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APS NEWS

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RESEARCH

New Results from MICROSCOPE Mission Tighten Constraints for Key Principle of General Relativity

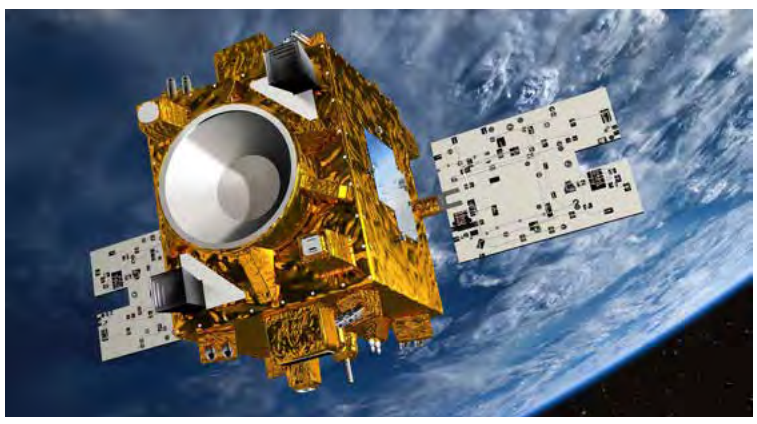
The satellite's free-fall experiments yielded the most precise confirmation yet of weak equivalence.

BY ABIGAIL EISENSTADT

In a grainy NASA video from 1971, the astronaut David Scott, donning a spacesuit and standing on the dusty lunar surface, holds up a feather and a hammer. "A gentleman named Galileo ... made a rather significant discovery about falling objects in gravity fields," Scott says. "Where would be a better place to confirm his findings than on the moon?"

He drops the feather and hammer. In defiance of the intuition of Earth-bound viewers used to seeing feathers drift slowly, both objects hit the ground at the same time. "How about that?" he muses.

The stunt introduced many to the weak equivalence principle (WEP), central to the theory of general relativity, but it wasn't a formal experiment. Now, new and final data from MICROSCOPE—a boxy satellite that, between 2016 to 2018, orbited more than 400 miles above Earth—has added to physics the most precise test yet of the WEP.



The MICROSCOPE mission satellite was decommissioned in 2018, but its final findings were published this week. CREDIT: JUILLET 2012, ILLUS. D. DUCROS / CNES 2015

The WEP dictates that two objects in the same gravitational field should accelerate in free-fall at the same rate, regardless of their configuration or mass, so long as there are no other forces (like air resistance, which slows a falling feather on Earth but not on the airless Moon).

The MICROSCOPE results, published in the journal *Physical Review Letters* on September 14, reveal the tightest constraints for the

MICROSCOPE CONTINUED ON PAGE 5

PEOPLE

Q&A: Lia Merminga Has a Vision for Particle Physics

As a child, she played hopscotch in the Athens suburbs. Now, the Fermilab Director wants the facility to lead the world in neutrino research.

BY SOPHIA CHEN

Lia Merminga still remembers her first glimpse of the US, as her plane flew in from Greece in 1983. During the descent into New York City, Merminga saw the densely packed skyscrapers of Manhattan.

"I just felt inspired," says Merminga, who hails from just outside Athens. "I said, 'My God, how privileged I am.' I wanted to do something big. I still have this feeling now."

From there, Merminga went to the University of Michigan, where she earned her physics PhD and began her decades-spanning career to innovate particle accelerators for high energy physics research. She began to lead these efforts, most recently heading the Proton Improvement Plan-II (PIP-II), an ongoing upgrade of the accelerator complex at Fermi National Accelerator Laboratory, outside Chicago. Founded in 1966, Fermilab's 6,800-acre site has played host to milestone experiments in particle physics, such as the 1995 discovery of the top quark.

Lia Merminga, Director of Fermilab
CREDIT: FERMILAB

This April, Merminga became the new director of Fermilab, the

MERMINGA CONTINUED ON PAGE 7

PROFILES IN VERSATILITY

Physicist Receives Grant to Test Nanoparticle-and-Laser Cancer Treatment in Humans

After losing her aunt to cancer, Dr. Hadiyah-Nicole Green dedicated her career to physics-based therapies.

BY ALAINA G. LEVINE

When Hadiyah-Nicole Green crossed the stage at her college graduation, she felt sure about what would come next. She'd start a career in optics—a good option for someone with a bachelor's degree in physics—and that would be that.

Life, though, had other plans. The day after she graduated from Alabama A&M University, she learned that her aunt, Ora Lee Smith, had cancer. Smith and her husband had raised Green since she was four years old, after the death of Green's mother and then grandparents.

Her aunt "said she'd rather die than experience the side effects of chemo or radiation," says Green, now a medical physicist and founder and CEO of the Ora Lee Smith Cancer Research Foundation.

Hadiyah-Nicole Green

Her aunt deteriorated quickly, and Green became her primary caregiver. In the last few months of Smith's life, Green says, "I saw her go from being the matriarch of our family, the glue that held

GREEN CONTINUED ON PAGE 4

MEETINGS

Gas Particles, Ferromagnets—and Voters?

Some researchers are using the tools of physics to study social processes like elections.

BY MEREDITH FORE

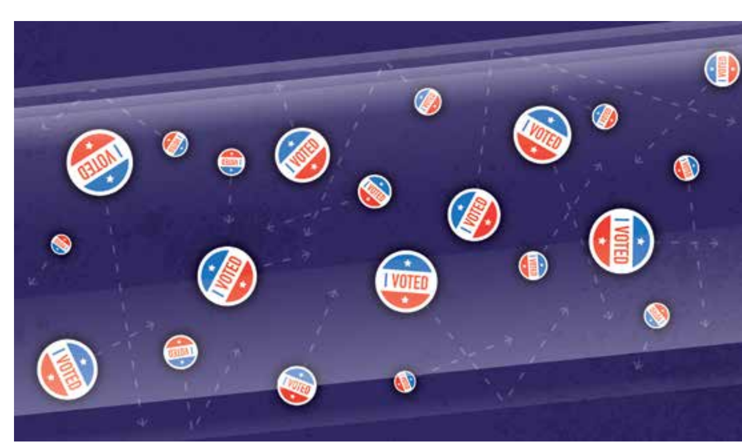
Imagine five coins on a table, labeled A through E. Three are heads, and two are tails. Many different configurations will produce this: A, B, and C are heads while D and E are tails, A, C, and E are heads while B and D are tails, etc. This can be extended to gas in a container: Many different configurations of particles can create the same overall pressure.

Now imagine an election with two candidates. Candidate A receives 45 million votes, and Candidate B receives 50 million. How many possible ways could the millions of voters submit millions of votes to cause this exact outcome?

Comparing an electorate to a gas might seem like a stretch, but applying physics to social systems—including elections—has produced interesting results. This August, scientists discussed some of this research at the 33rd IUPAP Conference on Computational Physics (CCP22), a meeting that APS co-sponsored.

Statistical physics, in particular, is used to explain the properties of a large collective from the properties of its parts. This is most often applied to different forms of matter, but in studies of large populations of people, the same principles might be relevant.

"Statistical physics is a very powerful tool to study large quantities," said Hygor Piaget M. Melo, a senior researcher at the Enrico



CREDIT: ELIA KING / APS

Fermi Research Center in Italy, who spoke at CCP22. "You can almost see the behavior of these systems as a collective action of particles."

In 1999, researchers published a paper in *Physical Review E* that analyzed the results of federal deputy elections in Brazil. When the candidates were ordered by the number of votes they received, the researchers found that a small fraction of candidates received the vast majority of votes; all the other candidates got very few. When graphed, this data closely followed a power law, a well-known mathematical relationship.

Enamored with the pattern, statistical researchers rushed to study the underlying mechanisms. "There was an avalanche of papers trying to explain this," Melo said.

In 2011, Brazil passed a law requiring candidates to publish detailed information about their campaign finances. Melo and his collaborators took advantage, investigating the relationship between campaign spending and number of votes in the 2014 and 2018 elections for federal deputies in Brazil. Could the data shed light on the power law seen across elections?

The researchers modeled the votes as particles in a gas and the candidates as energy states the particles could occupy, maximized the entropy of the system, and watched what happened with the distribution.

They found that the correlation was not linear: doubling the amount of money spent in a campaign did not double the number of votes a candidate received. Even so, the distribution of wealth matched the power law distribution of votes

VOTES CONTINUED ON PAGE 3

APS COMMUNITY

For Women and Gender Minorities in Physics, Community Builds Confidence

Lessons from the 2022 Advancing Graduate Leadership Conference.

BY LIZ BOATMAN

By third grade, Erica Snider knew, resolutely, that she wanted to be a physicist.

But that doesn't mean it was always smooth sailing. Snider, who has worked as a high-energy physicist at Fermilab for more than two decades, says that, early in her career, "I declined some talks… purely because I didn't have the confidence to get up in front of people."

That lack of confidence, she says, stemmed from her environment. Confidence is "massively affected by the people around us, the culture that we're in"—and for women and gender minorities, who make up about one-fifth of physics graduate students, finding a supportive community can be a challenge.

To help students overcome this challenge and build community, APS—with funding from the Heising-Simons Foundation—hosted a multi-day conference for women and gender minorities. The Advancing Graduate Leadership (AGL) Conference, which took place in August in Washington, DC, sponsored nearly 150 attendees from 34 states. Sessions focused on professional development, and topics ranged from coping with mental health challenges to cultivating inclusive leadership skills.

Snider, drawing on lessons from her own career, facilitated a session called "Developing Confidence and Presence." She opened by asking attendees if they had ever struggled with confidence in their physics careers. "Almost everybody in the room said that they felt as though [their confidence] interfered with their job, or that it affected their decision-making in ways that might affect their career," she says.

"That was certainly the case with me," she adds. "There was a point in time where I thought confidence was an immutable personality trait."

At the AGL conference, she sought to break down that myth. Confidence, she told attendees, is something you can shape "through your attitudes or your approach, the way you react. And presence is a skill—you can just learn it."

Xuan Chen, a postdoctoral research assistant in high-energy physics at Cornell University who attended the conference, is concerned about the confidence gap she sees in many of her peers. "If you talk to female students or students from minority groups," she says, "you will realize that they often do not feel confident, regardless of how much they have achieved in their field."

Chen plans to pursue an academic path after her postdoc. In preparation, she's focused on finding ways to promote a more inclusive culture in physics and academia as a whole, which is why she attended the AGL Conference.

Sam Kaufman-Martin, a PhD student researching the turbulence of wind energy kites at UC-Santa Barbara, flew from the west coast to participate in the event. Kaufman-Martin originally saw

AGL CONTINUED ON PAGE 6

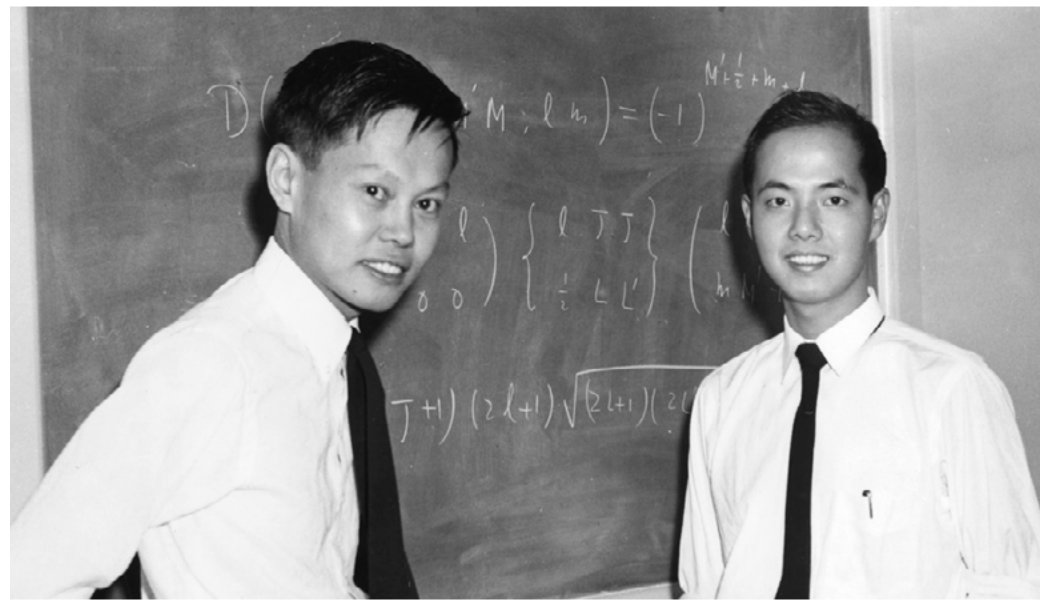
THIS MONTH IN

Physics History

October 1956: Lee and Yang Crack the Mirror of Parity

Until the pair's explosive paper, physicists assumed that particles would act the same when mirrored.

BY DANIEL GARISTO



Physicists Chen-Ning Yang (left) and Tsung-Dao Lee, whose 1956 paper on parity violation earned them the Nobel Prize. CREDIT: UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE (APF1-03706) / HANNA HOLBORN GRAY SPECIAL COLLECTIONS RESEARCH CENTER

On a hazy January day in Zurich 65 years ago, Wolfgang Pauli was composing a letter in untidy scrawl to his colleague Victor Weisskopf. He was dubious about a recent proposal, from Tsung-Dao Lee and Chen-Ning Yang a few months earlier, that parity—the basic symmetry between left and right in physical laws—might be violated. Pauli captured his skepticism in an immortal quip: "*Ich glaube aber nicht, daß der Herrgott ein schwacher Linkshänder ist.*" (I do not believe that the Lord is a weak left-hander.)

He wasn't alone. At the time, physicists believed all the known fundamental forces—electromagnetism, gravity, the strong force, and the weak force—obeyed parity symmetry. Why shouldn't the universe look the same in the mirror?

But two days later, the elegant mirror of parity was shattered. Initial data from Chien-Shiung Wu's experiment suggested Lee and Yang's theory was correct. In a second, frantic note, Pauli wrote: "*Sehr aufregend. Wie sicher ist die Nachricht?*" (Very exciting. How sure is this news?).

Lee and Yang's "Question of Parity Conservation in Weak Interactions," published October 1, 1956, took the physics community by storm. Their ideas provoked a frenzy of debate and experimentation, which just a year later landed the pair two Nobel medals.

At the time, physicists were plagued by a problem known as the "theta-tau puzzle." Two particles—now called kaons—appeared to have the same masses and lifetimes, but, somehow, different decays: thetas into two pions, taus into three pions.

Hypotheses proliferated. Some physicists proposed that the particles weren't identical after all—that tau was a smidge heavier than theta—or that high spin numbers might explain the strange decay. Ironically, Lee and Yang pitched an idea: Tau and theta might point to a new symmetry (ironic, given that their later, Nobel-earning paper argued for a *violation* of symmetry). Experiments quickly proved all these models wrong.

At a conference in April 1956, Yang discussed the theta-tau puzzle, prompting a debate. At one point, Richard Feynman asked a question of Martin Block's: "Could it be … that parity is not conserved … does nature have a way of defining right or left-handedness uniquely?" Yang replied that he and Lee had investigated the question but not reached a conclusion.

After the conference, Lee had a breakthrough while speaking with Jack Steinberger, which he recalled during a 2001 talk: "If parity is not conserved in strange particle decays, there could be an asymmetry between events… *This is the missing key!*" The conversation led Steinberger and his colleagues to search for parity violation in hyperon decay, but with too little data—just 48 detected particles—their results were inconclusive.

Meanwhile, Lee and Yang began to pore over existing data. "At that time, everyone believed correctly—at least as far as we know now—that parity was conserved in the strong and electromagnetic interactions," says Allan Franklin, a physics historian at the University of Colorado,

HISTORY CONTINUED ON PAGE 7

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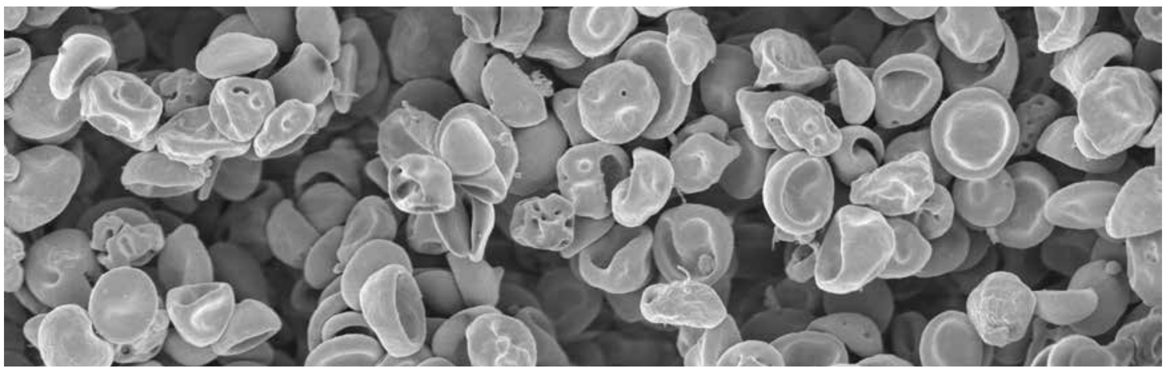
RESEARCH

In Proof-of-Principle Experiment, Researchers Use Tiny Chip to Separate Squishy Cells from Hard Particles

Microfluidic devices could help scientists sort sick cells by softness.

BY TESS JOOSSE



Red blood cells of someone with malaria. Healthy, round cells are interspersed with infected, misshapen ones. New research might help scientists sort sick cells, like those deformed by malaria, by softness. CREDIT: GRANDBROTHERS/ADOBE

When a mosquito harboring a malaria parasite bites you, the parasite attacks your red blood cells, changing the cells' disk-like shape and making them more rigid. The sick cells stick to the inside of blood vessels, causing malaria's slew of symptoms, like fever and vomiting.

Malaria isn't the only disease that changes a cell's physical properties: Cancer and sickle-cell anemia can, too. So being able to quickly, effectively separate sick, stiff cells from healthy, squishy cells could help scientists detect and study disease.

A study published August 8 in *Physical Review Fluids* details a proof-of-concept experiment to use soft cells' tendency to deform—that is, squish and change shape—to sort them on microfluidic devices, small instruments etched with tiny channels in which scientists can control and study fluid. The research could support the development of therapeutic or diagnostic microfluidic methods for separating complex mixtures of cells with different properties, like sick and healthy cells.

"This is the first time the experimental work has been done to show [that] actuation-like change of shape of soft particles, like a red blood cell, can move them forward," says Chaouqi Misbah of Grenoble Alps University in France, who was not involved with the paper.

In March this year, researchers at the University of Bayreuth in Germany published a hypothesis on this potential phenomenon in *Physical Review Fluids*. When soft particles deform in a flowing fluid, the drag on them changes. By pushing a mix of particles in a fluid forward and backward through a microchannel at different rates, it might be possible to push soft particles forward and leave the rigid ones behind, the researchers suggested.

A separate team at the University of Bayreuth decided to test this theory with red blood cells, which are particularly well suited for the experiment, says Pierre-Yves Gires, a co-author of the most recent paper. "They don't have a nucleus," he explains. "They can be deformable, as they have to fit through very thin capillaries" in the body.

To test it, Gires and his colleagues Sebastian Krauss and Matthias Weiss ran a mixture of red blood cells and hard plastic beads that wouldn't deform through the channels of a microfluidic device, which they designed and printed themselves. They ratcheted the particles in one direction for an interval of time, then reduced the flow rate and drove the particles backward for even longer. The soft cells would

MICROFLUIDIC CONTINUED ON PAGE 5

APS COMMUNITY

Physics Lab Kits Help Foster the Next Generation of East African Scientists

The kits—supported by the APS Innovation Fund—have already reached 1,400 students.

BY JESSE KATHAN

When Cecilia Rolence was a child in Mgeta, a small village in Eastern Tanzania, she was fascinated by a doctor from the village hospital.

"[I remember] how smart she was in her white coat," Rolence said. Her interest in science began to blossom. While her school had little laboratory equipment and few science instructors, Rolence found support in a female chemistry teacher, who empowered Rolence to enroll in university and eventually complete a PhD in materials engineering.

Now a textile and leather researcher at the Tanzania Industrial Research and Development Organization, Rolence is passing on her hard-won knowledge to help the next generation of young female scientists.

Rolence is part of the leadership team for WS2, an international collaboration of women scientists that aims to unite and support women in science and engineering around the globe. This year, the group distributed science lab kits to hundreds of schools across East Africa.

The organization was born after a 2016 conference in Arusha, Tanzania, when graduate students from the US and East Africa gathered to share their experiences and collaborate. There, Jill Wenderott, then a graduate student at Northwestern University, met Joyce Elisadiki, a Tanzanian engineer and physics lecturer at the University of Dodoma.

"We connected both over being women graduate students in STEM, but also recognizing the differences in being a woman in STEM in different parts of the globe, and thinking of how we could work together to share resources to support women," said Wenderott.

The two co-founded Women Supporting Women in the Sciences, an international collaboration of women scientists.

After hosting a series of professional development seminars, the organization received a grant from the American Physical Society's Innovation Fund to develop laboratory physics kits for students in primary and secondary schools.

Seven international development teams with members from East Africa and other countries developed kits with topics ranging from astronomy to optics, each with two or three experiments and then a design challenge. Among those tasked with lab-kit design was Rolence.

The experiments were crafted to explore complex ideas, like electrical energy, using extremely accessible components, like balloons and bits of paper.

"We wanted the supplies to be very easy to obtain," said Wenderott. "And we wanted each kit, if you were to use it with one student, for all of the supplies to be less than $2.75 USD."

The teams also focused on making sure the science kits would be interesting and accessible to young girls. "Sometimes physics examples can be a bit focused from sort of the male perspective, like playing with cars and balls and ramps," said Wenderott. "We were trying to design experiments that would be appreciated and enjoyed by boys and girls, wherever they were in the world."

She said students particularly connected with the food science kits, which explored food preservation with materials science and chemistry. "These are things that really everyone is going to enjoy and engage with, whether you're a young boy or young girl," said Wenderott.

Students in Arusha, Tanzania, using static electricity to pick up small pieces of paper. WS2's low-cost lab kits have reached students across eastern Africa. CREDIT: WS2

So far, seven types of lab kits have been distributed to eight partner schools across Uganda, Kenya, Tanzania, Rwanda, and Ethiopia, reaching 1,400 students—about 70% of them girls. The organization's goal is to reach another 3,600 students—at least 5,000 in total—with the rest of the money from the Innovation Fund.

The organization is also beginning to analyze feedback from the partner schools and surveys students took before and after the activities.

"There's been a lot of really positive feedback," said Wenderott. "We're hoping that we can see a change before and after, that maybe

KITS CONTINUED ON PAGE 6

VOTES CONTINUED FROM PAGE 1

initially seen in 1999.

"[Campaign spending] might not be everything," Melo said, but it seemed to explain "the majority of the distribution."

The elections in Brazil relied on open list proportional representation, where voters first pick the party they prefer, and then their preferences for individual candidates within that party. Seats assigned to each party correspond with that party's share of popular support.

The US, however, uses a "first-past-the-post" voting system, where a candidate who receives the most votes wins. The loser doesn't get representation, even if they received 45% of the votes and the winner received 46%.

This has dramatically impacted the two countries' politics. Where Brazil has five political parties that control the absolute majority of federal seats, the US has only two—to interesting effect, according to Alexander Siegenfeld, a doctoral student in physics at MIT, who has used physics to study instability and polarization.

"In a stable process, if I change the electorate's opinions by a little bit, the outcome changes by a little bit," he said. "[But] elections can also be unstable, where you get these really different outcomes from year to year even though it doesn't seem like the populace is changing their opinion that much"—at least, not relative to the swings in election outcomes.

His study, published in *Nature Physics*, found that US elections went through a phase transition—a common concept in physics—in 1970, from stable to unstable. He cited the transition from George W. Bush to Barack Obama in 2008, then from Obama to Donald Trump in 2016, as examples of relatively small changes in voters' party affiliation resulting in massive swings on the political spectrum.

> The researchers modeled the votes as particles in a gas and the candidates as energy states the particles could occupy.

"We can imagine a lot of reasons why this is problematic," he said. "It really encourages special interests to try to sway the election, because if they can just give a little push, they can have a big effect."

His team found that the Ising model, developed to explain the behavior of ferromagnets, describes how electoral systems can become unstable. In the model, interactions between magnetic dipoles in a ferromagnet can lead to a large-scale phase transition, where the system becomes unstable.

The key result is that after the phase transition, the instability of the electoral system leads to the development of "negative representation," where a small move in the electorate in one direction could lead to an elected candidate that tends toward the opposite direction. This may be a consequence of the two-party system, where each election is a choice between two candidates: for example, if the choice is between a center-left and far-right candidate, and the prevailing opinions move left, far-left voters may stay home if the center-left candidate's views are too far from their own.

Modeling voters as gas or magnetic particles might seem oversimplified—it is, say Melo and Siegenfeld—and there's plenty of debate about the limits of these tools. But Melo's and Siegenfeld's results speak to the potential of physics to help us understand our world.

"Humans aren't particles," said Siegenfeld, but the field might help answer a more fundamental question: "What are the conceptual approaches behind physics that have made the study of physics so successful, and can we apply those more broadly?'"

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

GREEN CONTINUED FROM PAGE 1

us all together, to someone who couldn't walk, bathe herself, eat or talk anymore. That was very disturbing at the deepest levels of my being."

Smith died after three months. In an almost unimaginably cruel twist, Green's uncle—Smith's husband—was diagnosed with cancer soon after. Green's uncle survived with chemotherapy, but the process took a traumatic toll: He lost 150 pounds and was left with disfigured skin and chronic diarrhea.

During her uncle's treatment in 2003, Green experienced what she refers to as a "divine download"—an electrifying idea inspired by her college internships at NASA's Marshall Space Flight Center and the Institute of Optics. "If a satellite in outer space can tell if a dime on the ground is face up or face down, and if a cell phone can target just one cell phone on the other side of the planet," she recalls thinking, "surely we should be able to harness the technology of lasers to treat cancer just at the site of the tumor, so we won't have all of these side effects."

In the nearly two decades that followed, Dr. Green rerouted her career, earned a physics PhD from the University of Alabama at Birmingham—the second Black woman to do so—and dove into cancer treatment research, with physics as her guide. In 2009, she developed a treatment that uses nanoparticles and lasers in tandem: Specially designed nanoparticles are injected into a solid tumor, and, when the tumor is hit with near infrared light, the nanoparticles heat up, killing the cancer cells. In a preliminary animal study published in 2014, Green tested the treatment on mice, whose tumors were eliminated with no observable side effects.

2016 was a big year for Green: She received a $1.1 million grant from the US Department of Veteran Affairs (VA) for her research, and, in April, joined the Morehouse School of Medicine as an assistant professor. Also that year, she founded the Ora Lee Smith Cancer Research Foundation, named after her aunt, to raise funds for clinical trials, which could cost more than $100 million.

This year, Green says, she was awarded a $1.2 million VA grant to launch a pilot study on her treatment with 10 veterans, research that's set to begin in October at the Atlanta VA Medical Center. "It's a small project, but it's a huge step for my research and the technology and my career," she says. "This is 20 years in the making. I get emotional thinking about it."

For Green, cancer research and physics go hand in hand. "My initial approach to physics is, what is the application? How

Hadiyah-Nicole Green (right) with her aunt, Ora Lee Smith. Green founded the Ora Lee Smith Cancer Research Foundation in honor of Smith, who died of cancer. CREDIT: HADIYAH-NICOLE GREEN

can it help people?" she says. "The work I'm doing now gives me a hopeful and purposeful outlet for applied physics, but it hasn't changed the way I look at physics fundamentally."

Physics has shaped her outlook, too. "It has made me very solution-oriented in everything I do," she says. "It gives me a greater sense of confidence." She attributes part of this to her doctorate advisor, Dr. Sergey Mirov. Under his guidance, "I had to slow down, pick [the material] apart, understand everything, and be patient with myself and with the process," she says. "The practice of getting something wrong—the iterations and revisions and noodling through 'what steps did I miss' and going back to the drawing board—is part of the process."

"That life lesson has helped me so much with building my team and nonprofit," she adds.

Her effort and impact have not gone unnoticed: Green has been named one of the 100 Most Influential African Americans in the US by *Ebony* and *The Root* magazines, and in 2020, she was named one of the Top 10 Women of the Century for Alabama, in a *USA Today* list that included Coretta Scott King and Rosa Parks.

Now, Green is focused on moving her research from mice to humans—an uphill battle, as fundraising for large-scale clinical trials is fiercely competitive, especially for early-stage research. The most recent VA grant is a start.

For her, the stakes are high. "There is a segment of the community who feel like they are forgotten when it comes to cancer—the people who chemotherapy and radiation don't save," she says. "This gets to me." So the work must go on.

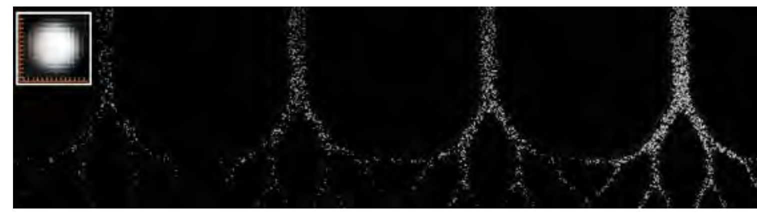
Alaina G. Levine is a professional speaker, writer, and STEM career coach, and the author of the book Networking for Nerds *(Wiley, 2015).*

RESEARCH

Scientists Create 3D-Printed Model to Study How Particles Move Through Blood

The research could improve embolization, a procedure to stop bleeding and fight tumors.

BY MARGARET OSBORNE



Four images of the vessel model. From left to right, particle concentration increases. CREDIT: Y. LI, O. AMILI, F. COLETTI / PR FLUIDS

To fight tumors, doctors sometimes use a procedure that starves tumors of blood. To "embolize" a tough-to-remove tumor, a physician passes tiny particles, such as gelatin sponges or beads, into a specific blood vessel, blocking it. Without oxygen-rich blood, tumors can shrink—and the process is less invasive than surgical removal.

But embolization has its limitations, and the ability to predict how these particles move in vessels could improve the accuracy and efficacy of the procedure.

In a new paper published in *Physical Review Fluids*, researchers report on a 3-D model they built to examine how various concentrations of particles affect their speed, acceleration, and distribution in a branching system, like a blood vessel.

"[Embolization] is not only for tumors," says Omid Amili, a professor of mechanical engineering at the University of Toledo and a co-author of the study. "It has multiple applications." Embolization is used to stop bleeding after injuries, for example, and even treat pain. It's also used in conjunction with chemotherapy drugs in the treatment of tumors.

Serious complications from embolization are rare, but every so often, the particles—usually no bigger than grains of sand—can block the wrong vessel and deprive healthy tissue of blood, or fail to block blood flow as intended. Predicting particle behavior, then, can improve the procedure's success.

Previous studies have looked at different factors affecting particle dynamics in the body, but "not many people have studied the importance–or the effect—of the particle concentration," says Yinghui Li, the lead author and a fluid dynamics researcher at ETH Zurich.

The team designed an idealized, symmetrical model of a blood vessel, which was 3D-printed out of clear resin by a collaborator at the University of Texas in El Paso. The model starts as one tube but then forks, like branches on a tree. By

3D CONTINUED ON PAGE 6

FYI: SCIENCE POLICY NEWS FROM AIP

US Revs Up Clean-Energy Campaign with Historic Climate Law

The Inflation Reduction Act adds billions to last year's infrastructure legislation

BY WILLIAM THOMAS

On August 16, President Biden signed into law the most ambitious set of initiatives to mitigate climate change the US has ever undertaken. The measures will cost $370 billion and mainly consist of tax incentives and grant programs aimed at decarbonizing the economy and bolstering resilience to climate-related hazards.

The law emerged from Democrats' efforts over the past year to use a process called budget reconciliation to advance large portions of their agenda. Unlike most bills, reconciliation legislation requires only a simple majority in the Senate to pass—in this case, the votes of all 50 Democrats, plus the Vice President's tie-breaking vote. But for much of the year, holdouts among the Democrats threatened to derail the party's plans.

Then, on August 8, Senate Majority Leader Chuck Schumer (D-NY) unexpectedly announced an agreement on a bill called the Inflation Reduction Act (IRA), which bundled the climate measures with tax and healthcare provisions. The bill moved quickly, with every Democrat in the House and Senate voting in favor and every Republican against.

The Act will significantly expand the Department of Energy's role in accelerating the deployment of clean energy technologies, building on the $62 billion that it's receiving through last year's bipartisan Infrastructure Investment and Jobs Act.

To manage the influx of funds from last year's law, the DOE has launched major initiatives: It created an Office of Clean Energy Demonstrations, set to be overseen by former energy company executive David Crane, a noted clean-energy

A technician checks a wind turbine at the National Renewable Energy Laboratory, a research facility in Colorado supported by the Department of Energy. The Inflation Reduction Act will pour billions into DOE programs to expand clean-energy infrastructure. CREDIT: WERNER SLOCUM / NREL

advocate. It's also hiring about 1,000 new employees to staff what it's calling a Clean Energy Corps.

Of the money from last year's infrastructure law, around $25 billion will support a new portfolio of commercial-scale technology demonstration projects in areas such as clean hydrogen, carbon capture and storage, electric grid reliability, energy storage, and industrial decarbonization. The IRA will add to this almost $6 billion specifically for reducing industrial emissions.

The DOE has also revived its loan program. In June, it guaranteed a half-billion-dollar loan, its first in nearly a decade, and in July announced plans to directly loan $2.5 billion to establish General Motors' domestic supply chain of electric vehicle batteries. The IRA will allow the department to go much further by authorizing it to guarantee up to $250 billion in loans for energy infrastructure projects over the next five years.

The IRA also increases tax credits for point-source carbon capture and direct air capture technologies. At the Environmental Protection Agency, the IRA provides over $1.5 billion to support methane emissions reduction in the oil and gas industry and authorizes new fees on excess methane emissions.

Additionally, the IRA includes $2 billion for science infrastructure projects at DOE national labs—funding that, although not directly climate-related, managed to remain in the bill during negotiations. The DOE has discretion over which projects receive funding, but potential recipients include the LBNF/DUNE neutrino project, the Electron-Ion Collider, the ITER fusion facility, and the Second Target Station at the Spallation Neutron Source.

William Thomas is a Senior Science Policy Analyst at the American Institute of Physics. Published since 1989, FYI is a trusted source of science policy news. Visit aip.org/fyi.

APS COMMUNITY

APS Members' Advocacy Helps CHIPS and Science Act Become Law

BY TAWANDA W. JOHNSON

Following the passage of the CHIPS and Science Act of 2022, which will bolster the nation's scientific and technological competitiveness, APS celebrates the sustained advocacy efforts by its members that helped the bill become law.

"APS is delighted," said APS President Frances Hellman.

The law authorizes significant funding increases for key scientific agencies and technology research and innovation, particularly for semiconductors. It also contains provisions that APS members and staff helped develop and champion, including policies that aim to broaden research participation to create a stronger, more diverse workforce; combat sexual and gender harassment in STEM; and address the liquid helium crisis by increasing federal support for helium recycling equipment.

APS members and staff participated in hundreds of meetings with congressional offices, joined key discussions with House and Senate committee staff, and sent more than 5,000 personalized communications.

Past APS President Sylvester James Gates Jr. advocated for key sections of the bill by co-authoring an op-ed in *The Hill*, writing letters to leaders in Congress and the White House, and participating in a global competitiveness panel sponsored by the Task Force on American Innovation, an alliance of US research universities, corporations, and scientific societies.

"When I heard the news about the bill becoming law, I felt a deep satisfaction that the work of APS members, staff, and leadership played such an important and sustaining role," said Gates, who is now the Clark Leadership Chair in Science at the University of Maryland.

Gerald Blazey, Vice President for Research and Innovation Partnerships at Northern Illinois University, co-authored the op-ed with Gates and testified before Congress about research funding inequities.

NSF-funded research at Georgia Tech, where scientists used lasers to study semiconductor properties. The CHIPS Act will funnel $52.7 billion into US semiconductor research, manufacturing, and workforce development. CREDIT: GEORGIA TECH/ROB FELT (NSF)

"The law offers several mechanisms to broaden participation in research and STEM," Blazey said, including at smaller institutions. In support of this effort, the law establishes a new category of academic institutions, the Emerging Research Institution (ERI), and creates a pilot program for partnerships between flagship research institutions and ERIs.

The law will also help the scientific community manage disruptions to the nation's helium supply. "[It's a] life saver for so many—in chemistry, physics, and engineering—all of us who use helium for cooling, for lifting applications, and in other specialized processes," said Sophia Hayes, Vice Dean of Graduate Education and Professor of Chemistry at Washington University in St. Louis. She advocated for the helium provision to analysts who assist both White House officials and two House congressional committees.

Programs that encourage helium recycling and reuse, and the infrastructure and equipment that support it, "will help sustain the US research enterprise" for decades to come, Hayes added.

The law also seeks to protect STEM workers from hostile work environments. According to a 2018 National Academies study, nearly three in four undergraduate women reported experiencing sexual harassment, which can deter them from STEM professions.

> The CHIPS Act is "the most significant science legislation in more than a decade."

To change this, the law created a working group that will develop uniform sexual and gender harassment policies and metrics for federal research agencies.

Mark Elsesser, Director of APS Government Affairs, noted that the law—"the most significant science legislation in more than a decade"—was the culmination of years of effort, which were vital to ensuring that it included three of APS's science policy priorities. "It would not have been possible without the hard work of APS members, leadership, and staff."

Tawanda W. Johnson is APS Senior Public Relations Manager.

MICROSCOPE CONTINUED FROM PAGE 1

WEP ever identified. Researchers analyzed free-falling objects on MICROSCOPE and found that the objects' accelerations differed by no more than one part in 10^{15} (a quadrillion), ruling out violations of the WEP at this level. These results build on MICROSCOPE findings published in 2017.

"Five years ago, the very good behavior of the satellite and the instrument motivated our team to publish the first results of the mission which, although preliminary, would be useful to scientists," said Manuel Rodrigues, a scientist at French aerospace lab ONERA and study co-author. "But now, for the second paper, we have refined those results—we have accumulated more data."

When it launched in 2016, the MICROSCOPE experiment was the next step in a long history of tests on Galileo's universality of free-fall, a principle crucial to Newton's gravitational theory. From 1885 to 1909, the physicist Loránd Eötvös performed one of the most famous of these tests: He used torsion balances, instruments capable of measuring tiny differences in force, to demonstrate the equivalence principle at a precision scale of one part in 100 million.

Eötvös's findings landed in the lap of Albert Einstein, who merged the equivalence principle with special relativity to describe the relationship between gravity and space-time. In 1915, he unveiled the theory of general relativity, which transformed our understanding of gravity and has passed every test thrown at it.

Yet Einstein's theory does not mesh neatly with quantum physics, the rules that govern nature on its smallest scale: atoms and their parts.

So, by testing the WEP with increasing precision, researchers might find its limit—a measurement that violates general relativity—and throw open the door to theories that unify quantum and classical physics.

"We are almost sure that there is a violation at a certain level, but it is difficult to predict what that level is," said Gilles Métris, a scientist at Côte d'Azur Observatory and study co-author.

For the MICROSCOPE mission, Métris and his colleagues designed an experiment to measure the acceleration of hollow alloy cylinders. A nested pair of each was stowed in one of two sensor units in the satellite. If the masses' acceleration varied by more than one part in 10^{15}, this would signal a violation of the WEP. To measure any variations, sensitive instruments aboard the satellite would pick up changes in the electrostatic forces that keep the masses in unison.

After the satellite's launch in 2016, the team faced challenges. Equipment had to be adjusted for temperature sensitivity, power consumption, and circuitry issues.

"Before it launches, you're not sure that the launch will be a success," said Métris. "You are not sure that the instruments will work, because they cannot fully be tested on the ground for how they will behave in space. There are so many possible sources of systematic problems." For example, the scientists had to scrub data of random glitches caused by crackles in the satellite's insulator.

But, he added, "the experiment still worked well." The team noted these challenges in their 2017 findings, but methodically resolved them in their new paper.

While the analysis does not reveal a WEP violation, the findings are significant. The study places the narrowest constraints yet on the scale at which any WEP violation could occur. It also recommends improvements, like equipment upgrades, for future experiments.

According to the researchers, these improvements could one day lead to a precision of one part in 10^{17}. Perhaps a WEP violation lurks there, ready to throw limits around general relativity and make way for grander theories.

"It's a kind of game. You have to bet to win, by doing this experiment, to see something," said Rodrigues. "This time we didn't. If one day we could see something, then it would be revolutionary."

Abigail Eisenstadt is a science writer at the American Association for the Advancement of Science.

MICROFLUIDIC CONTINUED FROM PAGE 3

deform during the forward motion, and as the scientists changed the flow rate, the soft cells inched along the channel while the hard beads were left behind.

But in a real-world application, you would want to separate sick and healthy cells from each other, not from synthetic beads. So the team set up two populations of HeLa cells, a type of cultured human cell, that had been treated with an enzyme called trypsin to prevent them from sticking to the microfluidic channels. They softened some of the cells with chemicals that disrupt a cell's cytoskeleton, then applied a mixture of the soft and normal HeLa cells to the microfluidic device and tested the asymmetric flow pattern.

The researchers were not able to segregate the two populations, an unfortunate but not unexpected result. "I'm not surprised they were not successful with HeLa," Misbah says. Gires agrees. Unlike red blood cells, HeLa cells contain nuclei that limit how much they can deform, he says. "That's one challenge when using this technique with stiff objects," Gires says.

A few cell-sorting methods already exist: Some push acoustic waves back and forth, while others use electromagnetic waves, Gires says. But an advantage of Gires' and his colleagues' system is that it's inexpensive. "It does not require some sophisticated device. It's just a simple microfluidic device with a pressure controller," Misbah says.

It's not clear, however, how energy-efficient the method would be, and Misbah says the process of sorting the cells from the beads "remains relatively slow." The speed and efficacy of the separation need to be tested against other sorting techniques before researchers can start thinking of direct applications, he says.

But even beyond its potential biomedical applications down the line, Misbah says, the work is "exciting from a fundamental point of view."

Tess Joosse is a science journalist based in Madison, Wisconsin.

KITS CONTINUED FROM PAGE 3


Of the students the lab kits have reached, 70% are girls. CREDIT: WS2

more young kids see themselves as liking science or being good at science." The organization will start releasing results in November and plans to have a complete report available in early 2023.

Now that the lab kits have been disseminated, WS2 is working to put artificial intelligence. And longer-term, WS2 leaders hope that the international relationships the organization is building will lead to future initiatives and even research exchanges with African researchers like Rolance and Elisadiki.

"There's different things that

So far, seven types of lab kits have been distributed to eight partner schools across Uganda, Kenya, Tanzania, Rwanda, and Ethiopia, reaching 1,400 students—about 70% of them girls.

the lab instructions—which include teacher and student manuals and surveys—online, where they'll be available for free use by instructors around the world. They're also working on translating the documents into other languages, such as Swahili and Portuguese.

Meanwhile, the teams that conceived the initial kits are already beginning to envision future experiments that could focus on topics like computer science or can arise from creating an international initiative that really tries to create these personal connections," said Wenderott. "The problems that we're facing . . . impact people that are not just in your local community, but really are in your global community. Finding ways that we can be collaborators across borders is really important."

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

AGL CONTINUED FROM PAGE 2


Attendees pose at the 2022 AGL conference in Washington, DC. CREDIT: MIDHAT FAROOQ/APS

the conference advertised in an APS newsletter and thought it sounded like a great chance to meet other non-binary or transgender scientists with similar career interests.

From Kaufman-Martin's perspective, limiting attendees to women and gender minorities created a more welcoming environment. "Being in a physics conference where I was not only recognized and included, but people were actually saying 'we *want* you here, as a non-binary person,' was really exciting," they say.

The conference also made Kaufman-Martin think a lot about the experiences of many women in physics. "Hearing some of the stories was pretty sobering," they say. "It's really hard to stay confident if everyone is telling you that you're not good enough."

As Snider indicated, some environments are better than others at supporting young physicists through the standard frustrations of earning a graduate degree, like an experiment failing. For Kaufman-Martin, it's vital to have a community "that can help you maintain confidence in the face of setbacks."

"These people—friends and family and colleagues—still value you and reflect that to you," Kaufman-Martin says. "It's not about your performance."

That type of strong support, according to Snider, can also help normalize the challenges of graduate students' and early career scientists' experience in physics. When people feel that their experiences and struggles are common and shared, they're likely to feel better—and this, in turn, can give them the confidence boost they need.

Liz Boatman is a staff writer for APS News.

3D CONTINUED FROM PAGE 4

the bottom, the single tube—the mother end—has split into eight daughter ends.

"It's a relevant geometry to the arterial branching in the liver," says Amili. "But also it happens in the respiratory system—our airways have very similar branching."

The team then attached the model to a water circulation system. A syringe pump injected fluorescent polyethylene beads and water into the mother end, and the daughter ends returned the solution into a holding tank with a particle filter. A pump pushed water from the holding tank back into the mother end.

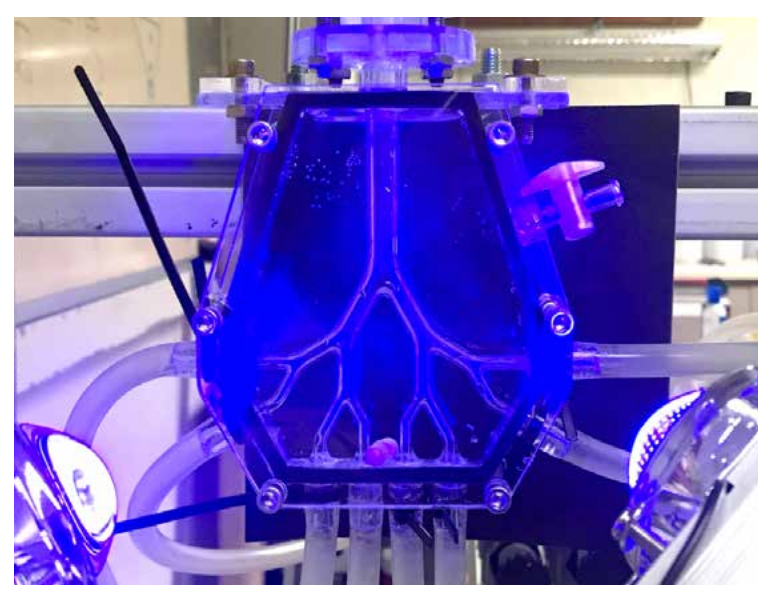
Using a high-speed camera, the researchers captured 3,000 to 5,000 images in 10 seconds of the LED-illuminated beads moving through the system. To determine the beads' velocity and acceleration as they traveled, the team tracked every individual particle, says Amili.

The team varied the volume fractions—or concentrations of beads—between 0.2% and 2% and tested how this changed the beads' movement. The more particles they added, the more their speed and acceleration decreased.

According to Li, that makes sense. Just as you're more likely to bump into someone in a crowded room than a mostly empty one, "when you have more particles within a certain volume, the particles tend to collide more," she explains. "They also have less room around them to move around or to diffuse."

But the team found something else, too: Although the flow rate and pressure were exactly the same throughout the eight branches, the beads tended to collect into the center branches instead of the outer ones.

Amili explains that when the particles are smaller in size, they tend to distribute themselves as expected—about evenly between


The researchers' 3D-printed model of a blood vessel. CREDIT: Y. LI, O. AMILI, F. COLETTI / PR FLUIDS

the branches. But when the concentration or size of the particles increases, they no longer follow this pattern. As a result, doctors who want to target certain blood vessels for drug delivery might increase or decrease particle concentration depending on their goal, the study suggests—though more research is needed.

Previous research from Amili and Filippo Coletti, the Principal Investigator and a co-author, had revealed similar results, but they had tested much smaller particle concentrations, and the team wasn't sure if higher concentrations would yield the same outcome.

"It was a mix of surprises and also exciting observations," Amili says. "What you expect is not necessarily happening in reality ... That's something that is important from the practical standpoint" for physicians.

And while their model is simpler and more symmetrical than vessels found naturally in the body, the team picked a shape that could be used across multiple fields of scientific research, Amili explains.

"In a way, we can represent how the drug beads get delivered in the airways, with the inhalers, for example, or in the embolization," he says, adding that the research is applicable to any branching system with particles of this size traveling through it. "We wanted to pick a geometry that is not only for embolization, but also has a more economical, generalized distribution that the physics community is interested in."

The researchers are already working on future studies, including a smaller system in which they can increase the particle concentration enough to observe how they clog blood vessels. They also plan to examine how particles interact with red blood cells, which could ultimately help researchers understand how drug deliveries move in the aorta, which has a different flow system.

"We would like to know how these particles travel in the aorta so we can direct them to a certain site," Amili says. "It's an interesting problem."

Margaret Osborne is a freelance writer based in Utah.

MERMINGA CONTINUED FROM PAGE1

first woman to hold the position. As director, Merminga oversees nearly 2,000 people working on cutting-edge experiments, ranging from the Muon G-2 experiment, whose 2021 measurement of the muon's magnetic moment may point to physics beyond the Standard Model, to the Long-Baseline Neutrino Facility currently under construction, designed to study properties of neutrinos that could help explain why the amount of matter dominates antimatter—and why the universe exists at all.

Under her leadership, Merminga hopes to solidify Fermilab's standing as a world leader in neutrino physics for decades to come. “We will do the definitive neutrino experiments here,” she says.

Merminga spoke to *APS News* about her life, career, and views on the future of particle physics.

This interview has been edited for length and clarity.

Merminga (right) and engineer Lidija Kokaska discussing PIP-II, an upgrade of the Fermilab accelerator complex. CREDIT: FERMILAB

SC: You're originally from Greece. Can you describe where you grew up?

LM: I was born in and grew up in Chalandri, in a suburb of Athens. I still have many friends living in the area. I grew up playing in the street in front of my house with other kids. We would play tennis, football, and a game like hopscotch. I walked everywhere—to school, to the bakery, to the farmer's market. The entire city had one high school, and we were split into girls and boys. The girls would go to school in the morning Monday through Wednesday, and the boys would go in the afternoon. Then the next week, the schedule would swap.

"By [age 15], I knew that I loved physics and math. ... This was the ultimate form of elegance."

How did you decide to become a physicist?

In Greece, at age 15, you have to decide whether to study the humanities or the sciences. By then, I knew that I loved physics and math. As I look back, I really enjoyed describing a physical phenomenon with the language of mathematics. To me, this was the ultimate form of elegance. I also liked that physics and math problems had a true answer that was not subjective.

My first exposure to science was through stories from my mother and grandmother about my uncle [George Dousmanis], who had a PhD in physics from Columbia University. He was legendary in my family, but he died very young, at age 37 [from a heart attack]. I met him once when he visited from the US when I was two years old, but I have no memory of it. Later on, when I became a graduate student, I got to read some of his physics papers. I appreciated how exceptional he was, and how unfortunate his untimely death was.

Also, at age 13, one of my middle school friends gave me a biography of Marie Curie written by her daughter Eva Curie. I just absorbed that book. Then, in high school, I had a fantastic female physics teacher. These all influenced my interest in physics.

You started in theoretical physics as an undergrad at the University of Athens, but then you pivoted to accelerator physics in graduate school at the University of Michigan. What led you to make that change?

I always loved theoretical physics, but it takes so long between developing a theory and experimentally demonstrating it. For example, the Higgs boson was predicted to exist in the early 60s, and it was not discovered until 2012. In between, thousands of people had to build the world's largest particle accelerator.

When I was in graduate school looking for a PhD thesis topic, my now husband—who was a friend at the time—was a postdoc at Fermilab. He told me about a graduate program in accelerator physics. I realized that with accelerator physics, you can do theoretical physics and validate those predictions using test facilities within months or a year. It also turned out that I love engineering. I decided to go into accelerator physics, and I have been having a blast since then.

What are the big challenges right now in developing future accelerators?

We've pushed accelerator performance in terms of higher energy, intensity, and efficiency. A grand challenge today is reaching higher energies using more compact machines. The ultimate breakthrough of our field would be to make plasma-driven accelerators [a method that would significantly reduce facility size].

A more near-term goal is to produce more efficient technology to create accelerators that use less energy. I'd like to see more progress on sustainable accelerators.

Without upgraded technology, future colliders would consume enough power for a small town. What are some strategies people are working on to make more sustainable accelerators?

People are starting to make more energy-efficient components, such as superconducting and radio frequency (RF) power sources. The design for the European Spallation Source [a neutron source under construction in Sweden] also collects the waste heat produced by the accelerators and then uses it to heat nearby buildings.

Future proposed colliders include a 100 TeV circular collider, linear electron-proton colliders like the ILC, and muon colliders. What's your opinion on what the particle physics community should invest in?

For the health of our field, it is incumbent to pursue these design studies of all of these different types. But we still need to resolve significant technical and physics questions for each of these approaches. Fortunately, these approaches require similar research and development. For example, several of them require high field magnets and highly efficient superconducting RF technology. CERN has chosen already to pursue a 100 TeV future circular collider.

What sort of behind-the-scenes activity goes into these huge particle physics projects?

There's not only a large number of people involved, but also a diversity of expertise and cultural backgrounds. For PIP-II [the upgrade to Fermilab's accelerator complex], we worked with partners in the UK, Poland, France, Italy, and more. Some are physicists, engineers, technicians, computer scientists, administrators, logisticians, and even import and export control lawyers. This diverse set of people working on a common goal—it makes for such an amazing outcome.

In 2019, a *New York Times* op-ed kicked off a public debate over whether the science has motivated the need for a larger collider, especially because the price tag is in the billions of dollars. What's your response to these criticisms?

Colliders are essential instruments that have helped advance our field in a definitive way. The Tevatron, which was the world's highest energy collider until 2011, helped discover the tau neutrino and the top quark. The LHC discovered the Higgs. In terms of discoveries, those investments have paid off hugely.

Several physicists at Fermilab have drawn attention to anti-Black racism in science. They helped organize a #ShutDownSTEM strike in 2020 and formed a group called Change Now, which wrote a document calling for racial justice and equity at Fermilab. How are you engaging with these issues?

Even before I took over as director, I knew I wanted to listen to our employees, our staff, and our users about the culture at our laboratory. As part of that, I launched what I call listening tours. I meet with groups of 10 to 20 people for 30 minutes to one hour. In our discussions, I mostly listen. My goal is to reach out to every single employee of our laboratory. We're about now one-third of the way through about 2,000 people on staff. It's evident that we have work ahead of us.

I've read the ChangeNow document and met with members of the group one-on-one to continue the discussion. I want to understand how people feel and what they have experienced historically. This deserves a long-term strategic plan, not a quick fix. I believe fundamentally that we need to have excellence and diversity in our workforce, business, and operations of the laboratory, in order to achieve excellence in our scientific mission. Excellence means an environment where everybody feels they can thrive, that they can advance their career, and they can feel gratification from their work.

Sophia Chen is a writer based in Columbus, Ohio.

HISTORY CONTINUED FROM PAGE 2

Boulder. Had anyone actually confirmed parity in weak interactions? The answer, Lee and Yang realized, was no. (In fact, experiments in the 1930s had already revealed parity violation, but everyone missed it, says Franklin.)

Many physicists were, like Pauli, dubious of parity violation. “Why should nature distinguish between left and right?” Franklin says. Feynman bet against it \$50-to-\$1, and Felix Bloch told his Stanford colleagues he'd bet his hat. “He later remarked to TD Lee, with whom I also spoke, that he was lucky he didn't own a hat,” Franklin says.

In a landmark experiment, Chien-Shiung Wu showed that physics sometimes violated parity, proving Lee and Yang's theory. Despite her instrumental role, Wu never received the Nobel Prize for her work—though Lee and Yang did. CREDIT: SMITHSONIAN INSTITUTION ARCHIVES

Doubts aside, experimentalists seized on Lee and Yang's idea. With advance notice in May 1956, Wu, their colleague at Columbia, dropped all her plans and designed an experiment using decaying cobalt-60. By December, she had enough data to demonstrate parity violation.

When fellow Columbia physicists Leon Lederman and Richard Garwin heard news of Wu's achievement, they realized they could reconfigure a muon beam to corroborate her result. Late on a Friday night, Lederman, Garwin, and a graduate student named Marcel Weinrich jerry-rigged an experiment using a coffee can, wooden cutting board, and Scotch tape.

“By six o'clock in the morning, we were able to call people and tell them that the laws of parity violate mirror symmetry,” Lederman later recalled. The universe, by a margin of roughly 1 in 10,000, really did prefer left to right.

Both results were published February 15, 1957, in *Physical Review*. Despite Wu's leading role and 26 Nobel nominations, she never received the prize, to the outrage of colleagues like Pauli. Her first recognition for parity violation came over a decade later, with the 1978 Wolf Prize.

The discovery of parity violation set the stage for the discovery of charge-parity (CP) violation, and, arguably, other symmetry-breaking phenomena that led to the foundation of the Standard Model. “The fact that parity itself was violated was just a huge change in the way we think,” Franklin says. For physicists who had treated nature's symmetries with reverence, it felt like a shocking betrayal.

Many physicists were, like Pauli, dubious of parity violation. “Why should nature distinguish between left and right?” Allan Franklin says. Feynman bet against it \$50-to-\$1, and Felix Bloch told his Stanford colleagues he'd bet his hat.

As Yang said in his Nobel acceptance speech: “This prospect did not appeal to us. Rather we were, so to speak, driven to it through frustration.”

Daniel Garisto is a writer based in New York.

THE BACK PAGE

Scientists Don't Succeed in a Vacuum. Why Expect This of Graduate Students?

Graduate student isolation existed long before the pandemic, thanks to go-it-alone culture in physics programs. Then as now, peer support groups can help.

BY ANDREA WELSH

Imagine you're in a subway car, packed shoulder-to-shoulder with other riders. Do you feel isolated? If you don't know any of the people around you, you probably do. That's because isolation isn't solved by the presence of others; it's solved by authentic connection with others. A crowd of strangers won't make you feel less alone.

It's no different in PhD programs. For graduate students, isolation is a major symptom of an always-on, go-it-alone culture in PhD programs, a culture that promotes overwork and leaves very little room for community. This culture, and the isolation it fosters, preceded the COVID-19 pandemic—but peer support groups can help reverse it.

CREDIT: JORM S/ADOBE

Many Graduate Students in Physics Have Long Coped with Isolation

In the cultures of many graduate programs, students have little time to devote to non-academic activities. They work long days, into evenings and on weekends, and when they're not working, they're still reachable by email, sometimes at all hours of the night. When I was a graduate student, I once received an email on December 24, when I was visiting family. When I didn't respond right away, I received one on December 26, asking if I had seen the previous email.

Students are also weighed down, day-to-day, by traditional metrics of success. Any deviation from the goals of an academic—to publish papers, get grants, or acquire a faculty position at a top institution—feels to many students like settling or failing, a deeply isolating experience.

Meanwhile, Principal Investigators (PIs), the faculty who lead research groups, often view students like apprentices, learning a narrow type of work that they'll continue somewhere else. This can leave PIs ill-equipped to do all the other things good teachers must do: Help students plan for their futures, cultivate students' individual interests, and build a sense of community.

The problem with all these norms is that they're usually unspoken. No PI needs to say, "I expect you to work 16 hours a day, or "If you don't publish work, you're failing." Even unsaid, these norms shape many graduate programs in physics. I felt this in my program, and many people I've spoken to have said they've felt it, too.

When you're entrenched in this culture, it can become hard to see its impacts—but the impacts are real and measurable. It's well-known that isolation can foster or worsen anxiety and depression, and this is certainly the case in students. Research has shown that at least a third of graduate students experience severe mental health issues, such as depression or anxiety; this percentage rises for cisgender women and students who are transgender or gender-non-conforming. Difficult relationships with advisors, financial insecurity, and a highly competitive job market all contribute to mental health issues. And suicide is the second-leading cause of death among college students—a horrifying statistic.

And that, I remind you, was pre-pandemic. Now enter COVID-19.

For Graduate Students, the Pandemic Exacerbated Isolation

In the early days of the pandemic, and almost overnight, students whose primary social contacts were office- or lab-mates were suddenly mostly alone. Faculty advisors who were already hard to contact, necessitating long waits outside their office doors, became unreachable. A student with a minor technical question—about, say, a Matlab function—could no longer turn to an office mate for quick help. Some groups tried to adapt by creating chat channels on apps like Slack or Discord, but many people still lacked connection and guidance.

Meanwhile, the already-fuzzy boundary between work and life blurred even more. Some graduate students never left their bedrooms; many attended Zoom meetings in pajamas, hidden out of camera view. Small, vital moments of in-person connection—walking together to a student center to grab lunch, or visiting a coffee shop with peers—disappeared, replaced by solo visits to the kitchen.

These issues had, and still have, profound effects on students. In a summer 2020 survey of nearly 3,500 graduate students at US institutions, 34% had moderate or higher levels of depression, 33% had moderate or higher levels of anxiety, and 32% exhibited symptoms consistent with a diagnosis of post-traumatic stress disorder. A full two-thirds of respondents reported low well-being overall.

And isolation isn't felt equally. Social circles in physics graduate programs are often small and homogenous, not only in background and experience, but also identity. Those from marginalized backgrounds often feel isolation more acutely, made worse by systemic racism, sexism, and transphobia.

There is evidence, too, that professional mental health services aren't reaching everyone equally, because of factors like lack of access, community stigma, and inadequate training on how to address the needs of specific identities. Research shows that students of color are less likely to get the help they need: 23% of Asian American students, 26% of Black students, and 33% of Latino students seek treatment for mental health issues, compared to 46% of white students. And even those students who do get treatment face challenges: Among students of color using mental health services, 70% have found these services more difficult to access since the COVID-19 pandemic.

This is where peer support groups come in. Support groups, while not a replacement for professional mental health treatment, can help bridge the gap.

Support Groups Can Protect Students from Isolation

There is no single type of support group—that's a strength—but all good support groups aim to create a community for folks with similar perspectives, identities, goals, or needs. For example, many schools have a society for women in STEM, and many have LGBTQ groups, campus spiritual groups, and groups for students of a certain ethnicity. Graduate physics organizations can serve this purpose, too. Over my own seven years as a graduate student, I belonged to multiple types of groups and even founded a few, including the Georgia Tech Society of Women in Physics, when I found support lacking.

Support groups are powerful tools because students need time and space to connect with peers non-academically, in an environment where they're valued as authentic, multi-faceted human beings, rather than merely researchers or apprentices. These spaces offer, first and foremost, the chance to find reprieve from work alongside peers who understand the stresses of an academic career. In these spaces, students can freely discuss challenges they're facing—and realize they're not alone in facing them.

The types of challenges that support groups can address are diverse. For example, a student facing microaggressions may connect with others who face similar (unacceptable) challenges. An international student might feel a sense of comradery with other international students; a transgender student might discover a community of supportive peers in an LGBTQ group that extends across programs. For me, finding others with invisible illnesses, often exacerbated by the stresses of graduate school, helped me understand that I wasn't the only one dealing with them.

Support groups can also help students discuss and resolve interpersonal issues with faculty advisors, relationships that can be stressful and isolating for students. Research has shown that PI mentorship styles correlate strongly with graduate student mental health, and laissez-faire leadership is associated with significantly increased levels of psychological distress. In support groups, students can share experiences and advice—how one student has broached difficult conversations with advisors, for example, or how another student has done career planning despite an advisor's shortcomings.

Perhaps most vitally, support groups can help students step outside their own research "bubbles" and contextualize their experiences. Inside the narrow bubble of her own research group, a student might accept an advisor's antagonistic behavior as normal—but outside that bubble, when she can learn from students in other groups, she might realize otherwise and feel empowered to fix it. Inside that bubble, another student might believe that her academic struggles stem from her own personal failings. Outside that bubble, she might realize that those struggles stem from her advisor's unrealistic expectations, and that, importantly, she's not alone in her experience.

Even though a support group can serve first and foremost as a resource for comradery and community, they can also provide vital support for career-building. Many people in support groups are in similar stages of their professional career. This allows them to gain and share crucial feedback on job-finding that advisors—often older, and further from the job-search process—might be unable to share.

For students who plan to stay in academia, support group peers often navigate the same processes around the same time—applying for grants and fellowships, searching for faculty positions, or negotiating salaries—which can give students avenues of support for years to come. For a student seeking non-academic careers, support group peers can help one another market their skills effectively, share networking resources, and prepare for a transition into a different work culture.

Faculty Must Proactively Back Support Groups—for Students' Sake

Many faculty are deeply supportive of their students' involvement in peer groups.

But some faculty are not, which I've learned from students across schools. I've met students whose PIs look down on support groups as "time away from work" or a "waste of time"—both quotes—including personal time spent at events for women in physics, and even at counseling. Once, I organized a coffee discussion for the Society of Women in Physics, which was advertised clearly on the door of the department lounge. A professor, walking in to grab his lunch, loudly interrupted to ask, "Why are you all sitting around?" We explained, but the damage was done. Multiple students in the group mumbled something about being away from the office too long and needing to go back. I didn't see them at the next events.

Worse still, students facing this kind of hostility may have limited room for recourse. They may feel that they can't bring up these issues with other department faculty, for fear of retaliation. After all, for students, years of effort are on the line—or even whether they'll ultimately earn their PhD.

For students' sake, departments and faculty in physics, and those in graduate programs more broadly, must do more to proactively back the creation and upkeep of student support groups. Students must be free to join and participate in groups that exist already, and—where networks haven't yet been established—they must be empowered to create groups of their own that address their specific needs. Alongside access to high-quality mental health services, this type of peer support can transform the experiences of graduate students in physics.

It isn't enough that some PIs choose to do the right thing; doing the right thing must be expected of everyone in a position of power in graduate programs. And neither is it enough that a group of students drifts around in the same PhD program. To feel connected, students must feel like part of a community.

After all, standing in a crowd of strangers probably won't make you feel less alone—but having friends by your side just might.

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