect of their discovery was stunning. After the lecture, Albert Einstein said to Lise Meitner, "It's so lovely it makes you cry" [2]. In a second paper [5] they showed that 4.9 eV excited emission of the 2537-Å UV line of the mercury atom.

Later, Franck took time off from his scientific career to serve as a volunteer in the German army during World War I and was seriously injured in a gas attack. After the war he returned and, in 1920, became professor of experimental physics at the University of Göttingen, then an important center for quantum physics. In 1925 he formulated what became known as the Franck-Condon principle, the basis of our understanding of the electronic spectra of diatomic molecules, and of more complicated molecules as well.

In 1933, Adolf Hitler passed the discriminatory legislation that prevented German Jews from holding government positions. Franck was exempted from the exclusion because of his service in World War I, but, "He chose to risk his career and personal safety by resigning his position so as not to be forced to dismiss his Jewish colleagues and students" [2]. He was the first German academic to do so.

He left Germany and went on to several tempo-

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Profiles in Versatility

Explaining the Science of Ribs and Roasts

By Katherine Kornei

Greg Blonder, a physicist by training and a Boston University engineering professor, is using science to explain great barbeque (BBQ). Blonder consults for cooking competitions and websites, dusting off textbook terms like "diffusion front" and demonstrating how some physics knowledge can yield the juiciest, most tender ribs and roasts.

Greg Blonder

The New Jersey native enjoyed cooking from an early age, and he regularly made his own meals while his undergraduate classmates at the Massachusetts Institute of Technology ate in the dining halls. He mastered the art of cooking for six, with nothing more than a hot plate and two pots. "The trick is careful preparation, blended with artful heat control," he says. Preparing and eating good food remained Blonder's avocation during his Ph.D. work at Harvard, where he investigated electron transport at interfaces between normal metals and superconductors.

After completing his thesis in 1982, Blonder joined Bell Research Labs, in Murray Hill, New Jersey, as a member of the technical staff in the physics division. Later he helped to develop products that took into account human psychology, such as software that asked users to input a picture-based password rather than a string of numbers. "Humans aren't very good at remembering numbers, and we were concerned that people were using dumb passwords because of this memory problem," said Blonder.

Blonder recalls getting together with some of his fellow Bell Labs scientists to roast a small pig luau-style. "We placed thermocouples in the soil and in the pig and then sat back and enjoyed a beer," he said.

Rising through the ranks from bench scientist to department head to AT&T Chief Technical Advisor, Blonder led a group in the 1990s working on early personal digital assistants, the precursors to today's smartphones. But the personal digital assistant was never marketed, and the project was dismantled in 1995 when AT&T spun off its consumer products division into Lucent Technologies.

After helping to create the new AT&T Labs Research, Blonder joined the world of venture capital, acting as both a founding CEO and an interim CEO. "A physicist's ability to make rapid back-of-the-envelope calculations allows you to quickly determine what needs fixing, without waiting for a detailed business plan," said Blonder.

Blonder's journey into cooking consulting began as he watched his wife, an accomplished pastry cook, occasionally struggle with a recipe. "Every once in a while a recipe of hers wouldn't work. I'd look at it, and realize 'That's not right thermodynamically,'" says Blonder. "I was beginning to wonder how much of this stuff was really science."

To find out, he'd retreat to his basement-turned-cooking lab and emerge a few hours later. Once, he placed a radiation shield over the heating element of his wife's oven to control the ratio of convection to radiative heat. Blonder's fix ensured that the macaroon cookies his wife was making did not brown excessively. It's his background in physics, he says, that gave him the skills necessary to improvise simple experiments that come up with definitive answers. "That really has helped me," he says.

Of all forms of cooking, Blonder is drawn most to BBQ. "I love BBQ because you get to work directly with fire, which flavors as well as heats," he said. "The challenge is to improve on 10,000 years of experience and to sweep out the myths while respecting the traditions."

In 2011, Blonder read an article on the website amazingribs.com about cooking brisket. The article described how the meat would plateau in temperature during cooking, an effect Blonder had experienced and found to be due to evaporative cooling. As a scientist, Blonder immediately noted that the article lacked something: "There was no graph showing this plateau," he recounted. He plotted his temperature data and sent the graph to the website. He received an eager response from "Meathead" Goldwyn, the website's editor, who told him that other questions in the BBQ world needed investigating, too. Blonder started to collaborate with amazingribs.com as a science advisor, and in 2016 he and Meathead published the *New York Times*-bestselling book "Meathead: The Science of Great Barbeque and Grilling."

Blonder has acted as a science consultant for over a half-dozen teams competing in BBQ competitions. "I've had teams call me up at ten at night in the middle of a competition looking for a quick fix to a problem," he says. He remembers one team that was having trouble achieving a "smoke ring," a red band around meat that is a visual sign of great BBQ. Blonder explained to the competitors that the presence of a smoke ring depends on the pH of the meat—meat that's too acidic won't produce a ring. He advised adding a little bit of baking soda to the meat before BBQing it to increase its pH, and the team successfully produced a smoke ring on their next round of brisket.

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2017 APS March Meeting Kavli Symposium

2016 physics Nobel laureates J. Michael Kosterlitz (left) and F. D. M. Haldane (right) spoke at the 2017 APS March Meeting Kavli Symposium on "Quantum Matter and Quantum Information." Also speaking were Kathryn Moler, Dale van Harlingen, Andrew Cleland, and Michel Devoret. For videos of all of the talks at the Kavli Symposium visit aps.org/meetings/march/

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sition of a paint pigment, she confirmed the authenticity of an 18th century Van Gogh still life.

"We used [XRF] to understand the pigment diversity [of the painting], and luckily we didn't find any pigments indicative of forgery [from that time period]," MacDonald explained. The team also used an XRF mapping system to analyze a one to two mm spot and find out what elements would show up underneath. "It showed elevated amounts of lead and mercury, a main constituent of red pigment and a fleshy tone."

The visual portion of the spot was not skin-colored, however, indicating that another painting was underneath. The high-resolution imaging technique known as neutron radiography revealed the hidden painting, confirming that the cash-strapped artist recycled his canvases.

Radiation and Restoration

At Los Alamos National Laboratory, Elena Guardincerri and her team want to draw up new blueprints for the famous Cathedral of Santa Maria del Fiore in Florence, Italy. As physicists, however, their main tool will be custom-built panels of muon detectors to reveal the domes' inner structure.

"Made up of two shells instead of a single wall, interestingly enough this dome was built without a temporary support structure," Guardincerri explained at the 2017 APS March Meeting in New Orleans. "The dome has cracks through both shells, which are still growing … the largest are about eight centimeters in length. There are a number of [us] who want to reinforce the dome before it falls."

Considered a heritage site by UNESCO, the 14th century dome designed by Italian architect Filippo Brunelleschi has an interior shell more than two meters thick, which is only known to bear brickwork and sandstone. No one knows if there are reinforcement structures, such as steel wire, between the shells. Some historians speculate iron chains are lining the inner walls of the domes, but no one piece of evidence settles the case.

"There are documents that show there were thousands of pounds of iron purchased during the construction of the dome, but the iron is mostly unaccounted for," said Guardincerri. "So [my team and I] thought we could use muon radiography to look inside this wall."

Heavier cousins of electrons, muons are the by-product of cosmic ray interactions with Earth's atmosphere. Known to penetrate objects hundreds of meters thick, muons afforded Guardincerri and her team the perfect way to paint a picture of what lies sandwiched between the shells of the domes. "By measuring the scattering angle, we can tell what the material was if we know the thickness of the material," explained Guardincerri.

A mock-up measurement was done at LANL in 2015—her students built a replica of the dome's thickest inner wall and hid three iron bars inside it. Two muon trackers, placed on either side of the wall, took data for 35 days, which produced a composite image. Although her team took measurements for a whole month, the steel bars were visible after only 17 days of data collection.

Guardincerri reported the results in Florence, and was approved by the cathedral's guild to develop thinner, portable muon trackers to install in the dome. The detectors to be used in their project are being built at the Georgia Institute of Technology, and she plans to begin muon imaging in January 2018.

"We will make pictures of select parts of the dome that will take a month for each image," said Guardincerri. "We will take three to four images at first to get a whole slice of the dome … and if the results are good and we find the iron chain (or something else), we will follow it all the way around [to look at] if it's broken [for restoration purposes]."

The Next Generation of Egyptian Historians

Decadent and mysterious, the ancient Egyptians left a vast variety of exotic relics behind—many of which are proudly shown off by museums and curators around the world. One of these conservators is Naperville Central High School, near Chicago, Illinois. As the only high school to own an Egyptian mummy, their oldest student (named Cleo) is known to be 2,000 years old, donated to the school in the 1940s by a man who apparently bought him in an Egyptian curio shop.

Volker Rose of Argonne National Laboratory in Chicago, IL, has used his experience with XRF and radiography to aid the school's students in examining the materials of pyramids and samples of Cleo, using the world-class equipment housed at Argonne's Advanced Photon Source.

"Because we are talking about a high school project, we don't have all the time in the world compared to a typical research group," Rose explained at the 2017 APS March Meeting. "We have been working for about half a year preparing [this] project, [but] we are very ambitious and we want to learn a lot … what we are getting out of this kind of work is so far at the publication level."

Rose and a select group of students have examined whether the building blocks of Egyptian pyramids were poured or carved of stone. Analyzing the materials for common elements like aluminum allowed Rose and his student researchers to relate the chemical structure to that in an authentic sample of Egyptian stone.

"There are some indications in the known microstructure [of pyramids] that they might be poured out of material, and [the students and I studied] geopolymers to understand the chemical makeup, and answer this long-debated question," said Rose. "It's harder than we thought to get a real sample, though …"

For his current project, which started at the end of March, his students will use XRF techniques to examine what kinds of materials were used in the funeral mask that covers Cleo's face, to look back in time to examine the cultural practices of her morticians.

Rose is known for his work with the Art Institute of Chicago in 2013, which revealed through microscopy that Picasso was the first to use common household paints in his later artwork. As a result, he developed a passion for art and science, which he now says fuels his drive to give younger generations of high-school students, like ones at Naperville, a chance to work hands-on with applied physics tools through Argonne's Exemplary Student Research Programs. "Science and the heritage of art defines who we are as people, so I think it's important to protect it and teach others that they can benefit from each other," said Rose. "It's our duty to work with the general public and high school students, and [these experiences] are opening up doors for me to directly engage with our next generation of scientists … it's very inspiring."

Hi Reddit, I Am A Physicist… Ask Me Anything!

By Rachel Gaal

After five years of studying the stars, Sarafina Nance of the University of Texas at Austin, came up with a stellar explanation for Betelgeuse's rapid rotation. To get the word out about her research, Nance published in the *Monthly Notices of the Royal Astronomical Society*, shared her discovery with her peers, and sat down to virtually discuss her work with the 16 million subscribers of the internet discussion forum 'Reddit Science':

"[Hi Reddit!]. I am a female astrophysicist who just published on the famous star Betelgeuse and found it may have swallowed another star. AMA!"

Like an interactive forum where users can pick and choose what they follow, Reddit is a large virtual community made up of sub-communities, known as "subreddits," dedicated to certain topics or ideas. AMAs (short for 'Ask Me Anything') were created by the Reddit community as an opportunity for intriguing individuals to answer questions about anything and everything.

"The cool thing about Reddit is that you can reach people from everywhere that you may not be able to reach in other ways," Nance told *APS News*. "Sometimes it's hard, [especially] if you are publishing something on physics, but with astronomy you can see it ... so [I thought] it would be a little more accessible in that sense."

The Science subreddit (/r/science), where Nance and many other scientists post their science-focused AMAs, has attracted over 16 million subscribers, and continues to be one of the top five subreddits out of the one million created by users around the globe. Reddit is now running an official Science-AMA series, where practicing researchers and groups of scientists from all disciplines can expound upon their experiences in the lab.

For Nance, she had always known Reddit as more of an entertainment source like many other social media platforms. After seeing more technical posts from the Science-AMA series, she thought about the possibility of sharing her discovery with the people of /r/science.

Sarafina Nance

"I decided to try an AMA and didn't know what to expect," she exclaimed. "But one of the [first] questions I got was my favorite, by a seven-year-old girl named Emma. She wanted to know how many galaxies I've found and how to become an astrophysicist like me! … Once I got that, I was even more excited."

Like many others who choose to participate in the Science-AMA series, the process of hosting your own virtual talk session can be less demanding than a live presentation and more flexible for those who are on-the-go with other obligations.

"It's not like you're standing in front of a crowd answering questions, you can pick and choose which ones you respond to on your own time," Nance explained. "I just focused on ones where I could communicate a lot of information, and the ones that reached out for mentoring. Picking the meatier [questions] and going from there helped generate conversation [among users]."

While AMAs are an innovative way to reach those outside of your academic circle, Nance found that not everyone reacts well to seeing terms like "magnetohydrodynamics" or "asteroseismology" in a personalized response to their query.

"It intimidates people when you are technical, and it tends to disengage [them]," Nance mentioned. "Just distilling your message in a way that's exciting for people—why it's relevant and how it excites you—is a great start. Once people see that, it makes [the experience] all worthwhile."

The Science-AMA series is only a single feature of /r/science; hundreds of articles about science news, journal papers, and research are posted daily on the webpage. And for users who create an account on Reddit, they are able to comment on any post they choose.

To further bridge the gap between practicing scientists and the general public, the subreddit also features the option to add some "science flair" to your comments. This system set up by administrators of /r/science aims to help distinguish between a credible or random comment. By providing a snapshot of your academic credentials to the moderators, a virtual "sticker" can be placed next to your Reddit username to show off your degree level, and area of study.

Anyone and everyone is always welcome to join Reddit, which continues to grow in subscribers each day. To learn more about the Science-AMA series and how to schedule your own AMA, you can download a free pdf of the submission guide at reddit.com/r/science. To view our selection of Nance's AMA, visit aps.org/apsnews.

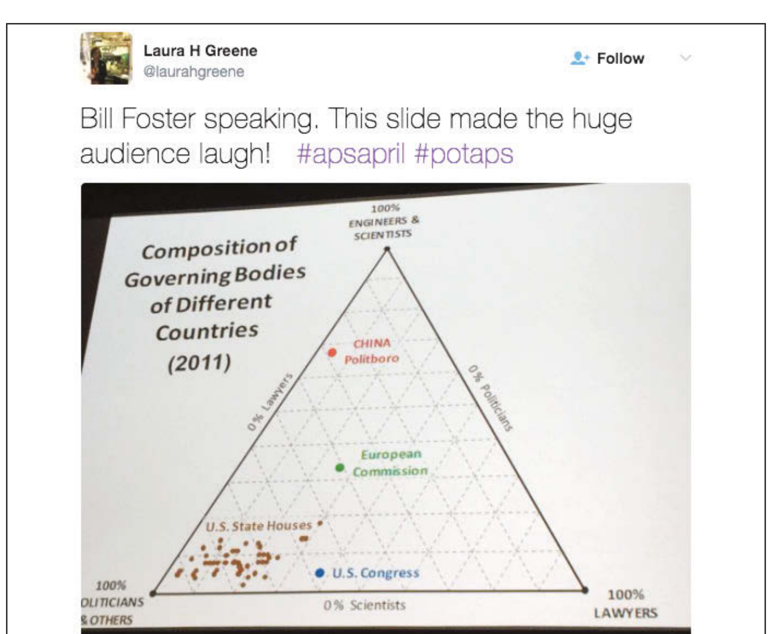
APS Meetings Go Social

By Gabriel Popkin

The Twitter revolution has come to APS meetings. Attendees of the 2017 APS April Meeting in Washington, D.C. sent hundreds of tweets with the tag #apsapril, creating a sort of parallel conference open not just to people in the physical meeting hall, but to anyone in the Twitterverse. And in New Orleans, physicists at the 2017 APS March Meeting sent out tweets tagged #apsmarch.

Twitter and other social media platforms can expand a conference's reach, and enable scientists to connect with each other and quickly find out what's going on, says Chelsea Pedé, communications manager at APS, who has tweeted as @APSPhysics since 2009. (Many individual APS departments also have their own social media identities.) She uses Twitter to promote conference sessions and communicate with conference attendees who may need assistance. "Every year I think we get a little bit better, and I think attendees use it a little bit differently," she says.

One way scientists increasingly use social media is to broadcast



Real-time tweeting at the 2017 APS April Meeting

and amplify material from conference presentations. This was exemplified during the "Diversity in troubled times" session on the March Meeting's opening day. University of Washington physicist Chanda Prescod-Weinstein (@IBJIYONGI), a Twitter user since 2008 who has built a following of more than 15,000 people, gave a historical presentation to around 100 attendees on how the Nazi regime sought to align German science with its ideology. Within minutes, excerpts and photos from the session were being shared, liked, and retweeted. One fan, physicist Todd Tinsley of Hendrix College in Arkansas (@prof_10sley), tweeted back: "My reading list just became much longer thanks

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and one is a researcher at a public university.

Mensah and Rosa found these women in an online database of African-American woman physicists—along with some dismal statistics. Based on the database, they estimate that no more than 90 African-American women have Ph.D.'s in physics, astronomy, or an adjacent field. "Black women were 11 percent of all women receiving bachelors degrees in 2010, but only 2.9 percent of women receiving physics bachelor degrees in the same year," they write in the paper.

Rosa, who majored in physics as an undergraduate, wanted to understand why these six Black women chose the field and stuck with it. She found that several cited supportive parents or extended family. They spoke about the necessity of financial aid. In addition, many had science teachers who recommended that they apply for certain scholarships or summer research opportunities when they were in high school. All six participated in summer research experiences during their college years. The women felt "invited" to physics, Mensah says.

But the invitation came with added challenges. Each of the interviewees was the only Black woman in their department at many points in their career. As students, they struggled to find a community. "Being the only one can be very isolating," Mensah says. In particular, other students would exclude them from study groups.

One woman ended up inviting herself. "I'm like, 'Oh, you guys are studying Tuesday at two? I'm going to come.' See, I didn't have to ask, 'Will you invite me?' I'm not going to wait for that," she told Rosa.

Desiré Whitmore, who identifies as "Blaxican"—black and Mexican—told *APS News* about similar challenges integrating into the physics community. (Whitmore did not participate in Mensah's research.) She earned a Ph.D. in chemical and materials physics from the University of California, Irvine, in 2011. But her entrance into the field was anything but conventional.

"My senior year of high school was really tough in terms of home life," Whitmore says. "My mother was abusive and a drug addict. She had five kids, and I was the oldest, so I had to take care of them."

Her mother wasn't paying the mortgage or the bills. "We were surviving because of school lunch," Whitmore says. At one point that year, she was homeless.

Her tumultuous home life derailed her plans to attend university immediately after high school. So she attended community college first before transferring to the University of California, Los Angeles, where she majored in chemical engineering.

"When I transferred to UCLA, I found this clique behavior," Whitmore says. "It was like high school all over again." Most of the other students had already taken multiple classes together, and she was the new kid. "They already had their groups, and they weren't really interested in me joining," she

Desiré Whitmore

says. "My first quarter—my first year, really—I just studied alone." She found a group only after other students realized that she scored well on exams, she says.

When Whitmore went to graduate school, she found that many assumed she hadn't earned her success. She received a National Science Foundation Graduate Research Fellowship to work on ultrafast lasers. "I was talking to this guy in my group, and I asked him, why don't you apply to these fellowships?" Whitmore says. "It's free money. You get paid to do your research. He said, 'I'm middle class and White. I'm not eligible for these fellowships.' I was like, actually you are. They're all merit-based and have nothing to do with the color of your skin."

After completing a postdoc at the University of California, Berkeley, Whitmore now teaches laser and photonics technology at Irvine Valley College, a community college in California. "I spend a lot of time with my students making sure they understand where I came from," she says. Some of her students are training for jobs as laser technicians, while others plan to transfer to a four-year university—like she did. She wants them to know that higher degrees are within their reach.

Sharing the success stories of Black women physicists is crucial to getting Black girls excited about science, Mensah says. "Science has its own social and historical context, and often we don't teach it," she says. "Teachers walk into their classroom thinking that they're just teaching about mechanics." But science teachers who avoid discussing social context implicitly reinforce the historically dominant narrative that physicists are white and male. Students of color pick up on the narrative and may feel excluded, Mensah says. She advises teachers to look for stories about the scientific contributions from underrepresented communities.

A few years ago, Whitmore starred in an online video about spectroscopy. She later received an email from a middle school teacher whose students wanted to ask her about her job. "These three girls are interested in spectroscopy because they see someone who looks like them," Whitmore says. "They see, oh my god, she's a real scientist. She's a Black woman, and I'm a Black girl—I can be that when I grow up."

The author, a contributor to Wired *and* Physics Girl, *is based in Tucson, Arizona.*

Education & Diversity Update

Woman Physicist of the Month

Sevil Salur

Sevil Salur is an experimental high energy physicist at Rutgers, The State University of New Jersey. She investigates the properties of the quark-gluon plasma at both the Large Hadron Collider at CERN in Geneva, Switzerland and at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory in Upton, New York. In 2014, Salur received a National Science Foundation Faculty Early Career Development Program award to support her experimental work. At Rutgers, in addition to supervising postdocs and graduate students, she has mentored eight undergraduate students (including four women) in research. Two of these undergraduate students received Goldwater scholarships. In 2013, she was named Rutgers Society of Physics Students' outstanding teacher. She has organized several conferences including Hot Quarks, a meeting specifically designed to enhance the direct exchange of scientific information among the younger members of the relativistic heavy ion community. Salur co-hosted the APS Conference for Undergraduate Women in Physics (CUWiP) at Rutgers in 2015 and helped organize the APS CUWiP at Princeton in 2017.

New Report Released: *Recruiting Teachers in High-needs STEM Fields*

Given the ongoing difficulty of finding highly experienced and well-educated middle and high school STEM teachers, especially in physics, chemistry, and computer science, the APS Panel on Public Affairs, American Chemical Society, Computing Research Association, and Mathematics Teacher Education Partnership surveyed over 6,000 current and recent majors in these disciplines. Among the major findings in the report are:

"Around half of STEM majors indicate some interest in teaching …

[Of these,] 80% say that various financial incentives [especially salary increases] would increase their interest. …

Undergraduate STEM majors underestimate teacher compensation … .

Students are most inclined to consider teaching in departments where the faculty discuss teaching as a career option."

You can find the report, *Recruiting Teachers in High-needs STEM Fields: A Survey of Current Majors and Recent STEM Graduates,* at go.aps.org/2l8yfrO

FRANCK continued from page 2

rary academic positions in Europe. In 1940, fearful that the German Army would confiscate their gold Nobel medals, Franck and German Physicist Max von Laue left their medals for safekeeping at Niels Bohr's Institute in Copenhagen. At one point, invading German troops entered Copenhagen and were marching near the Institute. They would surely confiscate the medals. What to do with them? In great haste Hungarian chemist, George de Hevesy, who was at the institute, dissolved the gold medals in aqua regia, a mixture of nitric and hydrochloric acids, and put the bottle containing the yellow liquid, inconspicuously, on a shelf. There it remained until after the war. The gold was then recovered and sent to the Nobel Society. They recast the medals and presented them to Franck and von Laue [6].

Franck came to the United States and spent most of his remaining career at the University of Chicago. After participating in the Manhattan Project, in a June 1945 report, he urged authorities to have a demonstration explosion of a nuclear weapon to achieve peace with Japan without actual use of the weapon. He then joined an unsuccessful effort to avert a nuclear arms race. His stand on the issue reflected his entire life of moral engagement on public issues. He died suddenly in May 1964, while visiting Göttingen.

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RIBS continued from page 3

When asked about the most important gadgets an aspiring chef should own, Blonder was quick to respond: a digital scale and a quick-reading digital thermometer. And if you're thinking of hosting a BBQ party, serve pork shoulder, Blonder recommends. "It's extraordinarily forgiving, and you can cook it and serve it three hours later and it still tastes good." Ribs are a bit trickier, he notes. "A lot of the flavor molecules in BBQ are extremely high vapor pressure, so they leave before your guests arrive," Blonder says.

The author is a freelance science writer in Portland, Oregon.

2017 History of Physics Essay Contest

The Forum for History of Physics (FHP) of the American Physical Society is proud to announce the 2017 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, 2017. 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, 2017.

International News

Investing in the Future of Global Science

By Teresa Ventura

Fast-moving disease epidemics, the effects of climate change on food and livelihoods, the urgent need for sustainable energy to power economic growth—these are challenges that know no boundaries. If we are going to make progress on these worldwide challenges, the population of problem-solvers tackling them needs to be equally global.

Romano Mwiririchia and students in the Department of Biological Sciences at the University of Embu, Kenya

We recognize that many physicists have an interest in the global scientific community and connecting with colleagues in developing countries. Through Seeding Labs, there are opportunities for the physics community to support scientists around the world and make a true impact on research and teaching, and we can use your help in many ways.

Seeding Labs is a nonprofit organization based in Boston dedicated to creating a generation of scientific problem-solvers in every country to tackle the most pressing problems facing their communities and the world. We accomplish this mission by supporting international scientists through connections to tools, training, and fellow researchers around the globe—researchers just like you and your fellow APS members. And by these means, we help foster the same advancement of scientific research, education, and international collaboration that is so important to members of APS.

Our core program, Instrumental Access, removes a barrier to scientific innovation and education in developing countries by donating modern lab equipment to research institutions and universities. Over the past nine years, we've supported 47 institutions in 27 developing countries with millions of dollars' worth of equipment and supplies. When you combine tools with talent, our partners achieve great things.

But why equipment?

We see equipment as the foundation for other critical resources, a foundation that allows scientists to generate new knowledge, leverage sustainable funding, and better prepare university students for the scientific workforce and innovation economy.

Instrumental Access awardees are selected annually after a rigorous application process. We determine their need for equipment and their ability to effectively use it to conduct meaningful research and help train the next generation of scientists. Last year, we selected 16 outstanding university partners from a pool of 65 applicants representing 26 countries. They are some of the brightest teachers and researchers across the developing world, and they focus on agriculture, climate change, energy, water safety, drug discovery, infectious disease, and more.

Seeding Labs

Vetja Haakuria and colleagues at the University of Namibia School of Pharmacy unpacking their Instrumental Access equipment.

Our program staff works with our partners to individually select a tailored shipment of equipment that they will put to productive use. This equipment comes to us through partnerships with more than 100 donors from both manufacturers and end users. We work with donors to identify, test, and collect high-quality instruments that will have a long and useful life in an overseas lab. Our donors include corporate and nonprofit research institutions, universities, and researchers like you—scientists who recognize the power of science to unite us all, regardless of geography.

How can you help?

Our Instrumental Access program is always in need of donated equipment and support to continue meeting the needs of the global scientific community. While Seeding Labs primarily supports researchers in biology and chemistry departments, many instruments found in physics labs would be useful, including microscopes, balances, and water purification systems.

Donating equipment is simple and takes just three easy steps:

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Eventually, Lookman wants to be able to tell a computer that he's looking for a semiconductor with some specific band gap and heat capacity, and have the computer spit out the chemical formula of a material that fits the description.

To achieve this, materials scientists are turning to density functional theory (DFT), first invented in 1965. Instead of framing Schrödinger's equation in terms of each particle's wavefunction—those complex probability amplitudes at the root of so many undergraduate headaches—DFT rewrites Schrödinger's equation in terms of a matrix known as the quantum density, which is much easier to compute.

But it's still not straightforward to formulate and compute the relevant equations for a particular material. You might divide a solid into repeating patterns of hundreds of electrons. Then you have to account for the three-dimensional interactions between each of those electrons. Researchers usually deal with the high number of calculations by making approximations—and still often need a supercomputer to complete the task. "And then you hope the approximation is close to the real answer," says graduate student Thomas Baker of the University of California, Irvine.

Baker's group, led by Kieron Burke at Irvine, demonstrated that they could use machine learning to simplify DFT calculations. They fed exact DFT results on short hydrogen chains to a computer, and through machine learning techniques, could then accurately calculate the properties of longer chains of hydrogen without time-consuming DFT computations. "With machine learning, you could run these calculations on a laptop instead of a supercomputer," Baker says.

Other groups at the meeting reported on how to translate simulations into experiments. For example, Lookman's group simulated different nickel-titanium alloys—and worked with experimentalists to make some of their simulated compounds.

Lookman's group searched for an alloy that would not fatigue upon repetitive heating and cooling. Such a material could be used as an actuator in an aircraft engine, he says.

They knew that the right alloy would contain some combination of nickel, titanium, copper, palladium, and iron. However, about 800,000 different combinations of these elements exist. To find their top contenders, the group taught a regular computer to search those combinations for the desired property using machine learning. They did this by showing the computer experimental measurements of 60 other nickel-titanium alloys, just like Google teaches its neural networks to recognize the image of a cat. Experimentalists were able to make 36 different alloys based on the computer's recommendation.

But even with these success stories, computer-based approaches have their limits. Sun, of LBNL, is skeptical of how broadly useful machine learning will be, despite the high number of talks at the meeting about it. "I made a joke in my talk," he says. "I said that the only neural networks we used were the neural networks of our nine trained materials scientists."

He points out that machine learning algorithms—like Google's image-recognition software—generally need to be trained with a lot of data. "And the reality is that materials science is not a big data problem," Sun says. "It's kind of small data. For big data, you need 10^9 data points. But metals, salts, ceramics, semiconductors, everything combined—there are only 10^5 of them. Within a small material class there might be as few as 100 or 1000."

Two of Sun's colleagues, Gerbrand Ceder of the University of California Berkeley and Kristin Persson of LBNL, launched the Materials Project, a database of material properties, in 2011. Using supercomputers and DFT, they have calculated thermodynamic properties for over 67,000 different inorganic compounds, many of which have never been experimentally made. Their goal is to serve as a "Google" for materials—an organized database where a researcher can easily look up the band gap, density, or conductivity of a material.

But it's challenging to translate these calculations to the lab. Computers often predict that a compound exists, but an experimentalist won't be able to make it, Sun says. In particular, he and his colleagues have had difficulty synthesizing certain so-called metastable materials. Diamonds, for example, are metastable. This means that even though they exist under standard temperature and pressure, they can't form under those conditions. Sun is focusing his research efforts on understanding why experimentalists can't make predicted compounds.

"That's the critical bottleneck," he says.

But even so, researchers have already developed new fertilizer chemicals and battery materials using computational methods. In 2015, researchers in Germany synthesized the highest temperature superconductor to date using DFT predictions. One thing is clear: The recipe for the next generation of materials is hiding somewhere in a computer simulation.

The author, a contributor to Wired *and* Physics Girl, *is based in Tucson, Arizona.*

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to @IBJIYONGI and her 'German scientists and complicity in Nazi Germany'."

Beyond serving as a publicity channel, social media can also, as its name suggests, catalyze community among conference attendees. Shane Larson (@sciencejedi), an astrophysicist at Northwestern University who joined Twitter in 2012, uses it to connect with other scientists who have common interests. "I definitely meet people I wouldn't have otherwise met because they know I'm tweeting and I know they're tweeting," he says.

Twitter has also helped Larson solve one of the classic meeting dilemmas—how to choose between simultaneous sessions. He can now sit in one room while keeping tabs on presentations in others via tweets posted in real-time (a practice known as live-tweeting). "You used to have make really hard choices about what to go to," he says. With Twitter, "You can always go back [to a session you didn't attend] and get a sense of what happened."

While tweeting during sessions might appear a distraction, Larson says that even when his thumbs are tapping on his touch screen, he's no less engaged with what's being presented. "The things I tweet about are almost always things I would have written down anyway," he says. "I just have to make sure those things make it into my paper notes."

Laura Greene, a physicist at Florida State University and 2017 APS president, agrees. "I'm paying attention, I take a picture, I try to say what speaker said in a few succinct words, and it helps me focus—and I'm having fun with it."

Greene is a relative newcomer to Twitter—she began tweeting as @laurahgreene last October, partly in preparation for her presidential term. Since then she's sent more than 400 tweets and amassed more than 200 followers. Her tweet of a photo of U.S. Representative Bill Foster's slide showing the dearth of scientists and engineers in Congress relative to the legislative bodies of the European Union and China garnered dozens of likes and retweets—not quite viral, perhaps, but among the top performers on the meeting Twitter feed.

Foster's slide was far from the only political content that meeting attendees posted. On Friday, January 27, just hours before the meeting began, Donald Trump signed an executive order banning residents of seven Muslim-majority nations from traveling to the U.S., sending shock waves throughout the nation and the global scientific community. Meeting attendees at times found themselves struggling to tune out politics and focus on the proceedings. Prescod-Weinstein posted photos and a video from a Sunday afternoon protest at the White House, just a few miles south of the meeting venue. APS Washington Office staff implored members via Twitter to take a few minutes to contact Congress.

In this fractious environment, Greene sees Twitter as a way to engage science policy makers with whom she might disagree politically, by connecting via a shared interest in science. "I'm looking for Twitter to be a platform for science diplomacy," she says.

Politics aside, Greene also hopes social media can help do science outreach directly to non-scientists. "I want to communicate to everyone, why we do science, the joy of it," she says. "That's a starting point."

The author is a freelance science writer based in Mount Rainier, Maryland.

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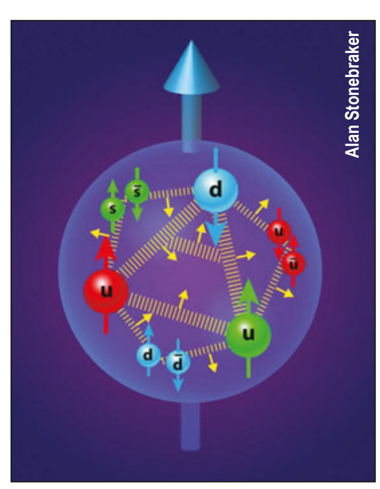
the proton. However, experiments in the 1980s revealed that quark spins only accounted for about 30% of the proton spin. The rest could come from gluons, which are massless particles that bind

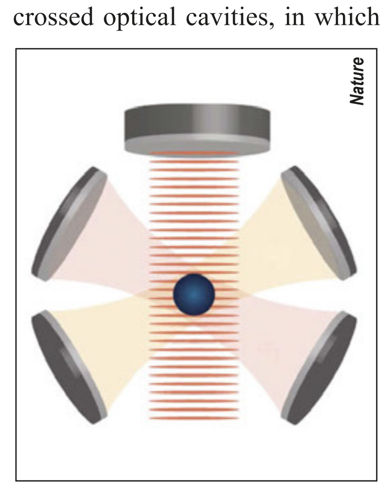


Source of the proton's spin

quarks and other nuclear material together. Using a model in which quarks and gluons reside within a 3D lattice, the χQCD Collaboration calculated how much gluons—which are spin-1 particles—align with each other inside the proton. The results, reported in *Physical Review Letters* (DOI: 10.1103/PhysRevLett.118.102001), showed that the net spin contribution from gluons is about 50%, which is roughly consistent with recent experiments. The remaining 20% of the proton spin is thought to be due to the orbital angular momentum of quarks and gluons as they move around inside the proton. (For more, see the Viewpoint in *Physics* "Spinning Gluons in the Proton" by Steven Bass, physics.aps.org/articles/v10/23)

Supersolids Spotted in Quantum Gases

Two independent research groups say that they have observed signatures of supersolidity in superfluid Bose-Einstein condensates (BECs). Supersolidity—alongside superconductivity and superfluidity—is a spectacular macroscopic quantum state of matter, in which a crystalline substance can flow like a liquid with zero viscosity. Starting in 2004, several groups claimed to have found evidence of supersolidity in pressurized, ultracold helium. In 2012, however, more sophisticated studies dampened the excitement, revealing that the early data were misunderstood and leaving supersolidity in the realm of conjecture. Now, Leonard et al. and Li et al. report in *Nature* (DOI: 10.1038/nature21067; DOI: 10.1038/nature21431) that they have seen the evidence of supersolid behavior in quantum gases cooled to nanokelvin temperatures. Leonard et al. placed a BEC inside crossed optical cavities, in which

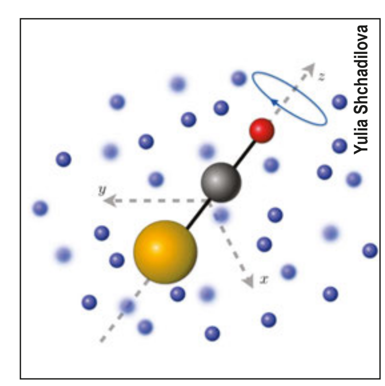


Trapping a supersolid

laser light caused the atoms in the condensate to crystallize and form a solid that retained the superfluidity of the condensate—a supersolid. Li et al. instead trapped a BEC in a double-well potential and "shook" it with lasers. This coaxed the atoms to arrange into a periodic striped pattern, which the authors interpret as solid order coexisting with the superfluid one.

Welcome the Angulons

Understanding how impurities interact with a quantum environment is a formidable theoretical challenge but, as Lemeshko reports in *Physical Review Letters* (DOI: 10.1103/PhysRevLett.118.095301),



Quasiparticles in molecules

there is a simple and elegant way to describe an important type of impurity: a molecule immersed in a quantum solvent. Analyzing experimental data, Lemeshko has shown that molecules in one such solvent, superfluid helium, form quasiparticles called angulons. A superfluid environment can strongly affect a molecule's rotation, thereby shifting its spectral lines, and to understand this, researchers have had to run complex numerical simulations limited to small clusters. Inspired by the quasiparticle concept of polarons—electrons with renormalized properties moving in materials—Lemeshko wondered if a similar quasiparticle approach could simplify the problem of rotating polyatomic molecules interacting with quantum solvents. Lemeshko has now demonstrated, through a comparison of theoretical predictions and experimental results, that angulons are especially helpful in understanding the rotational structure in the absorption spectrum of molecules immersed in quantum solvents. With simple analytical expressions available, analyzing experimental data will be much simpler. This may also help researchers use molecules immersed in quantum solvents as remarkably small sensors that are only a few atoms in size. (For more, see the Viewpoint in *Physics* "A New Angle on Quantum Impurities" by Yulia Shchadilova, physics.aps.org/articles/v10/20)

ANNOUNCEMENTS

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1. Identify good working equipment and supplies from your facility and send us a list of what you have. We can only accept full systems in good working condition, rather than components. We verify that your equipment matches the needs of our carefully screened scientists overseas.
2. You sign a donation form and pack up your equipment for transfer. You can ship to us or have us arrange for pick-up.
3. Through our Instrumental Access program, we match the appropriate equipment to the needs of the scientists abroad and coordinate shipping with them. We release you of liability and handle all necessary inspections, insurance, and paperwork needed for customs clearance and export control.

You can find a more detailed wish list of equipment that Seeding Labs needs at seedinglabs.org/equipment-wish-list/.

Don't have equipment to donate?

You can support the global scientific community in many other ways. We are always in need of philanthropic donations to enable us to get equipment from our warehouse into the hands of scientists around the world. Check out our website to make a personal donation and learn more about how you can get involved.

What is the impact?

Your donation supports the most talented scientists around the world, a vetted network of researchers with limited resources but immense potential.

A great example is Romano Mwirichia, Ph.D., at the University of Embu in Kenya. He is a microbiologist who trained at Yale University before returning to teach at Embu. In his application, he described an experience common to many of our partners.

"We have highly trained scientists who lack the tools to deliver quality training," he said. "Despite our advanced training in some of the best labs in the world, on returning back home we have to contend with poorly equipped labs or start from zero, like me. Access to more equipment will enable us to engage in research to address the unique problems we have in local settings."

Mwirichia and his colleagues in the Department of Biological Sciences received their Instrumental Access shipment in December 2016. It included more than $460,000 worth of equipment and supplies that will catalyze the university's teaching and research.

As a young university, they had lab facilities but little equipment of their own. Thanks to Instrumental Access, students will be able to do the lab work for their classes on campus rather than traveling to neighboring institutions.

The long-term impact Instrumental Access can have on academic science is undeniable. At just six Instrumental Access universities reporting in 2016:

- Research staff have utilized the equipment to advance 28 research projects and win new research grants worth $1.2M.
- Up-and-coming scientists used instruments from Seeding Labs to complete at least 31 Master's theses and 23 Ph.D. dissertations.
- More than 5,800 students each year are taking courses that incorporate the equipment, getting crucial hands-on STEM experience.

We'd love to talk more about how APS members can impact the global scientific community with a donation or a custom partnership with Seeding Labs—just send us an email at info@seedinglabs.org, or give us a call at 617-500-3014.

For more on Seeding Labs visit seedinglabs.org, @Seedinglabs, or facebook.com/seedinglabs.

Teresa Ventura is a development associate at Seeding Labs.

Teresa Ventura

The Back Page

Cosmic Humility

By Lawrence M. Krauss

Author note: The Greatest Story Ever Told—So Far *describes the revolutionary changes that have taken place in our understanding of the universe as a result of the development of the standard model of particle physics, its testing, and its implications for our past and future. Beginning with Plato, the story quickly moves to the 20th century and in particular describes developments since the 1950s, including the importance of the notions of gauge symmetry and spontaneous symmetry breaking in modern physics, which I think are not fully appreciated in the popular consciousness. Indeed the period 1955-1975—during which we emerged from great confusion in the growing elementary particle zoo, and went from understanding just one to understanding three of the fundamental forces in nature as fully consistent relativistic quantum theories governed by gauge symmetries—could be viewed as altering our understanding of the fundamental nature of our existence in a way that is comparable to the amazing decades from 1905-1925, which brought us special and general relativity and quantum mechanics.*

"These are the tears of things, and the stuff of our mortality cuts us to the heart."

So said Virgil as he penned the first great epic story of the classical era. They are the words I chose to use as the epigraph of this book because the story I wanted to tell not only contains every bit as much drama, human tragedy, and exaltation, but it is ultimately motivated by a similar purpose.

Why do we do science? Surely it is in part so that we can have greater control of our environment. By understanding the universe better we can predict the future with greater accuracy, and we can build devices that might change the future—hopefully for the better.

But ultimately I believe we are driven to do science because of a primal urge we have to better understand our origins, our mortality, and ultimately ourselves. We are hard-wired to survive by solving puzzles, and that evolutionary advantage has, over time, allowed us the luxury of wanting to solve puzzles of all sorts—even those less pressing than how to find food or to escape from a lion. What puzzle is more seductive than the puzzle of our universe?

"What puzzle is more seductive than the puzzle of our universe?"

Humanity didn't have a choice in its evolution. We find ourselves alive on a planet that is 4.5 billion years old in a galaxy that is 12 billion years old, in a 13.8-billion-year-old universe with perhaps a trillion galaxies that is expanding ever faster into a future we cannot yet predict.

So what do we do with this information? Is there special significance here for understanding our human story? In the midst of this cosmic grandeur and tragedy, how can we reconcile our own existence?

For most people, the central questions of existence ultimately come down to transcendental ones: Why is there a universe at all? Why are we here?

Whatever presumptions one might bring to the question "Why?", if we understand the "how" better, "why" will come into sharper focus. I wrote my last book to address what science has to say about the first of the above questions. The story I have related here provides what I think is the best answer to the second.

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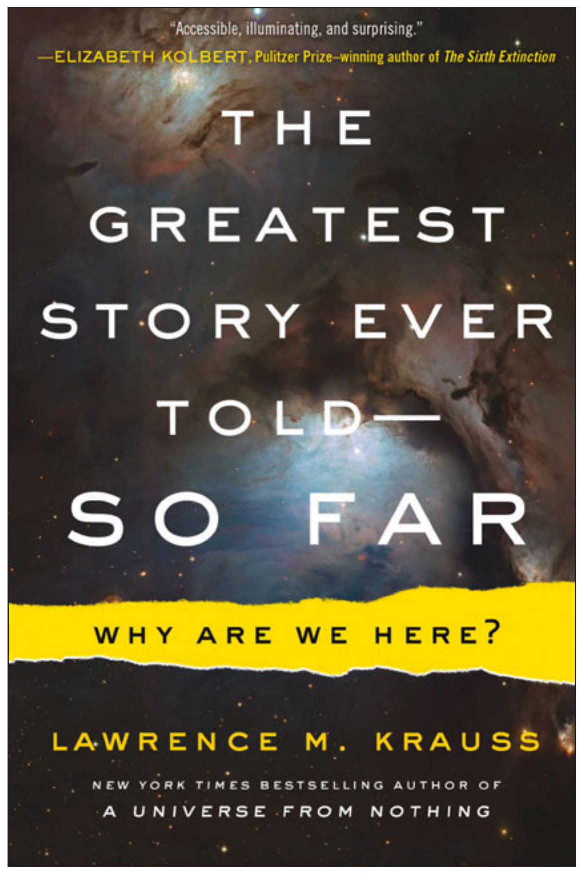
Faced with the mystery of our existence, we have two choices. We can assume we have special significance and that somehow the universe was made for us. For many, this is the most comfortable choice. It was the choice made by early human tribes, who anthropomorphized nature because it provided them some hope of understanding what otherwise seemed to be a hostile world often centered on suffering and death. It is the choice made by almost all the world's religions, each of which has its own claimed solution to the quandary of existence.

The second choice when addressing these transcendental mysteries is to make no assumption in advance about the answer. Which leads to another story. One that I think is more



humble. In this story we evolve in a universe whose laws exist independently of our own being. In this story we check the details to see if they might be wrong. In this story we are going to be surprised at every turn.

The story I have written here describes a human drama as much as a universal one. It describes the boldest intellectual quest humans have ever undertaken. It even has scriptural allegories, for those who prefer them. We wandered in the desert for forty years after the development of the Standard Model before we discovered the Promised Land. The truth, or at least as much of the truth as we now know, was revealed to us in what for most people seems to be incomprehensible scribbles: the mathematics of gauge theories. These have not been delivered to us on golden tablets by an angel, but rather by much more practical means: on pieces of paper in laboratory notebooks filled through the hard work of a legion of individuals who knew that their claims could be tested by whether they correctly modeled the real world, the world of observation and experiment. But as significant as the manner by which we got here is that we have gotten this far.

At this point in the story, what can we conclude about why we are here? The answer seems all the more remarkable because it reveals explicitly just how deeply the universe of our experience is a shadow of reality.

I also began this book with a quote from the naturalist J. A. Baker, from *The Peregrine*: "The hardest thing of all to see is what is really there." I did so because the story I have told is the most profound example of this wise observation that I know of.

I next described Plato's Allegory of the Cave because I know of no better or more lyrical representation of the actual history of science. The triumph of human existence has been to escape the chains that our limited senses have imposed upon us. To intuit that beneath the world of our experience lies a reality that is often far stranger. It is a reality whose mathematical beauty may be unimpeachable, but a reality in which our existence becomes—more than we might ever have imagined in advance—a mere afterthought.

If we now ask why things are the way they are, the best answer we can suggest is that it is the result of an accident in the history of the universe in which a field froze in empty space in a certain way. When we ponder what significance that might have, we might equally ponder what is the significance of that specific ice crystal seen in the early morning frost on a windowpane. The rules that allowed us to come into being seem no more worth fighting and dying for than it would seem to be to fight and die to resolve whether "up" in the ice-crystal universe is better than "down," or whether it is better to crack an egg from the top or the bottom.

Our primitive ancestors survived in large part because they recognized that nature could be hostile and violent, even as it was remarkable. The progress of science has made it clear just how violent and hostile the universe can be for life. But recognizing this does not make the universe less amazing. Such a universe has ample room for awe, wonder, and excitement. If anything, recognition of these facts gives us greater reason to celebrate our origins, and our survival.

To argue that, in a universe in which there seems to be no purpose, our existence is itself without meaning or value is unparalleled solipsism, as it suggests that without us the universe is worthless. The greatest gift that science can give us is to allow us to overcome our need to be the center of existence even as we learn to appreciate the wonder of the accident we are privileged to witness.

Light played a major role in our story, as it did in Plato's allegory. Our changing perception of light led us to a changing understanding of the essence of space and time. Ultimately that changing perception made it clear that even this messenger of reality that is so essential to us and our existence is itself merely a fortunate consequence of a cosmic accident. An accident that may someday be rectified.

"The greatest gift that science can give us is to allow us to overcome our need to be the center of existence even as we learn to appreciate the wonder of the accident we are privileged to witness."

It is appropriate here to recognize that the line in the Aeneid that follows the epigraph with which this book began was the hopeful cry "Release your fear." A future that might bring about our end does not negate the majesty of the journey we are still taking.

The story I have told is not the whole story. There is likely to be far more that we don't understand than what we now do. In the search for meaning, our understanding of reality will surely change as the story continues to unfold. I am often told that science can never do some things. Well, how do we know until we try?

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This story ultimately does not give the past special significance. We can reflect upon and even celebrate the road we have taken, but the greatest liberation, and the greatest solace that science provides, come from perhaps its greatest lesson: that the best parts of the story can yet be written.

Surely this possibility makes the cosmic drama of our existence worthwhile.

The author is Director of the Origins Project and Foundation Professor in the School of Earth and Space Exploration at Arizona State University. He is the author of over 300 scientific publications as well as 10 popular books, and writes frequently for newspapers and magazines as well as appearing on radio and television, and in films. He is a Fellow of the APS and has won the Society's Lilienfeld Prize and Burton Award, as well as the Oersted Medal of the American Association of Physics Teachers and the Gemant Prize of the American Institute of Physics.

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