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Sidney Nagel Delights in Disorder

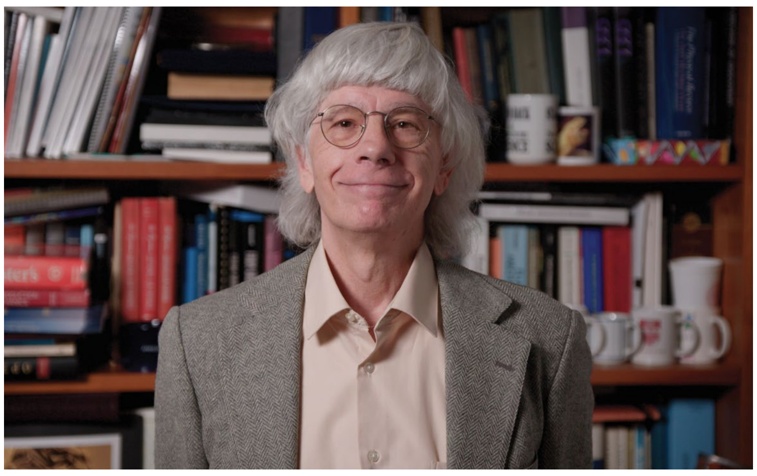
An interview with the recipient of the 2023 APS Medal.

BY RACHEL CROWELL

Honey dripping from a spoon; sand shifting in a pile. The world is replete with materials that seem simple, but whose behavior is puzzling beyond expectation. Sidney Nagel, a physicist at the University of Chicago and a leader in soft matter physics, relishes studying the quirky properties of glass, coffee stains, and more — materials that are "disordered," meaning their components are jumbled at random instead of organized symmetrically.

"I can't walk down the street and see a stain on the sidewalk [without stopping] to look at it," he says. "That's being a true nerd."

Nagel, who studies non-linear behavior in disordered systems that are far from equilibrium, is the recipient of the 2023 APS Medal for Exceptional Achievement in Research. The award recognizes Nagel "for incisive experiments, numerical simulations and concepts that have expanded and unified soft matter physics."



Sidney Nagel. Credit: APS

But earlier in his career, his work was received differently. "Disorder wasn't something to be studied," he says. When he began studying sandpiles, he received a particularly harsh response.

"I remember walking down the hall of my institute and someone said — loud enough that I could hear but behind my back — 'I don't know what's the matter with him. He used to have a promising career in science,'" he recalls.

But Nagel kept at it. "I like to choose problems which satisfy me not just intellectually, but because

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Scientists Investigate Salty Stellar Recipes

In large collections of stars, sodium is far more abundant than expected. To explain this, scientists bring a stellar reaction into the lab.

BY MEREDITH FORE

All atoms began as the universe's simplest ingredient: hydrogen. And when hydrogen is heated and mixed in the extreme environment of a star, complex nuclear reactions produce heavier elements.

We are made of these heavier elements — "star stuff," as Carl Sagan famously noted. But the precise recipes for star stuff are a bit of a mystery, since we can't exactly send a probe into the interior of a star to observe reactions as they occur.

At the Fall 2022 Meeting of the APS Division of Nuclear Physics in Spokane, Washington, experts gathered to discuss in detail how heavier elements are created in stars. Some researchers focused on the strange abundance of a specific stellar ingredient familiar to terrestrial recipes: sodium.

Salty Stars continued on page 5

A globular cluster of stars called 47 Tucanae. In some clusters, scientists have observed almost 100 times more sodium than exists in our solar system.. *Credit: ESO/M.-R. Cioni/VISTA Magellanic Cloud survey*

First a Bridge Program Graduate, Now a NASA Astrophysicist

Laura D. Vega has her eyes on the stars — the pulsating giants and red dwarfs, to be specific.

BY LIZ BOATMAN

Laura D. Vega graduated with her physics doctorate from Vanderbilt University in 2021. Credit: Laura D. Vega

Astrophysicist Laura D. Vega remembers when she first fell in love with stars.

She grew up in San Antonio, Texas, and her parents, originally from Mexico, often took the family on road trips to Coahuila and Zacatecas to visit relatives. On those long, overnight drives, Vega — peeking out the backseat window — would watch the dark sky glitter.

"San Antonio is a big city," she says. "You can only pick out the really bright stars … but in the desert, it's just dark. You can *really* see the stars."

Vega had questions — and she took them straight to the library. By sixth grade, she was tackling Stephen Hawking's *A Brief History of Time*.

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Study Reports the Impact of COVID-19 on Recent Physics Grads

Some undergrads, like those squeezed financially, were more likely than others to change their post-graduation plans.

BY LIZ BOATMAN

Wells Graham, a doctoral student in physics at Wake Forest University, knows all too well how dire the COVID-19 pandemic was for many undergraduates in science.

Graham graduated with a bachelor's in physics in 2021 from the University of North Carolina, Pembroke, a small university. He says that although his professors did a "great job" of adapting to online teaching during the pandemic, conferences were canceled, and he was never able to take the physics GRE subject test — key to beefing up his graduate school applications.

"Coming from a small school, I was banking on the physics GRE to strengthen my application," says Graham. "I felt I could not put my best foot forward." He's happy to have landed at Wake, but the process was difficult: He was accepted into just two of the seven physics graduate programs to which he had applied.

While some students, like Graham, stuck to their post-graduation plans despite the pandemic, others did not or could not. To study the issue, the American Institute of Physics (AIP) surveyed physics and astronomy seniors in the spring of 2021 about their post-graduation plans, and then again in the spring of 2022, to see if the seniors stuck to their plans. In November, AIP released their report, which captures the experiences of 1,823 seniors.

Undergraduates prepare for a poster session at the APS March Meeting 2022. *Credit: APS*

Anne Marie Porter, senior survey scientist at AIP and report co-author, says that her team sought to understand the factors that might push undergraduates out of physics.

"We asked about [students'] satisfaction with the different aspects of their institution's response during COVID-19," says Porter — including financial aid, learning accommodations, IT support for classes, access to mental health services, and on-campus living arrangements. "We really wanted to focus on impacts that could have longer-term effects, beyond just a window into that time period."

Porter and her report co-author Patrick Mulvey, research manager of the AIP Statistical Research Center, found that about three-quarters (77 percent) of respondents did what they had planned to do after graduation.

For example, of the students who had intended to get jobs, 85 percent actually did, including Theo Axtell-Adams. Axtell-Adams, who majored in applied physics and mechanical engineering at the University of Wisconsin-Stout, says that completing his undergraduate degree during the height of the pandemic had ups and downs.

"Trying to learn in that environment and with such a different structure was difficult for me," he says, referring to typically hands-on courses that the university pushed online. "Thankfully, I was able to complete an internship the following summer, and my capstone [project] happened the following year in person," he says. Axtell-Adams is

COVID-19 continued on page 5

How Sound Waves Could Power a Greener Air-Conditioner

At an APS meeting on fluid dynamics, researchers discussed thermoacoustic heat pumps, a decades-old technology they believe could emit fewer greenhouse gases than conventional cooling technologies.

BY LIZ BOATMAN

As global populations grow and the climate warms, humanity will need increasingly effective ways to cool itself off — on an enormous scale. Experts predict that, globally, the number of cooling systems, like air conditioners, could double or even quadruple by 2050.

Today, 3 billion refrigerators and heat pumps are in service, and air conditioners and electric fans consume 20 percent of electricity in buildings. As more of these technologies are used, waste heat, power consumption, and greenhouse gas emissions will grow, too.

For a world trying to rein in global warming, this is bad news.

One research team is working on a unique solution known as phase-change thermoacoustic cooling. Doctoral student Nathan H. Blanc of Technion, the Israel Institute of Technology, says thermoacoustic cooling has big advantages over conventional air conditioning. "With a longer technology lifecycle, it's much more sustainable," he says. Blanc presented recently published research at the 2022 APS Division of Fluid Dynamics (DFD) meeting in Indianapolis, Indiana, in November.

Blanc's co-authors are Guy Z. Ramon, his advisor at Technion, and Ramon's former postdoc, Rui Yang — the first author on their recent study, published in *Energy Conversion and Management*. Now, Yang is developing a related research program at the Technical Institute of Physics and Chemistry in Beijing.

Despite new interest in thermoacoustic cooling, the technology itself was pioneered in the 1980s. Greg Swift, a now-retired research scientist, started his career at Los Alamos National Laboratory as a postdoc working on alternative energy. At one point, his mentor left town on a trip — and came back with an idea. "We started out with simple experimental tests of the most basic thermoacoustic math," he says, and the field was born.

How does thermoacoustic cooling work? First, an inert gas is sealed inside a tube that's lined with heat-exchanging materials. Then a sound wave is fired into the tube. In low-pressure areas of the wave, the gas expands and absorbs heat; in high-pressure areas, the gas is compressed and expels the heat. Controlling the sound wave controls where heat is absorbed and released.

Although a wave only moves each bit of gas a short distance, the cumulative effect amounts to a "bucket brigade," creating a reliable heat-pumping system with few or no moving mechanical parts, Blanc said at the DFD meeting. This reduces the chance that the system breaks and lengthens its lifetime.

In fact, the technology is so reliable that a variation of it was recently launched into space aboard NASA's James Webb Space Telescope, to cool its mid-infrared light spectrograph instrument. "You would only send a technology to space, where no one is there to fix it, that you can count on," says Blanc.

Despite the historical contributions that scientists in the U.S. made to the field, if you search the phrase "thermoacoustic cooling" on Google Scholar, you'll find few recent contributions from U.S. researchers.

"Our flagship attempt to do something practical [with the technology] was a combustion-powered cryogenic liquefier of natural gas," says Swift. "We worked out the physics, made great progress on the en-

Cooling continued on page 6

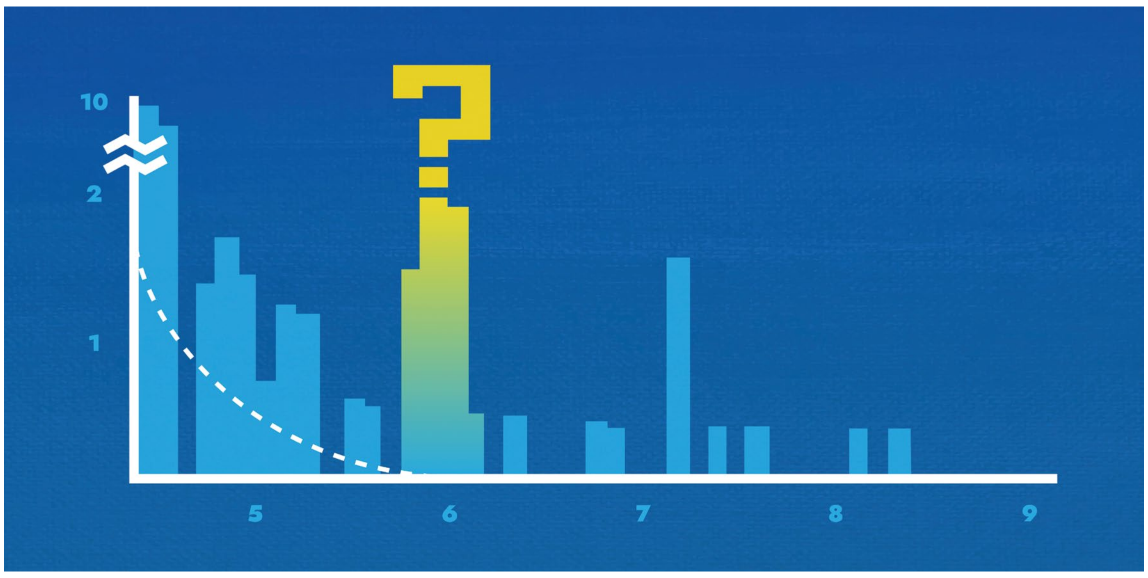
A rooftop air-conditioning unit. Global demand for cooling technologies is growing rapidly.

THIS MONTH IN PHYSICS HISTORY

January 1976: From the "Oops-Leon" to the Upsilon Particle

On the hunt for new particles, Leon Lederman's team "found" one that turned out to be a trick of the data. Then, a year after the "Oops-Leon" incident, they discovered the real deal.

BY DANIEL GARISTO



Credit: Elia King / APS

The history of particle physics is littered with spurious findings, blips in the detector that disappeared on second inspection. Most of these false discoveries have been buried under the deluge of real discoveries. But the "Oops-Leon," which would have been a new particle with a mass of 6 giga-electron-volts (GeV), remains unusually vivid.

During the late 1960s, the cohort of elementary particles was small but growing. Physicists had already discovered three types of leptons — electrons, muons, and neutrinos — and three of quarks — up, down, and strange. But the quarks were still just mathematical entities, not yet spotted in experiments, and the three remaining quark flavors — charm, top, and bottom — had not yet been proposed.

In 1967, Leon Lederman and his colleagues began a new experiment at Brookhaven National Laboratory, aimed at finding new particles. They slammed 30-GeV protons into neutron-rich uranium, which would decay first into virtual photons and then into pairs of electrons or muons — which could, in turn, be scrutinized by sensitive instruments for signs of new particles. To filter out the unwanted collision debris, the researchers used 10 feet of steel from World War II ships, which only muons could pass through.

The team expected the data to show a smoothly falling distribution of muon pairs and knew any bump could signal a new particle. But when Lederman's group saw a faint bump at 3 GeV, they convinced themselves it was nothing. "The signal [was] incontrovertibly there," says Dan Kaplan, an emeritus professor at the Illinois Institute of Technology who worked with Lederman later. "But they would have had great difficulty publishing this distribution as a discovery."

Seven years later, the 3 GeV particle, called the J/ψ meson, made from a charm and anticharm quark, was definitively discovered. Lederman knew he had missed out on a Nobel-worthy discovery and was determined not to miss out again.

At the newly operational Fermilab, Lederman and his team planned a repeat of the 1967 experiment, but at much higher energies of 400 GeV. For the experiment, called E288, the researchers would measure the results of particle collisions — and, if they found new particles, "publish these and become famous."

Notably, there was no explicit goal to find a heavier quark. Although physicists had found the up, down, strange, and charm quarks, models that predicted six quarks had not taken hold.

By August 1975, the E288 team began to see a distinct bump around 6 GeV, finding 12 events where the predicted background was four. The team calculated there was a 2 percent chance a signal that large would result from a statistical fluctuation alone. The team, it seemed, had stumbled on a brand-new particle, and it needed a name.

Chuck Brown, a member of the E288 team now retired from Fermilab, recalls a late-night shift with Jeff Weiss, poring over available Greek letters. "Iota was rejected since it resembles a question-mark — in hindsight, it would have been a better choice," John Yoh, the experiment coordinator, wrote in 1997. Then Walter Innes suggested that, if a particle named "Upsilon" turned out to be a mirage, they could simply call it an "Oops-Leon."

Incredibly, another Fermilab group also found evidence for a resonance at about 6 GeV using a different method and submitted their findings two days beforehand. Curiously, their result has been largely forgotten.

But data quickly cast doubt on both results. A few months later, Lederman's team repeated the experiment with muons and found no evidence of excess at 6 GeV, and an examination in 1977 finally ruled it out. The Upsilon was an Oops-Leon after all.

"People were searching around in the unknown," says Chuck Brown, a member of the E288 team. "It's, in some sense, just luck that we stumbled on [this particle]."

What went wrong? A decade earlier, Arthur Rosenfeld pointed out that "trials factors" — essentially, running an experiment multiple times — would lead to statistically significant "discoveries" that were flukes. To combat this, Rosenfeld proposed waiting until results met a strict statistical standard known as "five-sigma." But the standard was not adopted in earnest until the discovery of the top quark in 1995, argues experimentalist Tommaso Dorigo.

Although the E288 researchers included the effect of trials factors,

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I find that it's feeding something else," he says.

Nagel spoke with *APS News* about the beauty and complexity of disordered systems, and how physicists can chart their own paths.

This interview has been edited for length and clarity.

What does winning the APS Medal mean to you?

It means that the subject matter is being recognized. It was a fledgling field a few years ago, by my standards. I think a lot of people didn't take it terribly seriously.

This is really for the community of people who are studying these phenomena. It's a group effort to make this into a field that is exciting, has new things to say, and will bring new young people into the research area.

What are a few of your discoveries that have surprised you?

A surprise was what we did with splashing drops. The drop lands on a flat piece of glass, and if it's going fast enough, it splashes. We thought that was always going to be the case.

We were trying to figure out how fast the droplets were leaving the splash and how much energy was in them. We thought, "Let's pull a vacuum on this. Then we'll get a big splash." When we did this, the splash disappeared. The air around us is making the splash.

I could go on. One morning, I saw coffee stains on my counter. Suddenly, I realized these are bizarre, because all the coffee stain is at the edges of these drops. There was more liquid in the middle when the drops came down, and yet, at the end of the drying process, the solute particles [which give coffee its color] were all at the edge. This didn't make sense. I love surprises.

You're part of a collaboration called "cracking the glass problem," and you noted that studying glass has let you explore "new regimes of behavior" of materials. What have you discovered about that behavior?

If we understand the nature of disorder in the way that these disordered packings [of materials] can behave, what the elasticity is, this is a way of creating materials that we get to control. A new type of metamaterial, if you will. You could begin to think, "We could train materials."

This is something that we're working on now. How is memory stored in a material? How can you use that memory to control and manipulate the material? It's a new area that we hadn't conceived of, as part of what glassiness was about. But studying glassiness led us into this very productive area for me — the idea of memory.

Once I realized memory was something I wanted to study, I looked back and realized, "Oh, there's memory in so many of my papers from early on." I hadn't realized this was a subject that was central to a lot of studies, in different guises.

You've been credited with helping to bring the study of granular material, like sand, from engineering into the realm of physics. Tell me about your journey with that research.

In 1987, a paper had come out that said you could keep pouring sand onto this pile until it reached this angle of repose — the largest angle. The avalanches that come off the sandpile should be different sizes, and that should be a power law behavior. This was an idea called "self-organized criticality."

We found that this was spectacularly wrong, even though it's a beautiful idea. There's only one kind of avalanche that came out.

Along the way, we found that sand had many interesting properties. There was a temptation [to say], "Okay, let's go back to our serious work." [But] sand should be respected for what it does. Nature [had] just spoken to us and said, "Look, here's something totally different. Are you going to ignore it because society tells you, 'Oh, this isn't real physics'?"

We started playing with this material and realized that it was a lot more interesting than any of the theories [suggested]. This had to gain acceptance in the community.

What would you tell early-career physicists about how to find fun and joy in physics?

Everyone has their own way of working — some people want to work alone, other people like to work together. There are all different ways of doing physics. Figure out your way of doing physics that allows you to enjoy it [and] want to come back to it every day. The difficult part is that your ego gets into it; try not to pay that much attention to that.

Imagine you could answer any one open physics problem. Is there something you would choose?

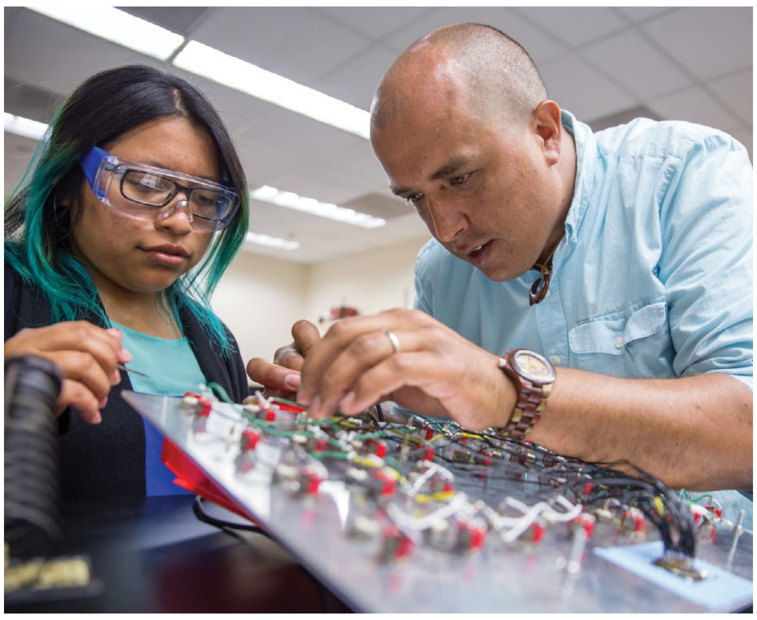
No, I don't think so. Rather than say, "Here's the big question I want to answer, and if I do that, I'll be rich, famous, whatever," I would rather have fun. It's very much the process that is fun.

Rachel Crowell is a math and science journalist based in Iowa.

APS Innovation Fund Fuels Quantum Education

Online communities help smaller undergraduate schools teach cutting-edge quantum science.

BY JESSE KATHAN



Justin Perron (right), a physics professor at California State University, San Marcos, works with a student. Perron and his colleagues Charles De Leone and Shahed Sharif received a grant from the APS Innovation Fund in Dec. 2020.
Credit: University Communications, CSUSM

The emerging field of quantum information science has far-reaching potential applications — uncrackable encryptions, sensors that enable location tracking without satellites, computers with unprecedented processing power. Although much of the field is still theoretical, technology companies and national laboratories are investing heavily in its development.

"I think we're approaching a tipping point," said Justin Perron, associate professor of physics at California State University, San Marcos. "There's going to be a case where it's financially beneficial to use these technologies."

Perron wants his students to get in on the ground floor of the discipline. But unlike large research universities, California State University mainly serves undergraduates, and the San Marcos campus only has two other faculty members with a background in quantum mechanics: physics professor Charles De Leone and math professor Shahed Sharif.

When the three began meeting to discuss how to teach quantum information science, the challenge they faced seemed stark: In such a highly interdisciplinary field, having a small faculty put Perron and his colleagues at a disadvantage. "We realized it was really hard," Perron said.

To build a new curriculum, he and his colleagues decided to look beyond the boundaries of their campus.

In June 2021, with the help of an APS Innovation Fund grant of about $82,000, Perron and his collaborators created a workshop called the Quantum Undergraduate Education and Scientific Training (QUEST), geared toward faculty of primarily undergraduate institutions. During the two-day workshop, nearly 100 participants from more than 60 undergraduate institutions met to discuss the challenges and opportunities of quantum information science education.

Perron found that instructors at other smaller colleges and universities were facing similar struggles to expand their programs. But bringing together quantum physicists, computer scientists, engineers, and other specialists made the conference a "brain trust," Perron said. Together, participants tackled common stumbling blocks around developing courses, integrating departments, and persuading administrators to support new programs. During one panel, leaders from Google, the University of Colorado, Boulder, and consulting firm Booz Allen

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New Models Expand Thermodynamics to Humidity-Driven Engines That Mimic Plants

Researchers rework traditional thermodynamics to study mechanisms that create motion from changes in humidity.

BY BAILEY BEDFORD

What do pinecone scales and steam engines have in common?

They both do work — and both can be analyzed using thermodynamics.

Steam engines and other heat engines, which are powered by temperature changes of a fluid, have been extensively studied and applied since the field of thermodynamics was founded in the 1800s. Now, researchers are exploring alternative methods of generating work, including mechanisms that mimic pinecone scales, which open because of changes in humidity.

In a paper published October 26 in *Physical Review Applied*, researchers describe new thermodynamical models of engines driven by humidity changes. Their work adapts traditional thermodynamics to this developing technology and applies the results to natural and artificial materials.

"Surprisingly, natural systems had a very high efficiency compared to artificial systems" in their analysis, says Ho-Young Kim, a mechanical engineering professor at Seoul National University and a co-author of the paper.

Engines that produce motion from a material's response to a humidity change are an example of technologies called soft engines. Soft engines can be driven by a material's response to other things, like changes in light, and can be parts of soft robots that forgo rigid parts, batteries, and combustion. These traits make soft robots promising for many uses, including in medical settings where batteries or hard edges might injure patients.

"I think this paper is very important for this field," says Zhu Liangliang, an engineering professor at Northwest University in Xi'an, China, who was not involved with the paper. He says that the thermodynamics and energy efficiency of soft machines are important for practical applications but rarely researched.

Kim says he was inspired to research humidity-driven soft robots by plants' motion, and that he was surprised to find a principle that governs both heat engines and soft engines.

Kim and colleagues followed in the footsteps of Sadi Carnot, a French engineer who studied steam engines in the 1800s. Carnot conceived of the cycle that describes an ideal, maximally efficient heat engine. The cycle describes a fluid (usually a gas) that changes temperature, volume, and pressure in four stages, producing work as it shifts between two temperature extremes. The researchers adapted Carnot's cycle into their own, describing instead a material moving between two levels of humidity.

The team carefully accounted for all the energy changes of a soft engine going through four steps: Ambient humidity increases, the material absorbs humidity and grows, ambient humidity decreases,

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Quantum Ed continued from page 3

Hamilton discussed the skills and knowledge students need to join the workforce.

Another panel focused on making programs inclusive for all students. Because the field of quantum information science is still in its infancy, instructors can shape a research community that is diverse from its inception, said Sharif. "We want to make sure that the educational opportunities are there for everybody, not just people from privileged backgrounds," he said. "The earlier the interventions, the better."

Creating curriculum outside of major research universities is already a big step, because smaller, primarily undergraduate schools, like many in the California State University system, "tend to have much more diverse populations," Sharif said. In 2021, 51 percent of CSU undergraduates were Black or Latino, compared to 29 percent of University of California undergraduates.

In the academic year following the workshops, 16 participants met in four online communities to develop curricula for quantum information science at their institutions. Some created summer courses to introduce undergraduates to the field, while others began building long-term plans to create whole courses or major concentrations.

For Sean Bentley, an associate professor of physics at Adelphi University who is developing a quantum science track for physics majors, the online group has been an invaluable resource. "Talking to people who have already been there, already done it — that saves you so much time," he said.

Although the groups ended in June, Bentley remains in touch with the other faculty in his group. Virtual resources have become especially important in the wake of the pandemic, he said.

"Conferences are great, but when you're all across the nation, especially if you're at a small institution where you don't have a lot of faculty to talk to, having these online communities where you can exchange ideas is really helpful," Bentley said. "This is something that hopefully will continue to grow."

At CSU San Marcos, Perron and his colleagues are designing a certificate program in quantum information science, which they hope to offer within the next two years. They're also drafting proposals for more funding to strengthen quantum education in the CSU system.

"You feel like an island at your institution when you're the only one in that field," Perron said. "We had a hard time trying to do it ourselves. We learned that we could return to the community and everyone else could help us figure it out."

Jesse Kathan is a science journalist based in Berkeley, California.

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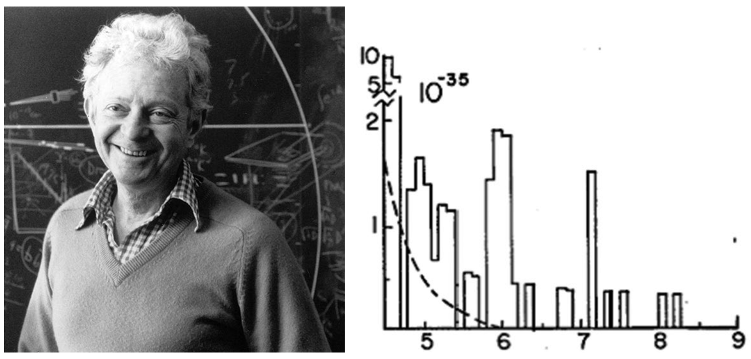

Leon Lederman, the physicist who led Fermilab's E288 team in the 1970s. The team initially identified a new particle — shown in the plot at right as a peak around 6 GeV — but, when the particle turned out to be fluke in the data, the Upsilon was renamed the "Oops-Leon." Credit: Public domain / Wikimedia commons

a five-sigma standard might have prevented them from claiming a discovery. But the team also made a mistake: They assumed the background scaled as the inverse cube of mass, whereas it actually fell exponentially. It wasn't 4, but more like 8. Over the increased background, 12 events are much less significant.

Undeterred, the E288 team continued taking data. In November 1976, Yoh noticed a small excess around 9.5 GeV, already more statistically significant than the Oops-Leon. In an act of faith, he wrote "9.5 GeV" on a bottle of champagne and kept it in the lab freezer.

But as the team was collecting more data to support the 9.5 GeV bump, it suffered what could have been a devastating setback. Just before midnight on May 20, a fire ravaged their electronics. "My birthday is May 21," Kaplan remembers. "I was saved a midnight shift by that." Lederman, who had dealt with a similar problem before, phoned a Dutch fire expert in the middle of the night. Through State Department contacts, Lederman got a visa approved in record time. The expert arrived on May 21, and the electronics were salvaged.

With the experiment back up and running, they gathered enough data to convince even the most cautious members of the collaboration that a particle at 9.5 GeV did, in fact, exist. The discovery was published in *Physical Review Letters* without review, under a new policy designed to deal with the priority disputes plaguing high energy experimental physics.

"People were searching around in the unknown," says Brown. "It's, in some sense, just luck that we stumbled on it. I mean, that was not the goal of the experiment."

The Upsilon was three times heavier than any previously discovered particle, but what it implied was even more astonishing: the existence of a fifth quark, the bottom quark. While some theorists had proposed six-quark models, the idea was nascent until the Upsilon propelled it forward into the modern Standard Model.

Though the Oops-Leon was a fluke, its legacy remains intertwined with the real Upsilon.

"There's an important theme here," Kaplan says. "You have to have the good fortune to have the opportunity to fail gracefully and be given a second chance."

Daniel Garisto is a writer based in New York.

Science Policy Successes in 2022

APS members worked tirelessly for this year's achievements.

BY TAWANDA W. JOHNSON

Dedicated volunteers helped APS accomplish its 2022 science policy goals, which included supporting legislation to strengthen U.S. science and technology innovation, combat climate change, and ease immigration for international scientists. Volunteers made more than 4,700 connections with Congress, including phone calls and emails.

"We're proud of APS members' hard work," said Mark Elsesser, director of government affairs for APS.

APS's 2022 science policy successes are highlighted below.

CHIPS and Science Act

The CHIPS and Science Act of 2022, signed into law on Aug. 9, is the most important bill for science and innovation in more than a decade. APS and its members were strong advocates for the bill. The legislation significantly increased authorized funding to federal science agencies and included provisions that APS has pushed for years to advance: creating a stronger and more diverse workforce, combating sexual and gender harassment in STEM, and addressing the helium crisis through increased recycling efforts.

China Initiative

APS was a leading voice in helping to end the China Initiative, a program intended to crack down on the illicit acquisition of U.S.-based knowledge or technical expertise, but which instead sowed fear among some Society members and curtailed legitimate scientific collaborations. APS held community events to highlight the policy's negative impacts and launched a grassroots campaign to raise awareness with Congress. APS leadership also met with FBI staff and Justice Department officials to push for changes. The Justice Department ended the initiative in February.

Congressional Visits Days

Nearly 70 APS members who attended the APS Annual Leadership Meeting advocated for APS's science policy priorities during the 2022 Congressional Visits Day. They met with congressional offices to discuss policy priorities, including funding key federal science agencies; supporting the Keep STEM Talent Act; supporting appropriations matching the authorization levels for the National Science Foundation's Robert E. Noyce Teacher Scholarship program, and championing legislation to improve the program's recruitment and retention of qualified K-12 STEM teachers; developing a national strategy for measuring methane emissions and a national database for those observations; and requiring a realistic testing and assessment program for U.S. Missile Defense systems.

Methane Emissions

APS and Optica produced a report that provided a technical assessment and policy recommendations to reduce methane emissions. The report informed the Methane Emissions Mitigation Research and Development Act, a bill introduced in the U.S. House of Representatives that would establish an Energy Department program to detect, quantify, and mitigate methane emissions. APS and Optica also facilitated briefings on the report to federal agencies and congressional offices.

Visas and Immigration

APS members advocated for federal efforts to keep the U.S. a destination of choice for international STEM talent. Two provisions in the COMPETES Act of 2022, which passed the House of Representatives, would help the U.S. reach this goal. One allowed F-1 visa applicants to express dual intent, indicating their interest to remain in the U.S. after completing their studies. The other created a pathway to permanent residency for individuals who earn advanced STEM degrees from U.S. institutions.

Tawanda W. Johnson is the Senior Public Relations Manager at APS.

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and the material releases humidity and shrinks to its initial state. The researchers identified the best possible efficiency of a humidity-driven soft engine, which depends on the two humidity extremes.

But a soft engine that faces no resistance isn't very practical, so the team adapted their model to account for the material pushing on something as it expands, which reduces efficiency. They then modeled the cycle for a type of soft engine that bends, using a mechanism similar to that in pinecone scales. This further decreases efficiency but can be advantageous in generating movement over a longer distance.

The researchers' results indicate that, for a bending soft engine, a thinner absorbent layer tends to be more efficient but also to produce less mechanical work. So, the team proposes using an alternative value, called the work ratio, to evaluate the performance of a soft material in engines that bend. The value reflects the portion of a soft material's hypothetical extractable work that is actually extracted by the bending mechanism — so the higher the value, the more effective the engine is at getting work from its soft material.

Using existing literature, the researchers calculated the work ratio of several engines based on various humidity-absorbing natural and artificial materials. They found that the work ratios for the engines using natural materials tend to range from 0.2% to 2%, while almost all the artificial soft engines that didn't use plant-based materials had work ratios below 0.1%. The analysis suggests plant-based bending soft engines are generally more than twice as good as their purely artificial counterparts at harnessing the potential work of their humidity-absorbing material.

"Plants are very, very clever creatures in making motions without muscles," Kim says. "We have to learn from plants."

The team suggests that the higher efficiency of natural materials is likely related to the pace of plants' mechanisms, which generally operate more slowly than those of their artificial counterparts.

Going forward, the team says their models can potentially be adapted to soft engines driven by the diffusion of other stimuli, like solvents, heat, or ions. Kim says their models provide a more guided way to develop materials for soft engines than trial and error.

"I'm not saying that this methodology should be adopted by every soft material scientist, but I'm just suggesting that you have to look at the energy efficiency of those soft materials," Kim says. "This is one methodology you can adopt."

Bailey Bedford is a science journalist based in the Washington, D.C. area.

Salty Stars continued from page 1

Though we can't peer inside stars to watch the cooking process, we can identify their elemental ingredients by analyzing the light they give off. Sodium has been found to have a variety of effects on stars, from changing their color to affecting their lifecycle. And in globular clusters, which are massive spherical conglomerations of up to millions of stars, scientists have observed almost 100 times more sodium than is present in our own solar system.

"Sodium is very easy to destroy. The star should have no problem destroying it," said Richard Longland, associate professor at North Carolina State University and researcher on the project. (To nuclear physicists, "destroy" means "change into another element.") "But there's a surprisingly large amount of sodium in these stars, so there must be something about the stellar environment that is keeping the sodium from being absorbed into other reactions."

Besides the mystery of sodium's abundance, scientists have also observed an anti-correlation between sodium and oxygen in stars. The more sodium there is, the less oxygen there is. But recipes that produce or destroy sodium don't tend to produce or destroy oxygen, and vice versa.

So the question becomes twofold: why is there so much sodium in globular clusters, and why is it correlated to the amount of oxygen?

"The problem is that we don't know," said Longland. "You can't see by looking at the outside of the star what the conditions on the inside of the star are, and that's why there's still a lot to discover. But this work can help us start ruling things out."

In the sodium-destroying reaction studied in this case, sodium absorbs a proton and turns into magnesium. Considering that stars are mostly made of protons, this would be an easy recipe to execute in a stellar oven. Kaixin Song, a graduate student at NCSU, replicated the reaction in a lab, shooting helium-3 at a sodium target to spark a proton transfer, and measured the reaction rates to see how often this might happen in a star. These reaction rates are fundamental to accurate stellar modeling, where theorists predict the abundances of different elements in different types of stars. The sodium-destroying rate Song found was lower than expected, but not low enough to explain the sodium abundance.

> "There's a surprisingly large amount of sodium in these stars, so there must be something about the stellar environment that is keeping the sodium from being absorbed into other reactions," said Richard Longland.

"It's very cool to me to be able to do things in the lab that correspond to processes in stars and supernovae," said Song.

While it's impossible to directly observe the nuclear reactions that create heavier elements in stars, there are exciting new possibilities for indirect observation of stellar interiors. Scientists have been studying "starquakes" — seismic activity within stars — to understand the composition of stars, in the same way that geologists use earthquakes to probe Earth's structure. And very recently, particle physicists detected neutrinos that were produced by a reaction in the interior of our Sun.

The precise details behind the creation of heavier elements might seem inconsequential, but research like this could help answer an important existential question: how our "star stuff" gets made.

Meredith Fore is a science writer for the Chicago Quantum Exchange.

Vega continued from page 1

Today, Vega is a postdoctoral researcher at NASA's Goddard Space Flight Center in Maryland. As a member of the Stellar Flares team, in the Exoplanets and Stellar Astrophysics Laboratory, she studies the ultraviolet light from M-type red dwarf stars.

Vega had dreamed of working at NASA since she was a child. In college at the University of Texas at San Antonio (UTSA), she realized that, to make that dream a reality, she'd need research experience.

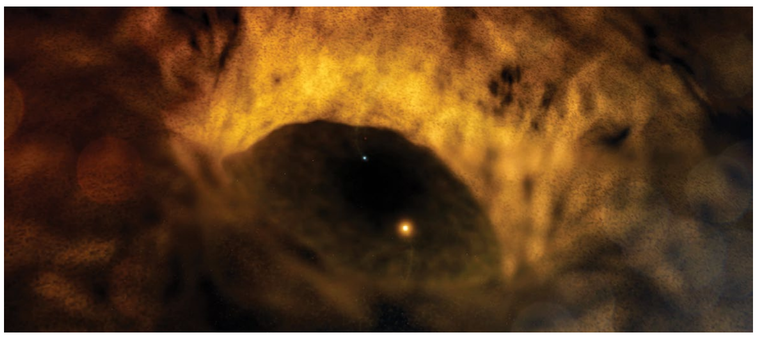
"I reached out to my Astronomy 101 professor, Eric Schlegel, asking if he had any opportunities," she says. "I was open to anything." She was in luck: Over the next several years, Vega helped Schlegel analyze X-ray data from two NASA telescopes. The projects put her on the fast track to NASA.

In her last semester, Vega attended a 2013 conference organized by the Society for the Advancement of Chicanos/Hispanics and Native Americans in Science. There, she met David Ernst and Rodolfo Montez Jr., from Vanderbilt University, who told Vega about the Fisk-Vanderbilt Master's-to-PhD Bridge Program, an APS Bridge Program partnership. The program, which helps students earn master's degrees from Fisk University and then doctoral degrees from Vanderbilt, has become a model for supporting students from underrepresented minority groups as they pursue advanced degrees in physics.

"I just fell in love with [the Fisk-Vanderbilt program]," she says. "I was like, this is what grad school is supposed to be like."

So after earning her physics bachelor's degree in 2013 from UTSA, a Hispanic-serving institution, Vega moved to Nashville, Tennessee, to start her master's degree at Fisk, a historically Black university.

"That was what I wanted — my heart was set on it," she says. "But I was also worried about moving from San Antonio. I had lived with my parents all my life."



While Vega was at Vanderbilt, NASA published a story on her research on U Monocerotis, a star system in the Milky Way. In this illustration, the two stars orbit each other in an enormous dusty disk. *Credit: NASA's Goddard Space Flight Center/Chris Smith (USRA/GESTAR)*

At Fisk, Vega researched a class of pulsating supergiant stars known as RV Tauri variables, including a star called DF Cygni. Discovered in 1926 by astronomer Margaret Harwood, DF Cygni was the only RV Tauri star in the original field of view of NASA's Kepler space telescope.

The Kepler mission was NASA's first intensive effort to find Earth-sized and smaller planets in the habitable zones of stars like our Sun. The telescope monitored more than 150,000 stars, including DF Cygni, to record their brightness over time — data which Vega used to complete her master's thesis.

DF Cygni is still Vega's favorite star, because of its connection to the pioneering work of astronomers like Harwood.

In 2017, after completing her master's degree and publishing her first paper in *The Astrophysical Journal*, Vega enrolled in Vanderbilt's astrophysics doctoral program through the Fisk-Vanderbilt Bridge Program.

Vega crafted a new project focused on U Monocerotis, a different RV Tauri star. U Monocerotis is the second brightest RV Tauri in the Milky Way, which only has about 300 of the pulsating giants. The star is actually a binary pair, and the larger of the two stars has twice the Sun's mass but 100 times its size.

When Vega faced a setback — she failed her first attempt at her qualifying exam, which would advance her to doctoral candidacy — she sought her friends' support. "When you talk to your close friends or peers who are also in graduate school with you," she says, you realize "we're all going through similar experiences of successes or failures."

Vega took the qualifying exam again and passed. "I felt relieved," she says, "but at the same time, I was still wondering, was it real?"

In 2021, Vega's research on U Monocerotis was published, and NASA featured an article on her work. A few months later, Vega walked across the stage to collect her diploma. Because of the pandemic, Vega's advisor, Keivan Stassun, was not allowed to place her hood, an important tradition to many graduates. Vega had to hood herself.

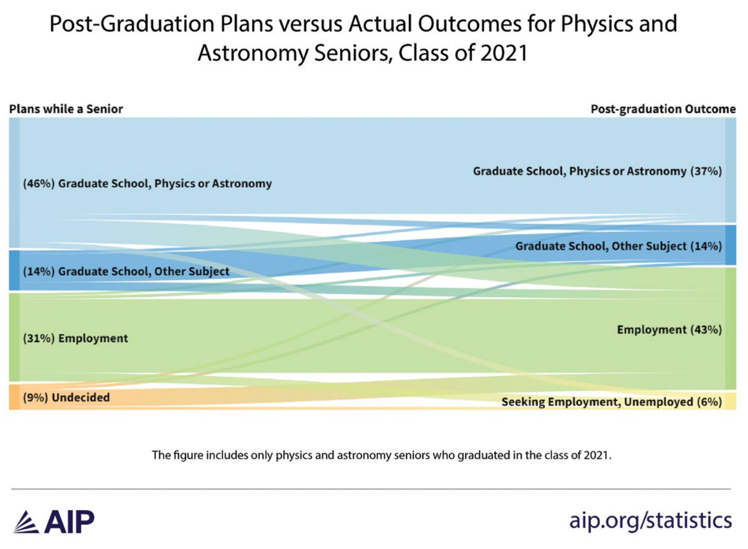
But that night, when Stassun joined Vega's family for a dinner celebration, he was able to place Vega's hood around her neck. She was certain — it *was* real.

Today, Vega is a year into her postdoc at NASA-Goddard. She's investigating the effects of red dwarfs' ultraviolet flare activity on planet atmospheres, and it's not easy work. "We have a large data set of simultaneous observations across many different telescopes," she says. All the observations must be carefully coupled.

What's next for Vega? "I hope to remain a scientist at NASA," she says. "I'll have to work hard to do that, but I have the motivation."

Liz Boatman is a staff writer for APS News.

COVID-19 continued from page 1



Credit: American Institute of Physics

now a Controls Engineer at Midwest Manufacturing after graduating in the spring of 2022; he says that his internship and in-person capstone experience were key to his job application.

For students who reported that they changed their post-graduation plans because of COVID-19, the largest shift was from planning to go to graduate school to planning to find a job. Many students who made this switch said they were feeling unprepared to apply to graduate school, had lost interest, could no longer afford it, or suffered from mental health challenges.

Although Axtell-Adams stayed on his intended path, he sympathizes with those whose plans changed. He says that because of the pandemic, he developed an adjustment disorder, which is a stress-related condition. "I'd never experienced that level of anxiety before, and it has taken a long time to get it under control," he says.

He isn't alone. Recent studies have shown that COVID-19 caused a drastic uptick in mental health challenges among U.S. undergraduates, worsening the increased stress and anxiety in this group observed well before the pandemic.

While 23 percent of physics and astronomy students who graduated in spring 2021 did not do, after graduation, what they had planned to do, that class still had similar overall outcomes to physics and astronomy classes from prior years. For example, according to Mulvey, 34 percent of the class of 2020 headed to graduate school, compared to 37 percent of the class of 2021.

But the pandemic's impacts are still felt in colleges today, sometimes in positive ways. Graham, in his second year of graduate school, says the biggest cultural shift he's seen at universities is "the now ubiquitous use of video call technologies such as Zoom." He says he likes this change. "Professors and research collaborators are much more reachable now," he says.

Axtell-Adams sees some benefits, too: "Classrooms are much more prepared for flexible and online learning now that they have been forced to try it."

Liz Boatman is a staff writer for APS News.

THE BACK PAGE

Opinion: To Save Science, Talk With the Public

Physicists' public engagement — in schools, with journalists, and beyond — can safeguard science. But academia's indifference, and sometimes hostility, to this engagement is standing in the way.

BY MICHAEL SMITH AND DON LINCOLN

A paradigm shift is occurring in our society: Somehow, unbelievably, knowledge and opinion are increasingly confused.

As scientists, we know that facts are facts, no matter how bad actors spin them, and that scientific consensus is generated by a rigorous process based on evidence and experiment. But denial of climate change, vaccine hesitancy, anxiety over nuclear energy, fears of GMOs, and even mistrust of individual scientists (e.g., Anthony Fauci) are rampant online and in everyday conversation. This misinformation bewilders the public, leads to policies that hurt people and the planet, and poses risks to science itself: Will science lose its ability to shape the future?

To reverse this dangerous direction, we scientists must go straight to the public. "Public engagement" is any effort to work with and inspire non-experts, and it takes many forms. A scientist might visit a classroom, speak on a podcast, invite the public to tour a lab, help design a museum exhibit, give or arrange a public lecture, or work with journalists on a science story.

Beyond this, though, public engagement should be an expected skill of our profession. It should be recognized by our institutions and used, along with research, teaching, and service work, in hiring and promotion decisions (as we discuss below, this is seldom the case today). This no-cost change at institutions would boost participation in engagement activities that can build back public trust in science and help our field.

> Public engagement is often evaluated indifferently or negatively during hiring, performance assessments, and promotion decisions… If you're doing outreach, so the thinking goes, you're not doing the important stuff.

Engagement work is needed because it gives science a human face, a proven way to build comfort and trust. And direct, person-to-person engagement can do more than simply provide information: By personalizing a topic, we make it relatable. For example, instead of debating the specifics of climate change, we can shift the discussion to the plight of those who have lost homes to fires in the western U.S.

And by discussing people's fears and misconceptions, engagement can go beyond trust-building: It can change the minds of people skeptical of science. The benefits of personal interactions with the public, which can surpass the benefits of reading an article or hearing a lecture, have been documented across a range of topics, including ocean pollution, vaccines, drug treatments, nuclear energy, and environmental disasters.

Unfortunately, we scientists face a dilemma each time we are offered a chance to engage with the public: We must choose between that effort or work that advances our careers. Public engagement is often evaluated indifferently or negatively during hiring, performance assessments, and promotion decisions, despite its importance for the future of our field. If you're doing outreach, so the thinking goes, you're not doing the important stuff.

This attitude throttles participation in engagement work. That's why we urge academic institutions — like universities, national laboratories, and research facilities — to change their policies and make participation in public engagement a criterion for hiring and career advancement decisions.

We envision public engagement as an addition to, rather than a replacement for, traditional hiring and promotion requirements. We also believe that these skills should be developed at all stages of a scientist's career, beginning with the undergraduate curriculum and expected of graduate students, postdocs, and faculty.

While the scientific community already has (albeit imperfect) ways of evaluating research, teaching, and administration, it has given little thought to evaluating public engagement. However, we recently suggested criteria that institutions could use to evaluate this work.

This will take commitment from all of us, and below we describe resources that can help. We also hope to get help from APS. At the time of writing, the APS Panel on Public Affairs is considering a draft statement that supports boosting public engagement efforts and recommends that institutions consider such work in hiring and career advancement decisions.

We realize, however, that change is hard, and that the academic world is particularly slow to reform. You need only look at the garb we wear at graduations to realize that universities value tradition. In our own field, the phrase "modern physics" describes century-old discoveries. For institutions to make a substantial change, it must be in the institution's interest.

Fortunately, effective public engagement has enormous benefits. Spreading the word about research successes can bolster an institution's reputation, a key to landing external funding. Events like science cafes, lab tours, or school visits can forge strong ties to the local community. And by working with journalists, you can share your science with the world, building public support for your next exciting, and perhaps taxpayer-funded, project.

Well-designed engagement events can also help build a physics identity for both facilitators and attendees — in other words, help them imagine themselves as physicists, with their own unique style. This has been shown to attract people to, and keep them in, physics. To adhere to best practices, the designers of these programs should collaborate with skilled facilitators or physics education experts.

Better still, public engagement can inspire the next generation of scientists, sparking curiosity in ways difficult to replicate in class. One of us, Lincoln, became a scientist in part because he read books by Asimov, Gamow, and Sagan, written for non-experts. In turn, he has met students who went into physics because of books he authored. Now, he hopes these budding academics will pay it forward.

The other (Smith) vividly remembers being enthralled by public science events, including a university chemistry demonstration at his high school, an evening chat session with a Nobel Laureate in college, and a lecture by Stephen Hawking as a postdoc. These drew him to a career in science and kindled his passion for engagement, to positive effect. For example, after Smith recruited a young scholar to research exploding stars, he learned that the graduate was inspired to study astrophysics by a public lecture Smith gave years ago.

Public engagement can also improve diversity in our workforce, which in turn strengthens our field. Consider, for example, the unexpected impacts of a video series that Lincoln makes for the Fermilab YouTube channel. These videos, geared toward the general public, explore particle physics and cosmology — and a significant fraction of applicants for a Fermilab summer internship, which aims to bring diverse young scientists into the field, cited the videos as inspiration for applying.

Engagement can also help individual researchers. As we and our collaborators recently detailed, engagement work can drive your research in new directions, lead to advances in your subfield, and build stronger relations between your community and institution. Because of this, public engagement should be considered integral to one's research, rather than something extra done on the side.

Given these benefits, we urge our community to step up engagement efforts. Event by event, we can help build back trust in science. We can also inspire the next generation of physicists, make our field more diverse and inclusive, and look at our own research in new ways. We hope that all our colleagues can experience the joy, creativity, and intellectual stimulation that we have obtained through engagement work.

How can you get started with public engagement? Like many of our colleagues, we never had formal training in this area, but now there are resources that can help. The new Joint Network for Informal Physics Education and Research (JNIPER), for example, brings together facilitators; physics education researchers, who track the impact of public engagement; and practitioners, the folks doing engagement work. JNIPER members share best practices, fuel creative new efforts, and learn from other like-minded physicists.

However, dealing with contentious issues or with people who are suspicious of scientific consensus takes special preparation. For this, consult the APS Science Trust project, which trains scientists to address misinformation and build trust in science through a slew of proven strategies — by empathizing with all points of view, speaking one-on-one with someone instead of having a public debate, and never attacking someone's core beliefs, for example. Participants practice role-playing with facilitators, which puts new skills to the test.

Trying to change the minds of science skeptics isn't easy. It requires creativity, hard work, and passion. But aren't these the tools of successful physicists? If we use these tools to unlock the secrets of nature, we can use them to rebuild society's trust in science. Let's work together to make this change — starting with the way our institutions value public engagement.

Michael Smith is an APS Fellow and Distinguished Scientist in physics at Oak Ridge National Laboratory. Don Lincoln is an APS Fellow, Senior Scientist in particle physics at Fermilab, and author. Both have enjoyed engaging the public on the wonders of physics for over thirty years. This article benefited from discussions with members of the APS Committee to Inform the Public, APS Public Engagement Office, Executive Committee of the APS Forum on Outreach and Engagement, and APS Division of Particle and Fields Snowmass Public Engagement and Outreach Topical Group.

Cooling continued from page 2

gineering — and then the flagship sank." Why? The team's liquefier would not have been as efficient as a traditional one, according to their estimates.

By the mid-2000s, Swift's work with thermoacoustics had ended, and most American innovation with the technology shuttered soon after, he says.

But Blanc's team isn't simply picking up where Swift left off. Instead of relying solely on an inert gas for heat transfer, Blanc's team is adding a phase-change fluid. The phase-change fluid is cycled between its liquid and gas phases to store and release even more heat. So far, the team has experimented with water, ethanol, and isopropanol.

Although the phase-change fluid restricts the system's temperature range, their prototype is still twice as powerful as traditional thermoacoustic cooling when pumping heat between temperature differences of 10°F, according to the team's most recent data. Calculations suggest that full-scale models could be more powerful, and might even outperform conventional air-conditioning technologies.

"I'm definitely intrigued," says Swift. "Getting most of the heat to happen with phase change instead of adiabatic pressure changes in an inert gas might be a game-changer."

That's exactly what Blanc, Ramon, and Yang are hoping for. The efficiency boost "provides an opportunity for thermoacoustic cooling to compete with classical technologies," says Yang.

Today, the team's heat pump prototype is powered by grid electricity, but Blanc says the next step is to design the pump so that its power comes entirely from heat — either solar or waste heat.

The trio has a lot of work to do, but they're optimistic. "I hope our research can make the large-scale application of thermoacoustic cooling into reality," says Yang.

Liz Boatman is a staff writer for APS News.

Opinion articles on the Back Page are member commentary; their views are not necessarily those of APS. To respond to an opinion piece or pitch your own (we welcome both), email letters@aps.org.