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APS News

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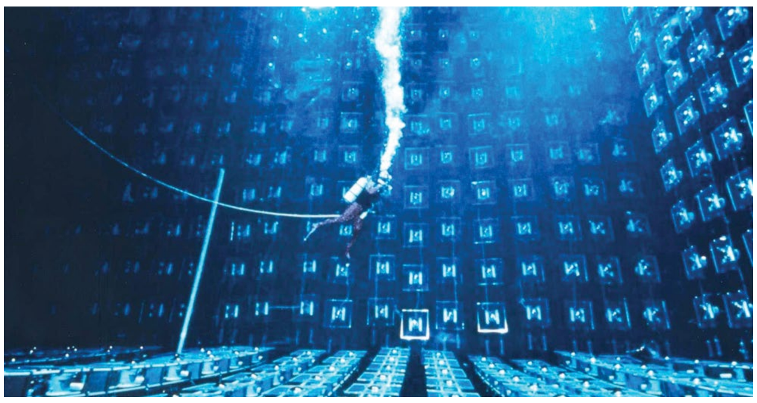
Two Thousand Feet Underground, a Once-in-a-Century Discovery That Shaped Particle Physics

The IMB detector was built to look for proton decay, but an unexpected neutrino measurement defined its legacy.

BY ERICA K. BROCKMEIER



A diver in the IMB's tank. *Credit: IMB Collaboration/UMichigan*

In a distant galaxy more than 150,000 years ago, a blue giant star exploded, spraying particles — including neutrinos, one of the most elusive subatomic particles known — across space.

Then, in the 1980s, neutrinos from this supernova were picked up by the Irvine-Michigan-Brookhaven detector deep underground in Ohio. The discovery marked one of the first measurements of neutrinos from beyond our solar system, helped kickstart the field of observational neutrino astronomy, and provided a starting point that next-generation neutrino detectors continue to build on.

But the discovery was also lucky: The detector was built primarily to study proton decay, rather than neutrinos. "When you build a new detector with new capabilities, you're sensitive to things that you never expected," says Henry Sobel, a physics professor at the University of California, Irvine, and one of IMB's original collaborators. The unexpected supernova would shape the legacy of IMB, which was recently recognized as an APS Historic Site for its role in neutrino science.

In the mid-1970s, teams of physicists were racing to build detectors that could measure proton decay, a hypothesized phenomenon that would confirm Howard Georgi and Sheldon Glashow's new Grand Unified Theory, one that sought to unite three of the four fundamental forces of nature. The winner emerged in Painesville, Ohio, a small city northeast of Cleveland: The IMB detector, the world's first kiloton-scale nucleon decay detector, began collecting data in 1982.

To look for proton decay, the IMB detector would need to track more than a nonillion (10^{30}) protons at once. If the lifetime of a proton is

IMB continued on page 5

Physicist Wins Valley Prize for Work on Many-Body Quantum Physics

Ruben Verresen's pioneering work may someday advance in quantum computing.

BY KENDRA REDMOND

Ruben Verresen. *Credit: Yana D. Petri*

When 12-year-old Ruben Verresen found his older brother's physics textbook and started reading it, he was miffed. The book held clues to the secrets of the universe, and no one had thought to tell him?

Now an assistant professor of molecular engineering at the University of Chicago, Verresen is the winner of the APS George E. Valley Jr. Prize, which recognizes early-career scientists who have made outstanding contributions to physics that are likely to impact the field dramatically. Verresen received the prize for his pioneering work on many-body quantum physics.

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Bharat Ratra, Winner of Lilienfeld Prize, on What's Next for Cosmology

Ratra thinks physicists may answer questions about dark energy and the universe's geometry within a decade.

BY LIZ BOATMAN

Decades ago, when applying to college in India, Bharat Ratra missed a score cutoff for entrance into one of his preferred engineering programs. That pushed him into physics — a lucky accident for the young Ratra, who would go on to become a distinguished professor in theoretical physics at Kansas State University.

Today, Ratra is the recipient of the 2025 Julius Edgar Lilienfeld Prize for his pioneering research in cosmology and particle astrophysics, and for his dedication to students and public engagement outside the classroom. "There are so many people whom I admire who have been previous recipients," says Ratra, so having his own work recognized is "pretty humbling."

Although he's best known for his contributions to the quantum mechanics of cosmic inflation and dynamics of dark energy, Ratra at times faced a less certain path.

Many Indian schools in the 1970s lacked funding for high-grade lab equipment, so Ratra often found college labs "pretty frustrating," he says. "It was easier to get better at the math and do more theoretical things." He excelled in all his early theory-intensive physics courses, and when the class "had the chance to do relativity," he was hooked.

Bharat Ratra. *Credit: Kansas State University*

In 1981, Pakistani theoretical physicist Abdus Salam, recipient of the 1979 Nobel Prize in Physics, was invited to India to deliver a series of talks on his work to develop the standard electroweak model, which would later evolve into the Standard Model. When Salam visited Delhi, Ratra — then an undergrad at the Indian Institute of Technology —

Lilienfeld Prize continued on page 6

Nobel Prize: Mimicking Human Intelligence with Neural Networks

The 2024 Nobel Prize in Physics honors pioneering work on artificial neural networks, which provided the foundation for many of the artificial intelligence technologies in use today.

BY MICHAEL SCHIRBER

Certain processes in the brain, such as recognition and classification, can be modeled as interactions of artificial neurons, or "nodes," in a highly interconnected network. This physics-inspired approach to human learning has been recognized with the 2024 Nobel Prize in Physics. John Hopfield from Princeton University and Geoffrey Hinton from the University of Toronto share this year's prize for their work on artificial neural networks, which have become the basis of many artificial intelligence (AI) technologies, such as facial recognition systems and chatbots.

An artificial neural network is a collection of nodes, each of which has a value that depends on the values of the nodes to which it's connected. In the early 1980s, Hopfield showed that these networks can be imprinted with a kind of memory that can recognize images through an energy-minimization process. Building on that work, Hinton showed how the couplings between nodes could be tuned (or "trained") to perform specific tasks, such as data sorting or classification. Together, the contributions of these physicists set the stage for today's machine learning revolution.

Neurons in the brain communicate with each other through synapses, and the number of synapses connected to any given neuron ranges from a handful to several thousand. Early studies in the 1940s showed that the firing activity of a particular neuron — the electrical pulses it generates — depends on the inputs received from connected neurons. Moreover, connected neurons that fire simultaneously can develop stronger mutual connections, eventually leading to memories that are encoded in the relative synaptic strengths. Many researchers became interested in reproducing this neural behavior in digital networks in which nodes replaced neurons and couplings replaced synapses. But solving real problems with these artificial neural networks proved computationally challenging.

John Hopfield and Geoffrey Hinton. *Credit: Ill. Niklas Elmehed © Nobel Prize Outreach*

Neurons in the brain are connected through synapses. One popular model of learning is that these connections become stronger (or weaker) depending on the correlated activity of the two connected neurons. Artificial neural networks are built on the principle that the strengths of connections between nodes can be tuned to produce a desired result.

In 1982, Hopfield opened a way forward. He proposed a simple network based on many-body physical systems, such as the atomic spins inside a magnetic material. In analogy with a neural network, each spin (or node) has a specific value based on its orientation, and that spin value can affect nearby spins through magnetic interactions (or couplings). The spins settle into a stable configuration based on the strengths of those interactions.

Taking spin physics as inspiration, Hopfield set up a network of N nodes connected through weighted couplings. Each node had a value of either 0 or 1, which could be changed (during random updates) depending on the weighted sum of all the other

Nobel continued on page 4

The Physicist Who Tracks Penguins From Space

As a student, Heather Lynch heard a speech by Al Gore that changed her career trajectory.

BY ALAINA G. LEVINE

Heather Lynch visits Cape Lookout in Antarctica. *Credit: Jeff Topham*

Physicists have long conducted research with space-based instruments. But at Stony Brook University, one physicist uses satellites to study something unusual: penguin poop.

Heather J. Lynch, a quantitative ecologist at Stony Brook's Institute for Advanced Computational Sciences, has developed computer vision tools that enable satellites to map penguin guano, which is pink in color. The guano can reveal the size, health, and movements of Antarctic penguins — and how stressors like climate change, tourism, and overfishing affect their populations. "The colony that is declining in abundance is a very different spatial patterning than a colony that's growing in abundance," Lynch says. Her team also used the method to discover one of the largest penguin colonies on the continent, in a region called the Danger Islands.

"My physics background has been really influential," she says. Viewed from space, the penguin colonies take on strange shapes, like "spots on the ground, or stripes, or complex labyrinthine patterns." With years of condensed matter physics and statistical mechanics under her belt, she says, "I ended up on this really long journey to understand the physics of penguin colonies."

10 years into the project, Lynch is still figuring out how the groups move. "They actually form a liquid order in the colony, [and] you can treat them as little atoms," she says, with "spontaneous symmetry breaking...driving a lot of this pattern formation."

Lynch became enamored with physics while at Princeton University. She focused her undergraduate thesis on quantum dots, which earned her the APS Apker Award, and then started her doctoral degree in physics at Harvard. "I liked what I was doing in physics," she says. "It remained very challenging and exciting."

But when Al Gore visited campus and delivered his famous presentation on global warming, Lynch was captivated. "This seemed like a problem that I should be working on," she remembers thinking. After earning her master's degree in physics, she transferred to the biology department for her doctorate.

Today, in her new role as Director of Stony Brook's Collaborative for the Earth initiative, Lynch unites experts whose work relates to climate change, whether via chemistry, the humanities, or physics. "I'm really trying to break down the traditional disciplinary barriers that keep these people from talking to one another, to make sure that we are in a position to tackle the really big environ-

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THIS MONTH IN PHYSICS HISTORY

Nov. 16, 1904: John Ambrose Fleming Patents the Vacuum Tube

Fleming's innovation kickstarted the age of electronics.

BY KENDRA REDMOND

Just one month after he conceived of the idea, British engineer John Ambrose Fleming patented the vacuum tube. Although the device would bring him some grief, its ability to convert alternating current into direct current would revolutionize communication and broadcasting, kicking off the electronics era.

"Just as the double helix inaugurated the age of molecular biology, Fleming's vacuum tube inaugurated the age of electronics — and dominated it until the advent of the transistor," said Fred Dylla and Steven Corneliussen in a 2005 paper in the *Journal of Vacuum Science & Technology A*.

Although the design came together quickly, the physical concepts it exploited had been swirling around Fleming's brain for years. As a teenager, he'd displayed an aptitude for math and science and a fascination with electromagnetism. He studied under James Clerk Maxwell at Cambridge University and worked in the newly established Cavendish Laboratory, benefiting from what he later called Maxwell's "supreme genius" for two years before Maxwell's death in 1879.

John Ambrose Fleming.

After receiving a Ph.D., Fleming became the science advisor of the Edison Electric Light Company's London branch. Thomas Edison's incandescent lamps — consisting of a carbon filament enclosed in an evacuated glass bulb — were lighting up the United States, and the new branch was tasked with operating his lighting systems and generators in Great Britain.

This positioned Fleming "to investigate carefully some of the problems connected with the physics of the incandescent lamp," he wrote in his book *The Thermionic Valve and its Developments in Radiotelegraphy and Telephony*.

> "Few inventions can have brought their inventors so much distress, disappointment and trouble," wrote Geroge Shiers in a 1969 *Scientific American* article.

In one of Edison's experiments with early lamps, he had inserted a metal probe into an incandescent bulb. The probe was attached to a galvanometer, which measures electric current. Edison noticed that charge flowed from the glowing filament to the probe — but only when the probe was positively charged. Noting that the current varied with voltage, Edison patented a lamp-style voltage indicator, but his investigation didn't go much deeper.

The current — dubbed the Edison effect — intrigued scientists, including Fleming. But no existing theory explained the phenomenon: It was the mid-1880s, and the discovery of electrons was more than a decade away. Scientists reasoned that the filament discharged negative carbon molecules.

Fleming began experimenting with Edison effect lamps, which consisted of an incandescent bulb containing an extra plate electrode with an external connection. Over the next several years, he repeated Edison's experiments and conducted his own, testing an assortment of filament and bulb designs.

Fleming noted that the bulb's negative leg was the "active agent" producing the Edison effect, and the space inside the bulb conducted only "negative electricity." He also found that when the lamp was activated by an alternating current, a continuous current flowed through a galvanometer connected between the extra electrode and either terminal.

"The glow lamp and the electric arc have revolutionized our methods of artificial lighting," he wrote in an 1890 paper for the Royal Society of London, "but they present themselves also as subjects of scientific study, by no means yet exhausted of all that they have to teach."

Around the time Fleming started the experiments, he accepted an invitation to establish and chair an electrical engineering department at University College London, England's first such department, where he lectured regularly and conducted research.

He began a new role around the turn of the century, this time as scientific advisor for Guglielmo Marconi's Wireless Telegraphy Company. The young Marconi was earning a name for himself by demonstrating long-distance wireless communication using radio technology. He enlisted Fleming's help for the first wireless transatlantic transmission, which took place in 1901. While proclaimed a success, the transmission underscored two difficulties plaguing radio communication: signal detection and amplification.

Marconi's technology could transmit radio waves over long distances, but the instruments for detecting the oscillating signals and translating them into direct current were noisy, finicky, and often unreliable.

The coherer, which converted alternating current to direct current, was "about as exasperating a tool for the purpose of making quantitative measurements as one could well imagine," John Turner MacGregor-Morris wrote in a 1955 article for the Royal Society's *Notes and Records*.

While mulling over the problem in October 1904, Fleming was struck by a flash of insight. He could create an electronic rectifier by placing an open metal cylinder around the filament of an incandescent bulb with an outside connection. When inserted in the circuit, "this at once gave us a means for converting the feeble but rapid to-and-fro motions of electricity in an aerial wire . . . into a current of electricity all in the same direction," Fleming recalled in a 1923 talk broadcast by the BBC. The vacuum tube was born.

Just a month later, the patent application was in. Fleming knew he was on to something, but his device came at a cost. "Few inventions can have brought their inventors so much distress, disappointment and

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Valley Prize continued from page 1

When Verresen, who is originally from Belgium, began a theoretical physics master's program at the Perimeter Institute in Canada, he was enthusiastic about exploring the wide range of topics — except for quantum-body physics, which didn't seem as interesting. But when the program exposed him to the field's frontiers, he did an about-face. "That's where the most exciting stuff is," he says now.

Part of what he finds so fascinating is the richness that can emerge from basic principles. Consider chess, Verresen says. Knowing the rules can give you a sense of the game, but not all the strategies and gameplay those rules can yield. Similarly, knowing the fundamental laws of nature can give you a sense of how the universe operates, but not all the behaviors, properties, and laws that can emerge from them.

Daily life is full of emergent structures. Water is one example, he says. At the molecular level, it's composed of many H_2O molecules bouncing around, "but as you zoom out, there's this effective notion of a wave." Waves have measurable sizes and speeds, they can travel and interfere, and there are equations that describe their behavior, he says. "Where did these laws come from?"

Verresen explores collective behaviors that could emerge in systems where "the weirdest theory we have" applies — quantum physics. Over the last 100 years, scientists have discovered rich emergent structures in these systems, he says, first by exposing solid-state systems to ultracold temperatures and, more recently, with well-controlled quantum platforms. The platforms enable experimentalists to precisely arrange many atoms and fine-tune the parameters to encourage specific collective behaviors. They're becoming increasingly capable.

Scientists can probe and measure systems in ways never before possible, says Verresen. For theorists like him, the platforms are playgrounds. Experimentalists can figure out what's possible, and theorists can dream up ideas to explore. Then, the two groups can collaborate on experiments, with the results fueling new explorations.

Quantum computing is a strong motivation for these types of projects. "To build a quantum computer, you're going to need an immense amount of control, and you're going to need a lot of qubits," Verresen says. "It's very naturally in unison with studying many-body quantum physics."

Theorists have predicted that under the right conditions, certain states will emerge in materials or systems that are especially valuable for quantum computing applications. In the past, experimentalists have struggled to realize and stabilize many of these states, but technology is catching up. And thanks to Verresen and his colleagues, there's a versatile tool at their disposal: measurement.

People usually think of measurement as a passive way to gather information, says Verresen, "but in quantum physics, measurement is a very active process." As a postdoc at Harvard University and then at both Harvard and MIT, Verresen collaborated closely with Ashvin Vishwanath and Caltech's Nathanan Tantivasadakarn in theorizing how experimentalists could use the act of measurement to chisel away at one quantum state in order to sculpt another desired state.

For example, Verresen says, "If I measure every other atom, can the [wavefunction of the] remaining atoms collapse so that we get a new emergent structure arising from it?"

The chiseling approach worked. In early 2024, the trio and collaborators from the quantum computing company Quantinuum published the results of an experimental study in *Nature*. On the company's newest quantum platform, the team utilized measurement to realize an elusive and sought-after quantum state known as a non-Abelian topological phase. The state potentially holds promise for computing because it produces quasiparticles that can store information.

Verresen isn't focused on quantum computing, although he says it's a bonus that his work on quantum processors may contribute to advances in the field. "My primary interest in this topic is the beauty of these emergent structures and what it can teach us about fundamental aspects of many-body quantum states," he says.

He's also intrigued by the origin of emerging phenomena and their relationship to the fundamental laws of the universe. Some emergent notions seem universal but aren't "fundamental" in the traditional sense of the word, Verresen says. If you have a quantum system "that interacts a bit, and you zoom out and all these structures can emerge, it does really invite the notion of, How much do we need to presume as fundamental?"

In August, Verresen started his role at the University of Chicago, where he's busy setting up a group to explore an assortment of topics under the many-body quantum umbrella. When he's not consumed with academic responsibilities, he lets his mind wander, wondering and playing with physics concepts. There are still secrets to uncover.

Kendra Redmond is a writer based in Minnesota.

A Time Standard for the Moon — Thanks to General Relativity

As part of an effort to establish a lunar time standard, researchers have used relativity to calculate time differences between Earth and the Moon.

BY ELIZABETH FERNANDEZ

NASA's Artemis program aims to establish a human presence on the Moon. The uncrewed Artemis I mission (shown here in June 2022) was completed in December 2022. A crewed lunar flyby (Artemis II) is scheduled for September 2025, and a crewed Moon landing (Artemis III) is planned for September 2026. To aid these efforts, scientists are working on an independent lunar timekeeping system. *Credit: NASA/Ben Smegelsky*

More than 50 years after their last visit, humans are preparing to go back to the Moon. As part of the Artemis program, NASA plans to land a pair of astronauts near the Lunar South Pole within the next few years, and other crewed missions are scheduled to be launched moonward in the coming decade. While this next generation of lunar explorers is getting ready, scientists on Earth are working out a new way to keep good time on the Moon.

Using Einstein's general relativity theory, these researchers have precisely calculated the expected differences between lunar and terrestrial clocks. The effort could help establish a time standard for the Moon, which would be instrumental in coordinating lunar exploration activities.

Technology has come a long way since the last Apollo mission in 1972. GPS navigation, for example, didn't exist for the Apollo astronauts as they explored the Moon's rocky expanses, but nowadays practically every phone is equipped with a GPS app to help us locate a restaurant or find the fastest route to home. GPS systems compute your location by measuring the time it takes a signal to travel between a GPS satellite and the receiver in your phone. But this computation only works by taking into account general relativity, which says that time ticks slower in stronger gravitational fields. If we take sea level as our reference point, then clocks at higher altitude — where gravity is weaker — will run faster. Clocks in satellites experience even less of Earth's gravity, so they should run faster still (but the net rate will also depend on time-dilation effects coming from the satellite's orbital motion). The typical GPS satellite runs about 38 µs faster per day compared to a sea-level clock at rest.

The Moon is even higher within Earth's gravitational field, but it also has its own gravity. The rate at which a clock will run on the Moon is complicated to compute, as it will depend on the clock's position and speed relative to Earth. "With the increasing number of lunar missions in the next decade, it will not be practical or feasible for each of those individual missions to obtain their respective times via a link with

Moon continued on page 5

US Puts Export Controls on Quantum Computers

Entities must be licensed to export key components, and they must disclose when certain foreign nationals are working on the technology in the U.S.

BY CLARE ZHANG

President Joe Biden observes quantum computing equipment at an IBM facility.
Credit: Adam Schultz / White House

In September, the Commerce Department announced export controls on quantum computing technologies, alongside new controls for advanced semiconductors and additive manufacturing technologies. The controls cover key equipment, materials, and software used in quantum computers, as well as some complete computers.

The department stopped short of requiring licenses for foreign nationals to work with these technologies in the U.S., instead implementing new disclosure requirements for certain foreign nationals. However, it has reserved the right to add license requirements in the future and is seeking input on what effects they would have.

The interim final rule, issued by the department's Bureau of Industry and Security, requires entities to obtain a license before exporting the items, with exceptions for countries that have implemented equivalent controls, making it "significantly more difficult for our adversaries to develop and deploy these technologies in ways that threaten our collective security," said BIS head Alan Estevez in a press release.

Sharing controlled technology with foreign nationals in the U.S. is generally subject to "deemed" export controls — the transfer is considered an export despite occurring inside the country. However, in recognition of the importance of foreign nationals to the U.S. quantum workforce, the rule creates exceptions for deemed exports, even for individuals from countries identified by the government as posing national security concerns or subject to arms embargoes, referred to as D:1 and D:5 countries respectively, such as China, Russia, and Iran.

The rule instead requires entities that share controlled quantum technology with these foreign nationals to record what information they release and to whom.

"What BIS is doing is sort of keeping the status quo and gathering information about D:1 and D:5 nationals working in quantum in the U.S., almost certainly with an eye to deciding a year or something from now whether that should change," former senior BIS official Kevin Wolf said in an interview.

The quantum controls on exports to certain allies enter effect on Nov. 5, while the rest of the new controls went into effect the day of the announcement, Sept. 6. The rule includes a request for public comment on the prospect of adding deemed export license requirements for D:1 and D:5 countries, as well as ideas for ways to address national security concerns without using deemed export licenses. BIS will accept comments on the new rule through Nov. 5.

Carl Williams, a quantum technology consultant and former NIST scientist, said that aligning U.S. controls with international partners is a positive move, but that the new reporting requirements pose a burden for young or small quantum companies.

"The big companies that deal with this, they have the infrastructure in place," he said. "The small companies, they will have to consult lawyers and get advice and learn how to do it, and then they will have to continually follow requirements... It just doesn't come cheap to a startup."

Kate Timmerman, CEO of the Chicago Quantum Exchange, said the rule aims to minimize disruptions to international collaboration. "They very intentionally focused [the export controls] in a way where it would not actually inhibit R&D going on both within the United States, as well as collaborative research that goes on between U.S. and international researchers," she said.

Clare Zhang is a science policy reporter at FYI, published by the American Institute of Physics.

APS General Election Results

APS is pleased to announce the results of the 2024 general election. Congratulations to our newly elected leaders! All terms begin on Jan. 1, 2025. Learn more about the winners at go.aps.org/genelect.

Gabriela González
Vice President

Angela K. Wilson
Treasurer

Mary James
General Councilor

Rodrigo B. Capaz
International Councilor

Krishna Rajagopal
Nominating Committee Chair-Elect

APS Partners with Scientific Societies to Fight Federal Anti-DEI Legislation

Recent bills target funding for diversity, equity, and inclusion programs at federal agencies.

BY TAWANDA W. JOHNSON

APS and two leading physics societies are launching a grassroots campaign to protect diversity, equity, and inclusion initiatives, which have been targeted by recent proposed federal legislation.

APS and the two societies — the National Society of Black Physicists and the American Association of Physics Teachers — support programs to increase the number of people from underrepresented groups in physics. The societies are increasingly concerned that a spate of proposed bills, which would cut funding for DEI offices and programs at federal science agencies, will harm efforts to recruit skilled individuals from underrepresented groups to pursue STEM careers.

In July, leaders from APS, NSBP, and AAPT met with members of Congress on Capitol Hill to share their concerns about the legislation. The event was supported by a Venture Fund grant from the American Institute of Physics.

Recent legislation has sought to cut funding to diversity, equity, and inclusion programs at federal agencies, including NASA and the Department of Energy. Credit: JHVEPhoto - stock.adobe.com

During the 2025 fiscal year appropriations process, all 12 appropriations bills in the House of Representatives included provisions to bar funding for executive orders around DEI programs and training. Additional provisions would prevent funding for DEI offices and programs at the National Science Foundation, the Department of Energy, the National Institute of Standards and Technology, and NASA.

"On an organizational level, just the threat of this language in these bills becoming the law of the land has had a negative effect on our programs," said Stephen Roberson, the NSBP president. "For example, some university and department leadership have discouraged or not supported their students' participation in our National Conference or Student Leadership Development Summit, when this was not an issue in the past."

"I hope that our membership starts to understand that they have real power to make change, whether that be through legislative means or by self-organizing to be better problem-solvers than the current decision-makers," he said.

Beth Cunningham, the executive officer of AAPT, shared similar sentiments. "We are concerned that anti-DEI legislation will impact the participation of AAPT members in events and programs that focus on creating systemic, structural changes leading to equity and excellence," she said. "Now more than ever, we need all students to say they belong in physics classrooms and can see themselves doing physics."

Tawanda W. Johnson is the senior public relations manager at APS.

Penguins continued from page 2

Penguins — like the Adélie penguins shown here — "actually form a liquid order in the colony," Lynch says, with "spontaneous symmetry breaking...driving a lot of this pattern formation." Credit: Heather Lynch

mental challenges," she says, referring to herself as a "chief cat herder."

"That's been nice to exercise those muscles [and] have at least a toe in all of these different disciplines," she says.

Many of Lynch's research findings are referenced by lawmakers, and for 20 years, she has supported Antarctic treaty negotiations, providing information to world governments and building tools for policymakers to use when they designate protection zones. As a result of Lynch's penguin investigations, the proposed marine protected area for the Western Antarctic Peninsula, currently under consideration, was expanded by about two million hectares to include the Danger Islands.

"It's the best example I can think of where you have a technological discovery, which is that we can find penguins from space, [and] we confirm it on the ground, and then it feeds directly into improved management," she says. "This area which was thought to be a penguin desert is now a penguin hotspot, and it's under protection now."

Because of the robustness and reliability of the satellite monitoring techniques, ecologists are now using them to track other species, including walruses, elephants, and even cows. She is also contributing to a project that will map mammals near Chernobyl, where radiation levels prevent investigators from taking data on the ground.

Lynch is celebrating, too. This fall, the American Association for the Advancement of Science honored her team with the Golden Goose award, which spotlights scientific studies "that may have seemed obscure, sounded 'funny,' or for which the results were totally unforeseen at the outset," but have benefited humanity.

Lynch believes physics has been key to her success. "I couldn't do what I do now without that background, so my advice is to be confident that the background you've received in physics is going to take you far and wide," says Lynch.

After all, "who's going to save us from climate change?" she adds. "It's going to be the physicists."

Alaina G. Levine is a professional speaker, STEM career coach, and author of Networking for Nerds *(Wiley) and* Create Your Unicorn Career *(forthcoming).*

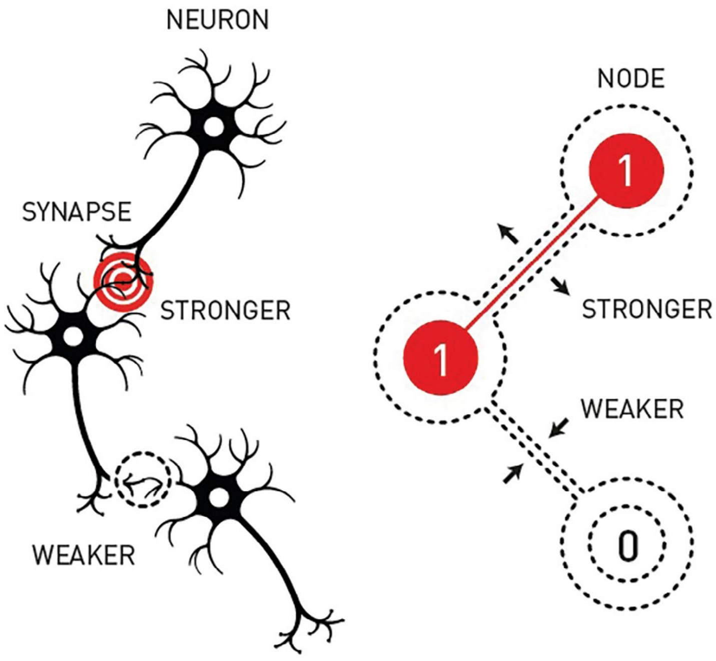
Nobel continued from page 1

nodes to which it was coupled. He defined an "energy" term based on the relative alignment of the connected nodes and showed that the network evolved toward a low-energy state.

Hopfield then showed that this spin-based neural network could store and retrieve a "memory" in one of the low-energy (stable) states. A real-world example would be memorizing a pattern in an image. Here, the network nodes are associated with the pixels on a screen, and the couplings are tuned so that the output (or stable state) corresponds to a target image, which might be, for example, the letter "J." If the network is then initialized with a different (input) image — say, that of a highly distorted or poorly written "J" — the node values will naturally evolve the image to the network's stable state. This process illustrates the network associating the input with the stored "J"-pattern memory.

The practical uses of the Hopfield network drew the interest of other researchers, including Hinton. In the mid-1980s, he and his colleagues developed a network called a Boltzmann machine, in which each possible node configuration is assigned a probability based on its energy. The researchers devised an algorithm that adjusted the network's couplings so that the probability distribution matched the statistical distribution in the target data. To make the method more effective, Hinton and colleagues introduced the idea of "visible" layers of nodes that are used for inputs or outputs and separate "hidden" layers that are still part of the network but not connected with the data. A variant on this design, called the restricted Boltzmann machine, became a precursor to deep-learning networks, which are widely used tools in fields such as computer science, immunology, and quantum mechanics.

Giuseppe Carleo, a machine learning specialist from the Swiss Federal Institute of Technology in Lausanne (EPFL), has used restricted Boltzmann machines to find the complex quantum systems. He says that Hinton and Hopfield laid the groundwork for a mechanistic understanding of learning. "The most exciting part for me as a physicist is actually seeing a form of elementary intelligence emerging from first principles, from relatively simple models that can be analyzed with the tools of physics," Carleo says.



Neurons in the brain are connected through synapses. One popular model of learning is that these connections become stronger (or weaker) depending on the correlated activity of the two connected neurons. Artificial neural networks are built on the principle that the strengths of connections between nodes can be tuned to produce a desired result. Credit: J. Jarnestad/Royal Swedish Academy of Sciences

Hinton was also instrumental in developing "backpropagation" for the training of neural networks. The method involves computing the difference between a network's output and a set of training data and then tuning the node couplings to minimize that difference. This type of feedback wasn't new, but Hinton and his colleagues showed how adding hidden layers could expand the utility of this process.

"This year's Nobel Prize goes to two well-deserving pioneers," says neural-network expert Stefanie Czischek from the University of Ottawa in Canada. She says the work of Hopfield and Hinton showed how extend far beyond the realm of many-body physics. "Even though the Hopfield network and the restricted Boltzmann machine have both been replaced by more powerful architectures in most applications, they laid the foundation for state-of-the-art artificial neural networks," Czischek says.

Over the years, neural networks have blossomed into a host of AI algorithms that recognize faces, drive cars, identify cancers, compose music, and carry on conversations. At the Nobel Prize press conference, Hinton was asked about the future impact of AI. "It will have a huge influence, comparable to that of the industrial revolution," he said. He imagines this influence will be welcome in some areas, such as health care, but he also expressed concern over the possibility that AI will exert a controlling influence on our lives.

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Moon continued from page 3

A composite image of the Moon, with data from 1994. *Credit: NASA*

Earth,” says Javier Ventura-Traveset, Lunar Navigation and Science Manager at the European Space Agency.

This challenge prompted the White House to issue a memorandum in April of this year to establish a time standard for the Moon by the end of 2026. Among the specifications for this lunar time, it should be independent of terrestrial clocks, accurate enough for navigation and science, convertible to Earth’s time, and scalable to other environments, such as Mars.

To help lay a framework for establishing a time standard on the Moon, Neil Ashby and Bijunath Patla of the National Institute of Standards and Technology, Colorado, calculated the clock ticking rate on the Moon and proposed a method to sync clocks on Earth with those on the Moon. “You have to have an estimate that accounts for the effects of relativity so that when a real clock is put on the Moon, we can compare its accuracy,” says Patla.

He and Ashby started by treating the Moon as a satellite without its own gravitational potential. The same treatment is used to calculate the relativistic offset for GPS satellites — the difference being that the distance from Earth is not 20,000 km (for the typical GPS satellite altitude) but rather 380,000 km (for the Earth-Moon separation). In this simplified picture, the Moon’s clock would tick about 58 µs faster per day than on Earth.

But, unlike a GPS satellite, the Moon has significant gravity. To model this, the researchers used generalized Fermi frames, a coordinate system that allowed them to treat Earth and the Moon together in a free-falling inertial frame around the Sun. By doing this, they determined that time on the Moon runs 56 µs faster per day.

Similar calculations were performed by Sergi Kopeikin from the University of Missouri and George Kaplan from the U.S. Naval Observatory, Washington, D.C. Like Ashby and Patla, these researchers found that time on the Moon runs on average 56 µs faster per day than on Earth. But Kopeikin and Kaplan use a formalism that includes higher order relativistic terms. “These additional terms, although periodic, have a significant amplitude that affects lunar navigation,” Kopeikin says. He explains that accounting for these periodic terms could offer nanosecond-level accuracy to Earth-to-Moon time conversion.

But knowing this conversion doesn’t solve all the issues of lunar timekeeping. “As the number of assets on the Moon increases over time and more robotic missions are planned, it is desirable that the rovers communicate and navigate on the lunar surface autonomously and be less reliant on Earth-based command and control centers,” Ashby says.

To implement an Earth-independent lunar time, Ashby and Patla suggest a network of clocks, both on the lunar surface and in orbit. This strategy would be similar to how a universal time is calculated on Earth. Across Earth’s surface, there is a network of hundreds of atomic clocks. Each of these clocks ticks at a slightly different rate, given its elevation. By correcting for the speed of these ticking clocks from general relativity, researchers have established a global reference called International Atomic Time (TAI). TAI is currently ahead of the Coordinated Universal Time (UTC) by 37 s, because UTC is adjusted with leap seconds to keep in sync with Earth’s rotation.

A network of clocks on the surface of the Moon would offer a Coordinated Lunar Time (LTC) that all space-faring nations could use. “An agreed-upon common lunar time reference will be essential to ensure the technical synchronization of lunar-based interoperable infrastructures, the economic development of the Moon, and the proper execution of scientific activities on the lunar surface,” Ventura-Traveset says.

A lunar time standard would have other benefits with regards to astronaut health, says Ethan Waisberg of the University of Cambridge, who studies space-related medical conditions. Establishing an LTC “would ensure consistency in experimental data logging by providing a standardized lunar time zone, making it easier to compare data across various groups,” he says. Such comparisons are critical, he says, in understanding time-dependent conditions that affect astronauts, such as an eye-swelling effect called spaceflight-associated neuro-ocular syndrome.

To distribute time signals across the lunar surface, clocks could be flown in satellites around the Moon. Ashby and Patla also suggest placing satellites at Lagrange points — stable points in the gravitational potential of Earth and the Moon. “A Lagrange point has the property that an object placed there will remain there, so it doesn’t take much fuel for station keeping,” Patla says. These satellites could also serve as time-transfer links between clocks on Earth and those on the Moon.

Looking further ahead, establishing a lunar time system could provide a better understanding of how relativity affects the speed of time on various celestial bodies, which might help us adapt our clocks for future destinations, such as Mars.

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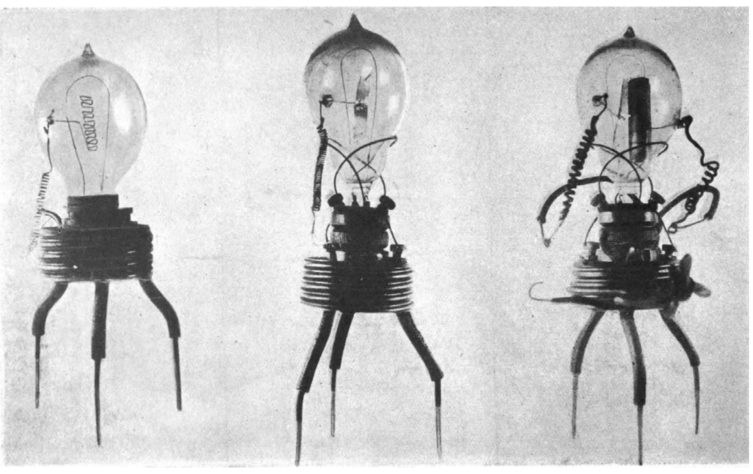
Vacuum Tube continued from page 2

trouble,” wrote Geroge Shiers in a 1969 *Scientific American* article.

In an effort to create a radio system that bypassed existing patents, U.S. physicist and radio pioneer Lee De Forest set out to develop his own technology. In 1905, he debuted a device similar to Fleming’s vacuum tube. When Fleming, who had already applied for a U.S. patent, pointed De Forest to his work, De Forest promptly dismissed it in a paper. Both patents were granted but, to his chagrin, Fleming’s was eventually ruled invalid.

“Small modifications of the original instruments have been christened, especially in the United States, by many strange and fanciful names,” Fleming wrote in his book. Uninitiated patent examiners may think devices are new when they are, in fact, “destitute of real novelty,” he said.

In the ensuing years, De Forest and others made key modifications that allowed vacuum tubes to function as detectors, amplifiers, and oscillators. That brought them to the forefront of not just radio technology but also telephones, televisions, and nearly all electronic devices prior to the invention of the transistor.



The first prototype Fleming valves, built October 1904.

Despite the U.S. patent resolution, Fleming was widely recognized for his pioneering invention and expertise in electronics. He continued consulting, researching, and giving lectures for decades. He was a well-liked professor known for his organized, clear lectures and tendency to talk fast. In 1926, he retired from University College London after more than 40 years of chairing the electrical engineering department. Three years later, he was knighted for his service to science and industry.

Fleming stayed scientifically active after his retirement. In 1932, the Physical Society of London noted that Fleming had been presenting papers at its meetings for nearly 60 years. “Sir Ambrose Fleming has not only made history in this interval, but also still holds a place on the stage of contemporary events,” the article reads. Fleming would give his last paper there in 1939, at age 90. He had been president of the Television Society of London for 15 years when he died in 1945.

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10^{30} years, scientists could expect to see one proton decaying each year; if no decay is observed, it means that a proton’s lifetime is longer than 10^{30} years.

To measure that many protons, the IMB team designed and built an 8,000-ton tank for 2.5 million gallons of purified water surrounded by 2,000 photomultiplier tubes. This massive Cherenkov detector, which measures charged particles as they pass through water, was constructed in the Fairport Harbor Morton Salt Mine, nearly 2,000 feet underground, to avoid cosmic ray interference.

IMB quickly ruled out the Georgi-Glashow model and several other proton decay lifetimes, says Sobel, which helped theorists at the time “push the boundaries” and generate ideas for new experiments. “Theorists continuously come up with new predictions, so by trying to be sensitive to different modes of proton decay, we were able to inform the theorists of what's possible and what's not,” Sobel says.

Neutrinos, meanwhile, remained extremely difficult to study. Although common, these subatomic particles are chargeless and nearly massless, and they only interact through gravity and the weak force. The particles were first detected starting in the 1950s, but even by the 1970s, “the weak interaction was incredibly mysterious, and there was this huge hole in our understanding of the forces of nature,” says Lawrence Sulak, a physics professor at Boston University who was part of the team that designed and prototyped IMB. “It was clear that if you wanted to understand the fundamental forces, you had to understand neutrinos.”

The supernova SN 1987A, as captured in 2024 by the James Webb Space Telescope.

Credit: NASA, ESA, CSA, Mikako Matsuura (Cardiff Univ.), Richard Arendt (NASA-GSFC, UMBC), Claes Fransson (Stockholm Univ.), Josefin Larsson (KTH)

Sobel and Sulak both say they and their IMB colleagues were aware that detecting a supernova was theoretically possible. “But the probability was a challenge,” says Sulak. “People knew that a supernova large enough to generate neutrinos that we could detect would only happen once a century, and with experiments typically only lasting for ten years, that means you would only have a 10% chance of seeing one.”

But the team got lucky. On Feb. 23, 1987, visible light reached Earth from SN 1987A, the explosion of a blue giant in the Large Magellanic Cloud that happened 166,000 years ago. After learning that the Kamioka Observatory, a Japanese neutrino and gravitational wave laboratory and IMB contemporary, had detected a burst of 11 neutrinos from the supernova, the IMB team took a closer look at their data and found evidence of another eight neutrinos, confirming theories that most of a supernova’s energy radiates away from its core in the form of neutrinos.

“Normally a neutrino interaction in the IMB detector happens once every five days, and here we saw eight in five seconds,” says Sobel, adding that the IMB team knew right away that they’d seen something significant.

IMB’s run ended in 1991, but its impact continues today. Not only did IMB and Kamioka influence the design of later detectors like Super-Kamiokande, their early observations on different neutrino “flavors” led to Nobel prize-winning findings on neutrino oscillation. Future efforts to understand neutrino oscillations, and the potential for neutrinos to break charge-parity symmetry, will be led by the next generation of detectors, including Hyper-Kamiokande and the Deep Underground Neutrino Experiment, or DUNE.

“Studying the neutrino has become a big physics business, and it all started with IMB and Kamioka and the properties that we discovered by operating those detectors,” Sobel says.

When it comes to neutrino astronomy specifically, experiments like the IceCube Neutrino Observatory are leading the charge in a field that, before IMB and Kamioka, had been an entirely theoretical enterprise but was considered essential for astronomy research.

“For really small wavelengths, you can only do physics with neutrinos,” says Francis Halzen, a physics professor at the University of Wisconsin-Madison, and the principal investigator of IceCube. “Neutrinos can also reach us from places in the universe where nothing else can get out — like close to black holes — so there was never any doubt that we wanted to do neutrino astronomy.”

As the world’s first gigaton neutrino observatory and Cherenkov detector, one that uses Arctic ice instead of purified water, IceCube has so far discovered high-energy neutrinos created by cosmic accelerators from across the universe and determined the sources of high-energy cosmic rays.

Halzen says that detectors like IMB directly inspired the methods employed by IceCube; this includes hanging the photomultiplier tubes into the ice cores from strings, which was modelled after IMB. “There was a long debate about the approach we would use at the time, and it’s clear we made the right choice to be inspired by IMB,” Halzen says.

While ongoing and future neutrino experiments are poised to help scientists understand these mysterious particles, both Halzen and Sobel also have their fingers crossed for yet another once-in-a-century supernova.

“Look at all of the physics we got from the 20 or so neutrinos that were detected from [SN1987A],” said Halzen. “The science we could do now if we observed another supernova would be incredible — those few seconds of physics would be the most important thing IceCube does.”

Erica K. Brockmeier is the science writer at APS.

Comedy as a Tool to Demystify Science

If we want people to take science seriously, comedy may be the key.

BY JESSAMYN FAIRFIELD

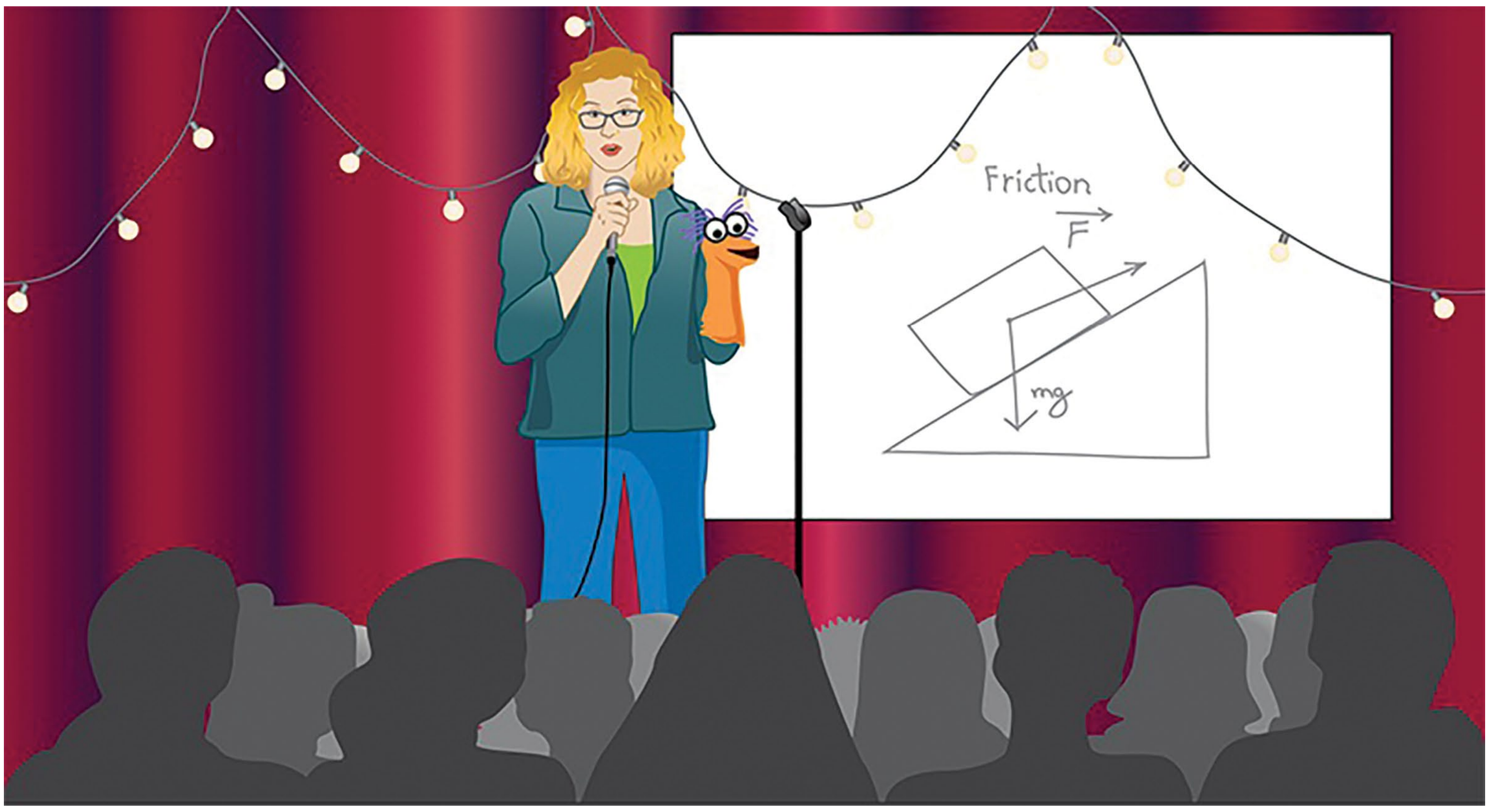
Most physicists will tell you that they don't want their work to be laughed at. In fact, current societal challenges, from climate change to the ongoing pandemic, are exacerbated when policymakers and the public don't take scientific evidence or mitigation strategies seriously. But having a sense of humor about science can be a potent communication tool.

Often, when people think of science jokes, they imagine something that might start, "A proton walks into a bar…" Great, if you know what a proton is. Lots of common examples of scientific humor are in-group jokes, whose endings may make sense only if you already possess scientific knowledge. But in my work over the past decade running Bright Club Ireland, I've trained academics to write stand-up comedy material about their research expressly to help their research make sense to a public audience. We run events at pubs and festivals — places without "science" in the name — and we recruit speakers from across all disciplines. They all take their work seriously, but they've seen the limits of what science can be conveyed through journal articles or features and op-eds in *The New York Times*, *Scientific American*, and other popular media. Taking a comedic approach often yields new insights into both science communication and science itself and can reach very different audiences.

When you listen to a joke, think about what you are doing. A good joke involves a story being told, a world with systems and laws set up as factual, and then comes the punchline — a reversal, a flip that upends everything you thought was true. You experience surprise (or, as humor theorists would call it, incongruity) when forced to change your perspective entirely and then the release of laughter in response. Laughing at a joke literally involves changing your mind, and a good joke can invite the audience into the speaker's expertise rather than dividing them into people who do or don't know what a proton is. Laughter is contagious when it's inclusive.

Simply presenting facts does not change minds and indeed can often make people dig their heels in to preserve their existing views. But the lateral approach of comedy, with its embrace of multiple perspectives, can be much more persuasive. Recent studies have found that humorous takes on research can increase the perceived credibility of the speaker and improve the listener's endorsement of scientific content. If we hope to combat fake news and encourage critical thinking about what science endorses, comedy has the core skills baked in.

Indeed, the mindset of comedy is quite like the mindset of scientific research. Both involve creative exploration — asking, If this is true, what else is true? — and an unwillingness to accept the status quo without verifying it for oneself. What's more, the inherently subversive nature of comedy provides a space to challenge the human biases that impact the supposedly objective conclusions we draw as scientists, including stereotypes around science and around who can be a scientist. It also acknowledges the emotive and affective impact of both scientific research and the experience of researchers who face elitism, sexism, racism, classism, homophobia, transphobia, and countless other issues in the culture of science. Scientists who spoke at Bright Club said afterward that the experience of writing comedy about their work helped them to feel more agency and empowerment. They were freed from a falsely passive voice to adopt a more authentic delivery, strengthening their professional identities as researchers.



Comedy's lateral approach can be more effective at changing minds than a direct presentation of facts. *Credit: S. Cross; APS/C. Cain*

When we ask the public to engage with scientists, we should be careful not to expect them to passively listen as they are berated by "experts." Members of the public can and should be a part of scientific discourse, and their fears must be taken seriously. Indeed, climate communication studies have found that engaging with prior knowledge, emotions, and emotional doubts is a critical component of public involvement in that topic. It stands to reason that the approach would apply to many more important and contentious topics.

The COVID-19 pandemic provided many examples of science communication having a huge impact, but it also unfortunately brought a reversion to the "deficit model," in which the audience is thought of as an empty bucket to be filled. We know, and have known for 20 years, that the deficit model doesn't work. If we wish to be heard, we also have to listen. Comedians who don't listen and respond to their audience are rarely funny, and science communicators who don't listen and respond to their audience rarely get their points across.

Although comedy can be culturally specific or rely on insider knowledge, laughter is a universal human experience. It can also be an incredibly powerful means of bonding groups of people together as they consider new ideas. If we as physicists want to be part of a society where science is a pillar of culture, a process that everyone participates in, then it may be time to start taking ourselves a little less seriously.

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Lilienfeld Prize continued from page 1

was so intrigued that he approached Salam after one of his talks. The two spoke for an hour, on topics ranging from graduate school to unified models of particle interactions. The conversation solidified Ratra's interests in theoretical physics.

The following year, Ratra started his doctorate at Stanford University. "It was a really interesting time," he says. The concept of inflation was brand new, and one of Ratra's first tasks was developing a quantum mechanical approach to modeling the energy density fluctuations generated during inflation of the early universe — a treatment that was more consistent than any done before.

Two years later, when physicists were developing superstring theories, Ratra shifted course again. "I really liked the mathematics of superstrings," says Ratra. "It's really beautiful, and it's the only known way of consistently combining gravity with quantum mechanics." His new trajectory landed him a postdoc at Princeton University in 1986.

But as his research interests evolved, Ratra realized he wanted to rely more on real-world measurements. "It was pretty clear to me by 1987 that there would be a lot of data coming in from telescopes," he says. That data was likely to open entirely new research in cosmology.

In the four decades since, rapid advancements in physics, aided by increasingly precise measurements of supernovas, cosmic background radiation, and baryon acoustic oscillations, among other phenomena, have been akin to "a revolution," he says.

More big shifts could be coming. From the Dark Energy Spectroscopic Instrument (DESI) survey, the Rubin Observatory Legacy Survey of Space and Time (LSST), and other near-future experiments, "we should get more and better data in the next decade that will allow us, hopefully, to determine whether dark energy is constant, or weakly varies in time and space," Ratra says.

He hopes we'll soon have more precise and accurate constraints on other cosmological parameters, like the Hubble constant, and that we'll find a more definitive answer on the geometry of space — whether our universe is flat, as current data suggests, or whether new data will point toward a different geometry, like a saddle shape.

But Ratra's priorities extend far beyond research: The Lilienfeld Prize recognizes his contributions to students and the public, as well. Ratra loves teaching, and his research mentorship has helped more than a dozen undergraduates continue onto graduate school, and some, to faculty careers of their own. "It's really satisfying," he says.

Ratra also co-developed a Kansas State general education course "Origins: Humanity, Life, and the Universe," designed to touch on a range of topics that have faced mounting public skepticism in parts of Kansas in recent decades. "We're in the center of the country, where people have very strong opinions about what should be taught, and what shouldn't," he says.

"I've been here 28 years, and twice the state school board has ruled that high schools shouldn't be teaching evolution, and once, … the Big Bang model," he says. "People have their beliefs, and a few feel they should be allowed to dictate what's taught."

> "We're in the center of the country, where people have very strong opinions about what should be taught, and what shouldn't," Ratra says.

"I think that's a really dangerous thing," says Ratra. "It's useful for people to understand the scientific background of what we deal with in everyday life," from the depletion of regional aquifers to the likelihood of new pandemics.

Using cosmology as a lens for teaching general education courses or developing educational outreach materials is an "ideal" way to introduce the public to "big questions about life," he says. After all, "everybody is fascinated by the Big Bang."

And through the high school outreach program QuarkNet, a National Science Foundation-funded program with hubs across the country, Ratra works with high school teachers and students from Kansas and Arkansas to expand students' interest in physics. Ratra and other Kansas State physicists bring real data from CERN and other cutting-edge scientific facilities directly into the classroom.

In one project, students and teachers use Fermilab-built detectors to measure the cosmic ray muon flux — particles produced by the interaction of cosmic rays with our atmosphere — and then correlate their measurements with weather data from NOAA. This lets students "track cold fronts as they move two to three hundred miles across the Midwest," he says.

"It's pretty impressive," he says. "Hopefully this award will help publicize the great cosmology research and physics outreach programs that we've built here at Kansas State."

Liz Boatman is a science writer based in Minnesota.