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Letters

Putting Things in Perspective

That’s a terrific photo on pages 4-5 of the spring Caltech magazine. BUT NO SCALE! How can I/we tell whether that’s 6 inches or 6 feet?

Don Lewis (BS ’56)

LAFAYETTE, CA

A Fond Memory

Seeing the mention of the newly named Lee F. Browne Dining Hall in the Spring 2022 magazine struck a chord for me. It must have been in the summer of 1979 that, as a PhD candidate in chemistry, I was approached along with Bob Kreh by Lee Browne to see if we might be interested in providing about six weeks’ instruction in chemistry, I was approached along with Bob Kreh by Lee Browne to see if we might be interested in the same place before me….

Weili Yu (PhD ’21) on Twitter

Kudos

All of your recent issues have been excellent, but today’s was outstanding. And so far, I have only seen the articles about Po-Shen Loh, Ardem Patapoutian, and the video about magnets. Keep up the good work!

Neil Sheeley (BS ’60, PhD ’65)

ALEXANDRIA, VA

Endnotes Sneak Peek

What do you remember most about your Caltech commencement day?

IT RAINED. We had a friend who attended about 35 Caltech graduations in a row, and we got to attend with him for about the last 10 before his death. Every time we’d sit with him, he’d say, “Hey, did you know that I’ve only ever been to one graduation where it rained? The sky just opened up, and every body just scattered.” And every time, I’d say, “Yes. That was my graduation.” I think he really enjoyed bringing that up.

Donnie Pinkston (BS ’98)

MONROVIA, CA

For more commencement memories, see Endnotes on page 40.

magazine.caltech.edu
SoCaltech

Commencement returns to Beckman Mall
CE10 plots an ambitious sustainability roadmap
A superposition snapshot; and more

A Lonely Off-Road

Up until this year, no one had ever hiked the entirety of Death Valley National Park from north to south in less than a week. In February, however, Caltech postdoctoral fellow Cameron Hummels covered the 170-mile route in four days—with six minutes to spare.

Death Valley, one of the hottest, driest, and least hospitable places in the world, is an unusual setting for a long-distance backpacking trip. But Hummels, a senior postdoctoral scholar in theoretical astrophysics, is part of the Fastest Known Time (FKT) movement, in which outdoor adventurers seek to traverse remote and difficult terrain as quickly as possible. Their efforts are authenticated using GPS records on exercise-tracking websites like Strava, leading to fierce but friendly competition with other athletes.

Hummels, abiding by the official FKT rules, traveled solo and unsupported, did not follow any trails or roads, and carried all of his food and equipment on his back. For water, Hummels relied on a few natural springs and seeps, some little more than mud puddles, which he had identified along the route and tested as part of his two-year preparation. Over the course of these four days in Death Valley, he experienced 60 mph winds, a haboob (an airborne wall of sand), temperatures higher than 100 degrees Fahrenheit, a salt swamp, arsenic- and uranium-laden water sources, a poisonous gas vent, and devastating fatigue resulting in visual, auditory, and olfactory hallucinations.

Why would anyone do this? “I think it makes the highs higher to have the lows lower, but it hurt a lot and was probably one of the hardest things I’ve ever put my body and mind through,” Hummels said. “It made for quite an adventure, but I hope to never do it again.”
CE10: Roadmap to Reduction

The Caltech Energy 10 project (CE10) is working to define the ambitious but achievable solutions needed to cut U.S. global warming gas emissions in half by the end of the decade. The CE10 public program, which took place on June 14 and 15, included livestreamed talks from Steven Chu, former U.S. secretary of energy; Sally Benson, current White House deputy director for energy; Kristen Siemen, chief sustainability officer at General Motors; and other experts in the energy and government sectors. The CE10 workshops on June 15 and 16 brought together key leaders to create a strategic roadmap for reducing global warming gas emissions that can realistically enlist broad public support.

“If you’re really optimizing economy-wide, you’re better off allowing that little bit of carbon to remain at the wholesale level and instead investing those dollars in reducing carbon emissions that may have a bigger impact in other sectors.”

Caltech trustee Pedro J. Pizarro (PhD ’94)
President and CEO of Edison International, speaking at CE10

Thanks to the Boss

Jean Somalwar, a graduate student in astronomy at Caltech, studies the stars in our galaxy and beyond. But she points to a different kind of star as one of her main inspirations: Bruce Springsteen. In fact, she says, the musician is the reason she got into college. A New Jersey native like the Boss, she has attended five Springsteen concerts (including three of his Broadway performances in New York) and has been a fan since she was 14. Somalwar even wrote her college application essay to Princeton University about meeting Springsteen at a 2016 book signing for his autobiography Born to Run.

“When I heard the emotional howls at the beginning of ‘Something in the Night,’ I had to stop working and just listen,” the essay reads. “Every line reflected my exact feelings, and for five minutes and fourteen seconds, the world disappeared.”

Somalwar began to collect Springsteen-related memorabilia when she was 16. The items, which include newspapers, magazines, concert tickets, and a poster, now fill up most of a wall in her home. “I’m under the impression that such displays are quite common among Springsteen fans,” she says.

For more information, visit: ce10.caltech.edu

A Human Wave

In quantum superposition, subatomic particles can act like waves and occupy many places at once—a little like how Caltech graduate student Piero Chiappina can be seen here performing every stage of a backflip at once. In reality, large, or macroscopic, objects like people cannot be in many places simultaneously, at least not without the help of photography. But researchers, including physicists like Chiappina, are working to scale up bizarre quantum effects such as superposition and entanglement so they can be used in quantum computers and other future technologies. (See page 11 for more.)
A Day for Degrees

On Friday, June 10, 2022, Caltech held its 128th Commencement with a ceremony on campus, marking the first in-person commencement since 2019. Hundreds of graduates processed in front of a crowd of cheering friends and family on Beckman Mall. The Institute honored graduates with 560 degrees: 218 bachelor’s degrees, 139 master’s degrees, and 203 doctoral degrees.

Additional commencement photos can be found on Caltech’s Instagram and Flickr accounts.

History in Space

Jessica Watkins, formerly a Chair’s Postdoctoral Scholar in the Division of Geological and Planetary Sciences (GPS) and a California Alliance for Graduate Education and the Professoriate (AGEP) Fellow, launched to space aboard a SpaceX Crew-4 mission from NASA’s Kennedy Space Center on April 27, 2022. She then made history as the first Black woman to serve aboard the International Space Station, where her work involves making geological observations. Watkins received training from Lauren Edgar (MS ’09, PhD ’13), now a research geologist at the USGS Astrogeology Science Center.

Watkins spent two years working at Caltech on the Mars Science Laboratory mission’s Curiosity rover with John Grotzinger, the Harold Brown Professor of Geology and Ted and Ginger Jenkins Leadership Chair for GPS. While a graduate student at UCLA, she worked at Caltech with Bethany Ehlmann, professor of planetary science and associate director of the Keck Institute for Space Studies. Both Grotzinger and Ehlmann traveled to Florida to wish Watkins good luck and watch the launch.

Watch a recording of the ceremony here:
SoCaltech

A New Hub for Math

Caltech trustee Richard N. Merkin, MD, founder and CEO of the Heritage Provider Network, will fund the Institute’s new Richard N. Merkin Center for Pure and Applied Mathematics. As a hub for mathematical research on campus, the center will bridge disciplines and connect research in disparate areas that focus on the development of mathematical ideas and foundations in fields such as pure mathematics, computational biology, and quantum physics.

Merkin and the Merkin Family Foundation have also provided funds to renovate the eighth floor of Caltech Hall. The reconfigured space, scheduled to open in early 2023, will provide a home for the Merkin Center as well as a base of operations for the American Institute of Mathematics (AIM), which will relocate from its current headquarters in San Jose, California. Sergei G. Gukov, Caltech’s John D. MacArthur Professor of Theoretical Physics and Mathematics, has been named director of the Merkin Center. A member of the Caltech faculty since 2005, Gukov is known for important concepts relevant to string theory, quantum field theory, and pure mathematics.

The Institute for Quantum Information and Matter (IQIM)

When John Preskill, now the Richard P. Feynman Professor of Theoretical Physics, arrived in 1983, he planned to continue his work in particle physics and quantum field theory. By the mid-1990s, however, Preskill had switched his focus to a field that owes its existence to ideas posed by Nobel laureate and Caltech professor of physics Richard Feynman two decades earlier: quantum information theory. It was a career change that eventually led to the creation of what is now called the Institute for Quantum Information and Matter (IQIM), Caltech’s long-standing home for cutting-edge quantum research.

Quantum information theory is the study of information processing on the quantum level. One of its primary aims is to guide the development of quantum computers, machines far surpassing even classical supercomputers on certain problems of fundamental importance. The IQIM, founded by H. J. “Jeff” Kimble, now the William Valentine Professor of Physics, Emeritus, received a grant from the Defense Advanced Research Projects Agency (DARPA), which was interested in quantum computing’s potential applications in cryptography. Preskill and Kimble then hired Alexei Kitaev, now the Ronald and Maxine Linde Professor of Theoretical Physics and Mathematics, as a long-term visitor.

Then, in 2000, Preskill and Kimble received a grant from the National Science Foundation, which they used to form the Institute for Quantum Information (IQI) that same year.

“NSF got a surge of funding for a program they called Information Technology Research, which included a lot of practical things, but also sort of a lurching fringe of blue-sky research. And that’s what we were part of,” Preskill noted in an oral history for the American Institute of Physics conducted by science historian David Zierler, who now serves as director of the Caltech Heritage Project.

Griffe Vidal (Postdoc: ‘01–’05), now a senior staff research scientist at Google, recalls those early days as a Caltech postdoc during a Heritage Project interview: “John had the vision … to hire interesting young people then apply a hands-off approach. He’s not the type of person who needs to control everything and everything.”

Liang Jiang (BS ‘04), a former IQI postdoc and current professor at the University of Chicago, told Zierler during a Heritage Project interview that weekly meetings were so full of discussion and questions that Preskill had to impose a time limit: “You could only talk for one minute because some group members would get really excited with the results and would talk a lot about their research.”

By 2011, advances in quantum computing hardware, such as superconducting circuits and qubits (the quantum mechanical analogue of a classical bit), gave Preskill and Kimble the impetus to apply for more NSF funding as a means to broaden the IQI’s scope to include experimental work. They received the funding, and in 2011, changed its name to the Institute for Quantum Information and Matter, for which Preskill serves as the Allen V. C. Davis and Lenable Davis Leadership Chair of the Institute for Quantum Science and Technology.

Spires Michalakis, staff researcher and manager of outreach at IQIM, described this name change in a recent Heritage Project interview as a “visionary move,” one that is still paying off: “We attach ‘M’—matter—on things that have to do with physics or even mathematical physicists or many people who were part of physics or even mathematical physics … who were not, basically, in one way or another, associated with IQIM. … If you look at the roster even now, for the second iteration of IQIM, the second cycle we have, there’s a pretty cool medley of people.”

For more on the history of IQIM, visit: magazine.caltech.edu/post/iqim-quantum-john-preskill

Disco is Back

The Caltech student experience is unlike any other. From the House System to SURF to JPL, there is a lot for admitted students to consider and process as they make their decision about where to enroll as undergraduates. That is why the Caltech Undergraduate Admissions Office hosts Discover Caltech. The two-day event, also known as DiscoTech, made its return to campus in April 2022 alongside ecosySTEMs, a one-day pre-program that offers historically marginalized and underrepresented students the chance to experience the new community they will be joining.

Formally called the Pre-Freshman Experience, DiscoTech drew 433 attendees in 2022, including 222 who also joined ecosySTEMs. They heard from current students, faculty members, administrators, alumni, and others about not only Caltech’s research, campus life, and commitment to diversity, but also what to expect after commencement. Nobel Laureate Frances H. Arnold, the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry; and director of the Donna and Benjamin M. Rosen Bioengineering Center, welcomed the crowd with a keynote address about her lab’s recent discovery of new enzymes using directed evolution.

EARTHQUAKE SCIENCE ON THE BIG SCREEN

For more than a century, Caltech’s Seismological Laboratory has transformed society’s understanding of earthquakes and geophysics through advanced instrumentation, data science, experimentation, engineering, and public outreach.

To celebrate the Seismo Lab’s centennial, the Caltech Science Exchange, in collaboration with the Dr. Lucy Jones Center for Science and Society, will host a public event in Beckman Auditorium in November called “Shaking in Our Seats: Earthquake Science on the Big Screen,” to explore the science behind earthquakes in films such as 1974’s Earthquake and 2015’s San Andreas. Moderated by seismologist Lucy Jones, a panel of scientists, engineers, and disaster-response professionals will provide insight into what happens during and after earthquakes, how scientists and government officials interact, and the future of the field. Audience members will hear what Hollywood has done right and what it has done wrong, learn how scientists are advancing their understanding of seismic activity, and discuss the potential for more accurate earthquake forecasting.

The event is scheduled for Saturday, November 12, at 1 p.m. For more information, visit: scienceexchange.caltech.edu/shaking

Origins

Above: Still image from the 2013 video “Quantum Computers Animated” produced by IQIM in partnership with PhD Comics. The video features IQIM’s John Preskill and Spiros Michalakis. Watch the video.
In the Community

A Spotlight on STEM in Rural Areas

On a sunny Saturday in April, in a stall sandwiched between lemonade and cotton candy stands at the 29 Palms Farmers Market, chemistry graduate student Andrea Stegner shows 10-year-old Kira Collins how copper film can be stretched, broken, and repaired thanks to the metal’s atomic structure.

Since November 2021, Stegner and other Caltech grad students and postdocs have driven to the market on the first Saturday of nearly every month to showcase the wonders of science to the community. Unusual specimens from Caltech’s extensive geology collection, such as augen gneiss and a meteorite, are often big hits in this 28,000-person rural community in the California desert. “Because of the area, people just love rocks,” says Elle Chimiak (MS ’19, PhD ’21), a visitor in geochemistry, as scents from the Mine Train Smokery barbecue stall waft by. Nearby, the local junior high school concert band plays “Twinkle Twinkle Little Star.” At a previous market, one mom even asked Chimiak if the group could come to her child’s birthday party.

“I had to sadly decline,” she says. “But I thought that was great.”

Chimiak, who came up with the STEM Stall idea, works in the lab of John Eiler, the Robert P. Sharp Professor of Geology and Geochemistry. She receives some funding from the American Geophysical Union’s Voices for Science program to cover gas and food expenses. While the science experiments wow the young visitors, the group has loftier aims. “We want to let people know if you want to be a scientist, there is not one route to this, and you do not have to be a perfect student to get there,” Chimiak says. As kids stop by to draw flowers and write their names on small sheets of copper film, the Caltech students also hand out postcards to adults that are addressed to area state and federal representatives, encouraging guests to ask their politicians for more broadband internet access and greater investment in STEM education.

“In rural areas like this, the broadband is terrible. We’ll be your science Google. If you have a question we can’t answer, we’ll return next month with an answer,” Chimiak says, wearing a tag that reads, “Ask me, I’m a scientist!”

Steven Buffer, a grad student studying electrical engineering, has a personal connection to the group’s mission having grown up on a farm in rural Minnesota. “I didn’t have a lot of science mentorship growing up, but I noticed when going to college that a lot of my colleagues had people who pushed them toward science,” Buffer says, noting he would like to help make kids aware of what science has to offer. “STEM was really quite a useful vector for me to do the things I’m doing today.”

Sandy Smith, who has owned the Farmers Market with her husband Roger Thomas for four years, loves having members of the Caltech community come by. “They’re so patient, and they’re good one-on-one with the kids and answering questions,” Smith says. “Our kids need to know that these options are out there. We have a national park, but I don’t think they realize, besides climbing on the rocks, what it all entails.”

—Omar Shamout
n decades past, when researchers had to bang away at typewriters to write up their scientific papers, they would often hit a snag. The machines, including the IBM Selectric series popular from the 1960s to 1980s, did not contain keys for mathematical symbols, such as the long “S” used to represent integrals in calculus. When it was time to type in an equation, the researchers had to hunt for golf ball-sized silver spheres that contained the proper characters to snap into the typewriter. Some sought workarounds to avoid the hassle.

“I didn’t have the patience to use the IBM Selectric and switch out the balls,” says John Preskill, the Richard P. Feynman Professor of Theoretical Physics. “When I was an undergrad, I typed my senior thesis but left space for the equations and wrote them in by hand. For my PhD thesis, a technical typist typed out what I had written in longhand.”

Today, typewriters have given way to personal computers and other modern technologies, making it easier for mathematicians and scientists to communicate their mathematical equations to collaborators and the rest of the world. Researchers share their formulas on virtual whiteboards, snap pictures of equations with their smartphones, and write out equations in documents using a much-heralded software program called \LaTeX\ (pronounced lay-tech).

Across the Caltech campus, scientists and mathematicians have various methods for writing in the language of math. Some have gone digital, while others still prefer the gritty, tactile nature of chalkboards. Fernando Brandão, the Bren Professor of Theoretical Physics, says he has switched over to digital pens and pads.
to write out equations. "I used to have equations written all over papers that were everywhere," he says. "Now I save paper and trees."

Not all researchers see these handwritten symbols and software codes the same way. Some call math the language of nature, while others describe it as a tool for abstract reasoning. Nevertheless, the researchers agree that mathematical notations allow them to reveal hidden patterns and structures in our world related to stock markets, computers, black holes, and even living beings.

"Math lets you encapsulate a lot of ideas at once. It lets you find incisive solutions that get to the heart of a problem," says Tom Hutchcroft, professor of mathematics. "Imagine playing a game of chess and having to write a paragraph about each of your moves. This is what it would be like to do math without the equations."

**Ancient Arithmetic**

The first written mathematical notations date back thousands of years and can be found carved into clay tablets, stones, and wood. The ancient Egyptians depicted numbers in powers of 10 with symbols, or hieroglyphs, such as lotus flowers, fingers, and frogs.

The modern mathematical symbols we know did not come into fashion until the Renaissance, which began in the 14th century. Before the symbols were introduced, the ancient Greek mathematician Archimedes, for example, derived the value of pi by using hexagons to approximate circles but did so without the use of the pi symbol, \( \pi \), which was not introduced to represent the mathematical constant until the early 18th century.

As math progressed, so did the need for mathematicians and scientists to write down their equations. The advent of the typewriter in the 1870s made the job easier, but it was still a cumbersome task. In fact, many published papers, including those by Albert Einstein, who was a visiting professor at Caltech on three occasions, and longtime Caltech physics professor Richard Feynman, contain handwritten equations sandwiched between typewritten text.

Einstein actually wrote on the front and back of envelopes to carry out his calculations, explains Diana Kormos-Budrewicz, Caltech’s Robert M. Abbey Professor of History and director of the Einstein Papers Project. That archive includes one such envelope from 1919 on which Einstein jotted down unidentified calculations. "This was a year after World War I ended, and there was a terrible paper shortage. People reused all paper before recycling was invented," she says.

**LaTeX Revolution**

Preskill and other Caltech researchers recall the invention that finally relieved researchers of the burden of switching out typewriter balls.

Beginning in the late 1970s, Donald Knuth (PhD ’63) developed a typesetting language called \( \text{T\AEX} \), which allowed researchers to more easily type out mathematical symbols. Leslie Lamport, a computer scientist then working at SRI International in Menlo Park, California, took \( \text{T\AEX} \), a step further to create the document-preparation system known as \( \text{LaTeX} \), which uses the language of \( \text{T\AEX} \). For example, to type the symbol \( \pi \) into a document, a researcher would write the command "\$\pi\$" into the \( \text{LaTeX} \) program.

"\( \text{LaTeX} \) has changed the way we communicate with each other," says Professor of Theoretical Physics Xie Chen, who, like many other scientists, uses the \( \text{TeX} \) language to denote mathematical symbols when writing technical papers and even emails to colleagues. Sometimes, she says, they do even bother to translate the codes back into mathematical symbols because the codes are so ingrained in their heads.

Smartphones have also changed the ways scientists communicate math; it is easy to snap pictures and send photos of formulas to one another. Virtual whiteboards have become more popular too, says Sergei Gukov, the John D. MacArthur Professor of Theoretical Physics and Mathematics. Gukov and many other researchers took part in online math communities during the pandemic that allowed them to connect with one another virtually in classroom-like settings and tackle various math and science problems. These communities were developed by the National Science Foundation–funded American Institute of Mathematics, or AIM, which will move its headquarters to Caltech in 2023. "The virtual whiteboards were key to these online communities and felt very much like real blackboards," Gukov says.

The rise in popularity of videoconferencing has added yet another tool for mathematicians to communicate with one another, Preskill says: "Sometimes on Zoom, you just write an equation on paper and hold it up to the camera."

**Analog Beauty**

Even with the advent of new communication tools, some researchers prefer to go old school. Monica Jinwoo Kang, Sherman Fairchild Postdoctoral Scholar Research Associate in Theoretical Physics, says she loves to write equations on her blackboard. "The fact that the blackboard is so big helps me think more clearly," she says. She even has a favorite chalk: a Korean brand called Hagoromo.

"The difference between other chalks and Hagoromo is striking: the grip, the feel, and the effectiveness," she says. "In Korea, Hagoromo is associated with scientists and mathematicians. In the US, people associate it with artists. I think the Korean influence is making its way into the US."
What Does Math Mean?

If math can be expressed in words, what does this say about the true nature of math? Are mathematical symbols merely human inventions used for expressing abstract ideas, or are they part of a fundamental language of the universe that exists independently of us?

Christopher Hitchcock, the J. O. and Juliette Koepfl Professor of Philosophy, says there are two main camps when it comes to the meaning of math and numbers. The first group follows ideas put forth by the ancient Greek philosopher Plato, who believed mathematical objects are real and possess identities that exist beyond ourselves.

"Plato thought that mathematical truths would be true even if we didn’t exist," explains Hitchcock. "Think of a line in geometry that is infinitely straight and perfectly thin. It’s not a physical object: there is nothing in our world that is like this. But it still has an existence independent of us. Another way to think of this is to ask: If there are an odd number of trees in the forest and nobody is there to count them, is the number still odd? Plato would say yes."

Many scientists agree with this Platonic view. Physicists in particular often describe math as the language of nature. Feynman, the late Nobel laureate who taught physics at Caltech for nearly four decades until his death in 1988, said in a lecture at Cornell University in 1964: “To those who do not know mathematics, it is difficult to get across a real feeling as to the beauty, the deepest beauty, of nature. ... If you want to learn about nature, to appreciate nature, it is necessary to understand the language she speaks in.”

But as Hitchcock explains, other philosophers believe math is merely an invented tool of science and not an inherent part of our reality. Hartry Field of New York University has gone so far as to reformulate Newtonian mechanics without references to numbers. Field argues the structures described by math are fictitious and not literally true: To understand this viewpoint, Hitchcock gives the example of three plates on a table. It is possible, he says, to describe the plates without using the number three. You might describe each plate and point out that they are different from one another. In a similar way, you could say that each plate has six cookies. You could use multiplication to figure out there are a total of 18 cookies, but you could also derive a sentence describing each cookie and say they are different from one another without using the number 18. Exercises like this, he says, are meant to illustrate that math is simply a tool. "You can use logical reasoning to explain things without numbers," Hitchcock says. "But as the numbers get higher this becomes increasingly difficult. The numbers make the calculations much simpler." Hitchcock himself believes in a more Platonic view of numbers. They are real, he says, but "in their own peculiar way." Whether or not numbers and math are real may remain an open question, but one thing is clear: mathematical writings scribbled on papers, digital pads, and coded in LaTeX continue to elucidate the wonders of our world.
multi-institution collaboration that includes a Caltech-led imaging team has generated the first image of the supermassive black hole at the center of the Milky Way galaxy. This result provides conclusive evidence that the body, known as Sagittarius A* (Sgr A*), is indeed a black hole and yields valuable clues about the workings of such massive objects, which are thought to reside at the center of most galaxies.

The Sgr A* image was produced by an international research team, called the Event Horizon Telescope (EHT) Collaboration, which includes more than 300 researchers from 80 institutions around the world. The result includes key contributions from an imaging team led by Caltech’s Katie Bouman together with Kazunori Akiyama of MIT Haystack Observatory and José L. Gómez of The Institute of Astrophysics of Andalusia in Spain. Joining Bouman, who is an assistant professor of computing and mathematical sciences, electrical engineering and astronomy; a Rosenberg Scholar; and an investigator with the Heritage Medical Research Institute, were former Caltech postdoctoral researcher He Sun and current postdoctoral researchers Aviad Levis and Junhan Kim.

This is the second-ever image taken of a black hole. In 2019, the EHT collaboration released an image of a black hole named M87*, found at the center of the more distant Messier 87 galaxy. Taking an image of Sgr A* at 27,000 light-years away from Earth is akin to taking a photo of a single grain of salt in New York City using a camera in Los Angeles. To accomplish this, EHT collected data from eight radio observatories scattered across the globe to form a single “Earth-sized” virtual telescope.

“This image from the Event Horizon Telescope required more than just snapping a picture from telescopes on high mountaintops. It is the product of both technically challenging telescope observations and innovative computational algorithms,” Bouman said at a press conference announcing the new image. “Taking this picture of our black hole proved even more challenging than imaging the M87* black hole.”

Although the black hole itself is completely dark, we can see a telltale ring of glowing gas surrounding a dark central region called a “shadow.” The size of the shadow observed, which theory says depends primarily on the black hole mass, precisely matched the mass estimated by prior observations. The new view captures light bent by the powerful gravity of the black hole, which is 4 million times more massive than our sun. The team collected entire nights’ worth of data over the course of multiple days, a bit like a traditional camera with a long exposure time. Members of the EHT went to the ends of the earth to collect these measurements: Caltech’s Kim, for example, helped prepare a telescope near the South Pole.

Because the data came from only a small number of telescopes peering at an object far away, the EHT team was left with incomplete data to use to construct the image of Sgr A*. To reconstruct an image, they developed computational imaging algorithms that could make inferences to fill in the blanks.

“Through literally years of exhaustive tests on both real and synthetic data we are now confident that there is compelling evidence that the true underlying source has a ring structure,” Bouman says.
Getting personal

New Caltech alumni discuss how their lives have changed due to the COVID-19 pandemic, and what was on their minds as they approached Caltech’s first in-person commencement in three years.

In the best of times, a Caltech education requires an enormous amount of hard work, dedication, and resilience. But you would be hard pressed to find anyone who would describe the last two and a half years as the best of times. The COVID-19 pandemic brought new challenges to the lives and work of the Caltech community, and students at the Institute have handled these stressors in different ways. Here, some of Caltech’s newest alumni reveal how they turned negative situations into opportunities for positive growth. They also talk about what it meant to endure a pandemic during their time at the Institute.

From left: Diego Olaya, Ayooluwa Odemuyiwa, and Ella Watkins-Dulaney
Katherine Rinaldi • PhD, chemistry

Rinaldi defended her PhD thesis in 2021, but is participating in this year’s in-person commencement. She works at renewable-energy company H2U Technologies.

How has the pandemic impacted you?
It was hard, but I was lucky. I had done all my experimental work, and I was doing system-modeling work on my computer. As far as a direct impact on my work, it was pretty minimal. But doing a Zoom defense online was weird. From a personal interaction standpoint, dealing with the pandemic was hard. And with so much going on in the world, it was hard to concentrate on my work. It was also hard to be separated from my family, who live on the East Coast. Trying to navigate how to maintain relationships and keep connections with people was a challenge. I think the pandemic laid bare how important connections with other people are..."}

Diego Olaya • BS, physics

Olaya will pursue a graduate degree in physics at the University of Colorado at Boulder.

What effect has the pandemic had on you?
It feels like a lot of the seniors are making up for lost time this year. I’m trying to strengthen a few friendships that I’m hoping might last after I graduate. Many of my social interactions this year are partly colored by the fact that seniors are all going to graduate in relatively short order. To some degree, that means if I’m given the choice between taking an extra class that is somewhat interesting or leaving that space in my schedule for unstructured flexible time, I’m going to take the latter. Whereas, perhaps in more normal times, I would’ve taken the former.

What does it mean to you to have an in-person commencement?
Were we to graduate virtually, all of the traditions celebrating the achievements of the senior class and how each house sends off its seniors would have been gone. Things like Ditch Day, Interhouse, rotation, and even how the houses interact with prospective students when they come visit, are passed down from class to class by experience and repetition. For example, some houses have not had an Interhouse that anyone younger than us remembers. Our class was the only class currently on campus that has ever had an in-person Ditch Day. Those are extremely valuable parts of the Caltech experience..."}

Isabell Yang • BS, biology

Yang will work as an EMT before applying to medical school.

What effect has the pandemic had on you?
Having more free time at home forced me to confront some mental health challenges that I had put off due to the rigor of Caltech studies. I am much better at understanding what I need to live a healthy and balanced lifestyle. I am kinder to myself and give myself the time to take a break without feeling guilty, and that helps me to be so much more productive. I already knew I wanted to go into health care, and I wished I could already be helping people out, especially when so many people were struggling.

Did you ever talk to anyone about what you were going through?
After my freshman year (in 2018), when I was going through those struggles, I was pretty transparent with my volleyball coach, Tom Gardner, because that was when I decided I was going to take a gap year. I said, “I really enjoy playing for Caltech, but I don’t know if I can continue.” He was really supportive. He wanted what was best for me, and it didn’t seem like he only cared about the team. Since then, when I got back, we’ve been really close, and I was chosen to be a team captain. The other captains and I talk with him often about how the team is doing and what their energy and attitude is like. All of that made us really close.

What does it mean to you to have an in-person commencement?
In my freshman and sophomore years, I couldn’t imagine finishing at Caltech. My focus wasn’t on graduating, it was just on taking it one day at a time, one assignment at a time. I think I won’t realize how big of a deal it is until I’m actually at the ceremony and receive my diploma.

Spencer Schneider • BS, computer science; business, economics, and management (double major)

Schneider will work at Meta as a software engineer.

What effect has the pandemic had on you?
It made me a lot more reflective. I took a year off. I got to live on my own, work with the Washington Wizards as a software engineer, and get a taste of the adult world. It made me more appreciative of the unique things in college, like getting to wake up whenever you want and deciding to do your work whenever you want. In general, I’m trying to live in the moment and appreciate the situation I am in now because it can change at any moment. I’m OK doing my own thing a lot more, especially since the majority of my friends have graduated. I had a lot of time to figure out what I wanted to focus on when I came back to school. This past year, I took a lot of project courses because I feel they’re relevant to the skills that I want to develop. I was more focused.

“I’m trying to live in the moment and appreciate the situation I am in now...”
Ayooluwa Odemuyiwa

- BS, computer science

Odemuyiwa will work at Meta as a software engineer.

As ASCIT president in 2021–22, how did you help other students adjust not only to life at Caltech, but to life at Caltech during a pandemic?

There were a lot of first years enrolling without knowing anything about the school, and it was really hard to reach a lot of them. I was an FCC [fresh camp counselor] during orientation. I saw a lot of them burning out and not really feeling connected to the school. A big thing for me was trying to find ways to engage them, to make them feel connected, and make them feel like actual students. Some things we did were to make a first-year support committee, and we also connected them directly with upperclassmen by setting up lunches with them over Zoom.

Were you able to find help on campus?

Yes, as part of the Freshman Summer Research Institute at Caltech, I connected with Monique Thomas and Tao Dimitriadis in the Caltech Center for Inclusion and Diversity (CCID) office. I reached out to Monique, who’s a Black woman, and talked about my experiences and was very honest with her about how I was feeling. Lee Coleman [from the counseling center in Student Wellness Services] was also very helpful. He visited me and talked to my mom. Also, the deans, Kristin Weyman and Lesley Nye. They were very supportive when I had to take some time off for a couple weeks. The TAs and professors were accommodating during that time and helped me get on my feet. Understanding that school is hard and that I was struggling was my biggest realization that came from the first year. The support I received from faculty, staff, and others really taught me the importance of giving back to my community through leadership service, and I went on to serve as ASCIT president, in Ricketts House leadership, and with the Black Scientists and Engineers at Caltech.

Did you find a home here at Caltech?

Absolutely. Caltech has definitely trained me to be someone who’s acutely aware of the importance of representation in STEM and also just the importance of understanding that you don’t know everything. And once you acknowledge you don’t know everything, you can do anything.

Shrikesh Deshmukh

- BS, mechanical engineering (minor in environmental science and engineering)

Deshmukh will work at SpaceX as a Starlink engineer.

What was there a moment that crystallized the gravity of the pandemic for you?

At the beginning of the pandemic, I was sitting in Browne Dining Hall having lunch. The TVs were flashing with all this information on COVID. I was one of the last people to leave campus, as it felt like a ghost town. That’s when I realized, wow, this is the real deal. Later on, Caltech said we were not going to have fall term in person. I then realized this could go on much longer than we had originally thought.

What effect has the pandemic had on you?

I used to be on the track and field team, but COVID gave me time to consider if I really wanted to continue the sport that I had been doing for nearly a decade. It was a very difficult decision to leave, but it allowed me to pursue other opportunities that I’ll only find at Caltech and allowed me to get more involved in project classes, robotics, and dance. Dance was just a hobby before, but since returning to campus, I’ve spent much more time on it and now lead the Dance Team. I’ve learned a lot of different styles and am even teaching my own classes, which I would not have imagined I’d do four years ago. After being off campus for so long, I really try to make the most of every moment I have left before I graduate.

What does it mean to you to have an in-person commencement?

In-person commencement drives home a feeling of accomplishment, marking the end of my chapter here at Caltech. It means a lot to me, as it cemented the feeling that I’m transitioning from one era of my life to another.

Did the pandemic change the way you go about your research?

The nature of my research allowed me to make progress without having to go to the lab. Data collection using crowdsourcing platforms is a new trend in my field. It’s much easier to reach a diverse sample of participants, and to get the data quicker. It comes with challenges as well. I had to monitor the studies and answer questions all day long, and to act fast and solve problems as they arose. For example, the site we used for recruitment became completely unusable at one point, and we had to manually provide study links to every single participant.

Yanting Han

- PhD, neurobiology

Han will work as a postdoc in the lab of Ralph Adolphs (PhD ’93), Bren Professor of Psychology, Neuroscience, and Biology at Caltech.

Did the pandemic alter the focus of your research?

The pandemic probably had a positive influence on my research rather than negative. I study human emotion experiences by evoking emotions using stories and videos, and collecting self-report ratings from participants. During the pandemic, I co-led the COVID-Dynamic Longitudinal Study, which tracks people’s psychological changes during the pandemic in multiple domains, including emotion and mental health, decision-making, attitudes and beliefs, and so on. We realized that it would be nice to take advantage of the opportunity and sample naturally occurring emotions in people’s daily lives in addition to the evoked ones. This allows us to study those emotions in comparison to the evoked ones and in the specific context of real-world events. Although this is still early stage exploration, we’ve already seen many interesting things. For instance, collectively, moral disgust went up for George Floyd’s death, and surprise went up around Election Day.

“Once you acknowledge you don’t know everything, you can do anything.”

“After being off campus for so long, I really try to make the most of every moment I have left before I graduate.”

To hear from more new alumni about their experiences, visit magazine.caltech.edu/post/new-alumni-2022

“Did the pandemic change the way you go about your research?”

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“Was there a particular moment over the last two years that crystallized the gravity of the pandemic for you?”

I come from China, so I was aware of the coronavirus earlier. I had planned to go back home and visit family for the Spring Festival in January 2020, which I always do. But I canceled the flight, knowing what was going on in Wuhan. At the time, I wasn’t seriously concerned that it would become a global pandemic. But by March, I remember it was difficult to get masks. When we did get masks, it felt uncomfortable to wear them in public even though it was obviously the correct thing to do.”

magazine.caltech.edu
When aerosol expert Richard Flagan could not come to campus to investigate the effectiveness of masks at stopping transmission of the SARS-CoV-2 virus, he brought the work home with him specifically, to his home garage and its collection of woodworking tools. That is just one of the many ways Caltech researchers had to adjust not only the work being performed in their labs, but also the manner in which that work took place after in-person operations nearly ground to a halt in early 2020. Since then, many more intrepid scientists, engineers, and students have sought to refocus their work to address the needs of the global health crisis, despite hardships like limited capacity rules, shortages in resources, and fear of an unknown and evolving virus.

Nearly two and a half years later, those scientists have made crucial contributions to both local and national efforts to control the spread of the SARS-CoV-2 virus. These life-saving advances were made possible thanks to new funding, more public health data, a greater understanding of the virus and its effects on society, and the desire of students to help. Here are some of the major developments that have taken place in labs across campus, the unique challenges they presented, and the rewards they delivered.

Safeguarding the Workplace
Flagan, an engineer and expert in aerosol processes, flew to Helsinki in February 2020 to participate in a workshop about atmospheric particle formation experiments at the European Organization for Nuclear Research (CERN).

“I was very nervous to travel,” Flagan says. “I had been aware of COVID since the first press reports, and the descriptions sounded like an airborne disease transmission, but that was not the message that was being delivered.”

By the time he returned to campus, Caltech was just days away from shutting down nearly all research.

Receptions were being made, however, for studies involving COVID-19. Initially, Flagan’s laboratory was involved in a study of how the first major lockdowns affected air quality. Soon, concern arose about how to open laboratories again.

“The variability of mask effectiveness became one of the central questions,” Flagan says.

Flush with state-of-the-art aerosol instruments in his laboratory, he realized that testing masks was a great match for his research group. There was just one problem: as a person over the age of 60, Flagan was up against the strong recommendation to avoid coming onto campus, even for critical projects.

Enter Buddhi Pushapawela, a postdoctoral researcher who had joined Flagan’s team in November 2019. Alone in the lab, she set to work in June 2020 to build an experimental apparatus using whatever parts she could find, scouring campus for masks to test how effective they were at blocking the virus. But first, she needed to figure out how to seal the masks to the sampling instruments.

In his home workshop, Flagan cut custom wood frames that Pushapawela used to clamp the masks to the plates.

“No matter what I did, I could not get the masks to not leak,” Pushapawela said.

Whenever I had issues, I showed the setup to Professor Flagan through video calls and got his advice on how to do the modifications,” says Pushapawela, now a clinical assistant professor of physics and astronomy at the University of Alabama in Huntsville. “I have the theoretical background and the subject knowledge, but I used some of the instruments for the first time for the face-mask testing project.”

During the experiments, she measured particle penetration, breathing difficulty, and performance at different oxygen flow rates. It was a process that took nearly two hours to complete for each mask, but Pushapawela managed to test more than 400 samples, including N95s, KN95s, surgical masks, and cloth masks. Based on those results, Flagan and Pushapawela made recommendations...
that guided Caltech’s initial purchase of masks to help prevent campus-wide for the 2021 fall semester. In addition, Flagan conducted webinars, presentations, and discussions on social media to inform the public about the effectiveness of various masks. The team published a paper with their findings in the journal Aerosol Science and Technology in December 2021.

“I believe we made a contribution to stopping the spread of COVID-19 and saving lives from COVID-19, at least among the Caltech community,” Pushpawala says.

A Universal Vaccine?

Structural biologist Pamela Björkman is no stranger to viruses. She has dedicated her career to investigating the body’s immune response to viral pathogens, and she had already received supplemental National Institutes of Health (NIH) funding to study the emerging SARS-CoV-2 virus by February 2020. But even with many similar studies under her belt, this undertaking felt different.

“Everybody knew that it was going to be very bad,” Björkman says. “And running a lab was very confusing back then. We had density rules, we had to have shifts, and we had to constantly figure out who could work where and space people far apart. I was very worried that we would have an outbreak in the lab. We didn’t, but I remember being very nervous about that.”

Despite these stresses, the Björkman group has made significant progress in its goal to develop a universal vaccine against current and future coronaviruses.

First, Christopher Barnes, now a postdoctoral scholar in Björkman’s lab and now an assistant professor of biology at Stanford, detailed the structures of antibodies produced by the body to fight COVID-19 and discovered how those antibodies bind to the virus’s spike protein (the parts that invade host cells) to stop the infection process. Barnes found that the antibodies attach to a part of the virus called the receptor-binding domain, or RBD. But not all the antibodies were binding at the same place on the RBD and the RBDs varied between the original SARS-CoV-2 virus and its newly emerging variants, as well as between related coronaviruses found in animals.

And so, Björkman says, “we did something we’ve been trying to do for HIV and other viruses in my lab for a long time. We made a nanoparticle that’s a mosaic, meaning it co-displays different versions of the antibody target on the virus.”

Alex Cohen (PhD ’21), now a postdoctoral scholar in the Björkman group, designed a mosaic nanoparticle to present eight different RBDs on 60 attachment sites. Testing of the concept in animal models as a vaccine showed that the nanoparticles evoke strong immune responses to not only the viruses included in the vaccine, but also to additional coronaviruses not included in the vaccine. Further testing has revealed the mosaic nanoparticle approach prompts antibodies to target harder-to-reach but more-conserved elements of the virus RBD, as opposed to the parts that may change with a new variant or type of coronavirus. This means the vaccine should provide broad protection regardless of how the virus mutates in the future or if new coronaviruses spill over from animals into humans, making it a strong candidate for a potent universal vaccine. The Björkman group has received funding from the Coalition for Epidemic Preparedness Initiative to conduct Phase 1 human clinical trials.

“This vaccine candidate can be used as a booster, since most people are already vaccinated or have been infected with SARS-CoV-2,” Björkman explains. “It would be more protective, I believe, against possible future emerging viruses, and you wouldn’t need to change it as we are confronted with more SARS-CoV-2 variants of concern.”

Modeling Transmission

As the pandemic raged on and classes remained virtual, many students wanted to get involved in COVID-19 research. Yasser Abu-Mostafa (PhD ’83), an expert in machine learning, decided to give students in his spring 2020 computer science class a project. The result was a model to predict the spread of the virus that consistently beat out estimates made by the Centers for Disease Control and Prevention (CDC).

“We switched the entire research and teaching effort to focus on forecasting the spread of COVID-19 in the United States,” says Abu-Mostafa, who had been working on a fundamental theoretical question in deep learning prior to the pandemic. “The students are the ones who took the initiative, and I went for it based on my assessment of the value of artificial intelligence technology to help with what was clearly a national emergency.”

The CDC model used data from 45 major models at universities and institutes across the country, but it did not emphasize artificial intelligence (AI), which has the power to discover patterns in hidden data that humans might miss. Early tests of Caltech’s AI-driven CS156 model, named for the class where it began as a competition, showed it was more accurate than the CDC model nearly 60 percent of the time. Though it proved extremely valuable, Abu-Mostafa says it was not easy to accomplish.

“We needed to steer the whole ship in a completely new direction in short order,” he explains. “This involved organizing the biggest team I have ever supervised, setting up the computational and data infrastructure, securing the funding, and, most importantly, formulating the scientific vision and the strategy to implement it successfully.”

It started with a class of more than 150 students producing 40 viable models for predicting the spread of COVID-19. From there, the top 10 models were aggregated, and a research team that included a core group of students from the class took the findings forward to create a model with an expanded scope, making rapid and precise predictions about mortality rates, numbers of infections, and test positivity rates.

“In the early days of the pandemic there were massive data gaps and uncertainties in everything from case levels to rates of mask wearing,” says graduate student Dominic Yurk (BS ’17, MS ’21), who was the lead teaching assistant for the course and continued as a member of the research team when the class ended. “Figuring out how to make valuable predictions from highly uncertain data was a new and valuable research experience.”

Shortly after initial results of the model were made public in summer 2020, the California Department of Public Health asked for access to the team’s daily prediction files, which informed the department’s decision-making as it managed the pandemic.

“We expected to do well given our expertise in AI, but beating all the national models put together was a surprise,” Abu-Mostafa says. “While I am used to taking scientific risks, this experience encouraged me to take organizational and funding risks that are against our nature, when the opportunity arises.”

The COVID-19 model also inspired him to look at other medical problems that machine learning might help solve.

“It was my first experience in research that can, and likely did, save lives,” Abu-Mostafa says. “I haven’t done that before in my career, and the experience made me more energized in my current focus on medical applications of AI.”

Measuring Viral Load

Viruses need hosts to multiply, but exactly when a person is contagious is not always easy to pinpoint, especially with a new pathogen.

“The world clearly didn’t have information on how to detect SARS-CoV-2 early, before people transmit the infection,” recalls chemical engineer Rustem F. Ismagilov about the early months of the pandemic. “It was not known how much virus there was and, therefore, what sort of test would be good enough to detect it, and in which sample types, like saliva or nasal mucus, the virus was.”

With the interdisciplinary team of researchers that makes up his lab, which is committed to improving global health, Ismagilov set out to answer those questions. The lab partnered with the Pasadena Public Health Department (PPHD) to launch a large community-based study to investigate how viral load changes in different sample types over time after someone has been infected.

Aerosol expert Richard Flagan in his garage, where he built frames used in tests to gauge the effectiveness of various masks against SARS-CoV-2.
Here’s how it worked: contact tracers from local public health departments, clinics, and testing sites, including Caltech’s Student Wellness Services, shared study details with people recently infected with SARS-CoV-2 and their uninfected housemates. The 410 participants who enrolled self-collected their samples once or twice a day for about two weeks and sent the samples to the lab to be analyzed with a high-sensitivity research assay. The Ismagilov lab team then calculated viral load in each sample type (sputum, naso-swabs, and throat swabs) to see where the virus accumulated first and figure out how sensitive a diagnostic test would need to be to detect the virus in that sample.

Although they are still analyzing data, Ismagilov’s team has released three preprints online and a publication in the Journal of Clinical Microbiology that outline several important findings thus far: the virus generally appears first in oral samples, which suggests that many early infections are not being detected by nasal-swab tests; viral load is highly variable among sample types, suggesting that there is no single best COVID-19 test type and better testing strategies are needed; and taking COVID-19 tests first thing in the morning helps improve test sensitivity significantly, suggesting a simple change that can make tests more reliable.

Ismagilov says performing a large study like this amid the pandemic added challenges to every aspect, from getting the study organized, designed, and launched, to running the study and securing the necessary and often scarce lab reagents. “It would have been easier to do nothing, but the team felt very strongly they had to make this contribution,” Ismagilov says.

The Ismagilov lab’s COVID-19 study is already having a ripple effect on the group’s future work. To make the COVID-19 study a reality, the group built a new infrastructure for conducting longitudinal community-based studies, says Natasha Shelby, scientific research manager for the Ismagilov lab and study administrator for the COVID-19 study.

“That infrastructure will open so many doors to study health conditions that have been challenging to understand,” also says, adding that the group has plans to publish their study design templates to help other labs launch similar studies and get critical data right when a new pathogen emerges.

“We answered the questions we set out to answer,” Ismagilov says. “I witnessed incredible dedication and self-sacrifice, not only from our lab but from many other members of the Caltech community, including volunteers who made the study possible.”

Yasser Abu-Mostafa is a professor of electrical engineering and computer science. The student research that led to the creation of the CS156 model was supported by Caltech trusts and alumni Charles Terbey (BS 10, MS 14), the Sumio Ungawadzura Research Fellowship program, and the Charles Innovation Fund, established by entrepreneur and Caltech alumnus Gary Chinard (BS 105, MS 14).

Pamela Björkman is the David Baltimore Professor of Biology and Bioengineering and a Marsden Institute Professor. Her work on a universal vaccine is funded by the Marsden Institute for Translational Research, Welcome Inc., the National Institutes of Health, and the Bill & Melinda Gates Foundation, among other supporters.

Richard Flanagan is a Ph.D. student in Astrophysics and Mathematics at Caltech. He’s part of the NuSTAR team, led by Fiona Harrison, which is dedicated to studying the universe through the telescope’s high energy X-ray vision.

The NuSTAR space telescope still has more to see. After a decade in space, the small but powerful NuSTAR science telescope has more to tell us. NASA’s Nuclear Spectroscopic Telescope Array (NuSTAR), led by Caltech and managed by JPL, turned 10 years old in June. This space telescope detects high-energy X-ray light and studies some of the most energetic objects and processes in the universe. The mission’s principal investigator is Fiona Harrison, the Harold A. Rosen Professor of Physics and the Kent and Joyce Klesia Leadership Chair of the Division of Physics, Mathematics and Astronomy at Caltech. Here are some of the ways NuSTAR has opened our eyes over the last decade.

Illuminating Black Holes

Black holes do not emit light, but some of the biggest ones we know of are surrounded by disks of hot gas that glow in many different wavelengths of light. NuSTAR can show scientists what is happening to the material closest to the black hole and reveal how black holes produce bright flares and jets of hot gas that stretch for thousands of light-years into space. The mission has measured temperature variations in black hole winds that influence star formation in the rest of the galaxy. Recently, NuSTAR supported the Event Horizon Telescope (EHT) in its effort to capture the first-ever direct images of the shadows of black holes. (For more on EHT, see page 25.)

Finding Hidden Black Holes

NuSTAR has identified dozens of black holes hidden behind thick clouds of gas and dust. Visible light typically cannot penetrate those clouds, but the high-energy X-ray light observed by NuSTAR can. In recent years, scientists have used NuSTAR data to find out how black holes become surrounded by such thick clouds, how that process influences their development, and how obscuration relates to a black hole’s impact on the surrounding galaxy.

Solving Supernova Mysteries

Stars are mostly hydrogen, but NuSTAR observations have shown that when they explode as supernovae, they become an asymmetrical mess. The space telescope solved a major mystery in the study of supernovae by mapping the radioactive material left over by two stellar explosions. It traced the shape of the debris and identified the elements that make up the act of explosion.

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Tiny Lifeforms,
Big Impact

The Center for Environmental Microbial Interactions’ support of early-stage projects reaps big rewards for science and scientists.

By Andrew Moseman

For decades, microbiologists had hunted for microbes whose growth is fueled by oxidizing manganese, an abundant element found across natures and in materials such as steel. Geochemical evidence suggests such microbes should not merely exist but abound across many environments, yet those particular metal eaters had remained frustratingly elusive. Since the search for such microbes had befuddled so many researchers before, continuing to hunt for them seemed futile. Instead, Leadbetter, an environmental microbiologist, filled some idle moments in the lab by searching for microbes that might interact with manganese in entirely different ways. Geochemical evidence suggests such microbes should not merely exist but abound across many environments, yet those particular metal eaters had remained frustratingly elusive. Since the search for such microbes had befuddled so many researchers before, continuing to hunt for them seemed futile. Instead, Leadbetter, an environmental microbiologist, filled some idle moments in the lab by searching for microbes that might interact with manganese in entirely different ways.

Fortunately for Leadbetter, he forgot to do the dishes. Upon returning from a 2015 summertime guest-teaching stint at the Marine Biological Laboratory in Woods Hole, Massachusetts, Leadbetter found that he had left dirty glassware containing manganese to soak in the office sink. In the intervening three months, the manganese in the glassware had turned from a light beige to a dark brown, possibly a sign that bacteria had oxidized the manganese. Now all he had to do was prove it.

Former Caltech researcher Hang Yu collaborated with Leadbetter on what would become years of hard work to confirm those really were the long-sought-after microbes. After completing his doctoral studies under Victoria Orphan, a geobiologist and director of Caltech’s Center for Environmental Microbial Interactions (CEMI), Yu wanted to further investigate these manganese metabolizing bacteria. CEMI made it possible. “When Hang left my group,” Orphan says, “CEMI was able to support him to do a short postdoc with Jared and take this new novel culture Jared had discovered over the finish line.” Their initial study on these metal-eating microbes became a paper in the journal *Nature* and a microbiology sensation, one that could, for example, be useful for treating water containing manganese (which often discolors drinking water and has an unpleasant taste).

Formed a decade ago in recognition that researchers across the Institute’s divisions study microbial life in some way, CEMI has grown to include more than 10 percent of Caltech’s faculty. Thanks to philanthropic funding, the program can support several pilot projects annually and has backed 85 in the 10 years of existence. These projects may have big potential but are often in the early stages of discovery, which means they are not quite ready for the federal grant application process. The researchers doing that work probe questions that will aid in the fight against antibiotic-resistant infections, lead to better ways to clean up the environment, and illuminate the links between the human brain and the microbes. CEMI is Caltech in microcosm, catalyzing the Institute’s signature brand of interdisciplinary collaborations and bold new ideas in the field of microbial interactions.

Orphan says the center’s nimble nature allows it to deliver support right when it is needed, such as with Yu’s postdoctoral research or to explore new ideas that come from students rather than from principal investigators. “We do microbiology in a very different way,” Orphan says. Caltech researchers inspired by the features and talents of microbes have tried to use their unusual properties to discover new chemistries or catalysts. Others—like Orphan, Leadbetter, and biologist Dianne Newman, who was CEMI’s inaugural director—focus on microorganisms themselves and how they drive other geochemical cycles, interact in natural communities, and impact environmental habitability in a way that then impacts the whole planet.

“Within CEMI, microbiology is broadly defined in a way that I think gives the students and postdocs a perspective that is unique to Caltech,” Orphan says.
that play critical roles in their environment. The question, Newman used her deep knowledge of the microorganisms Orphan (above) and other cells to understand how they respond to the presence of foreign DNA, which is detected at a molecular level, and how this process helps them to survive and thrive in the absence of oxygen.

For the past decade, Newman had been part of CEMI since its inception in 2012, is an exemplar of its ethos. Her lab focuses on microbes that form on a surface. In particular, she wanted to look at the properties of biofilms whose cells are oriented in a specific direction, which can create a gorgeous iridescence. "Their unique optical properties are much like what you see with peacock feathers or butterfly wings," she says.

Newman appreciated the chance to work with a microbiologist after making the leap into the field from biology. "Sometimes you need help," he says. Similarly, Priya Chittur, a graduate student working with chemical engineer Julia Kornfeld (BS ’83), the Elizabeth W. Gilloon Professor of Chemical Engineering, became interested in biofilms, which are communities of microbes that form on a surface. In particular, she wanted to learn about the properties of biofilms that become the subject of her CEMI research.

Southern California was likewise an inspiration for graduate student Shiva Dehajian, who wanted to explore the emergence of a pathogen that is a concern for the region’s groundwater. Mahajan received CEMI funding in 2021 for an ongoing study of the mechanisms bacteria use to pump dangerous contaminants out of a cell, a project that unites the expertise of Newman, Doug Ross, the Roscoe G. Gilkey Dickinson Professor of Chemistry, and Bil Clemens, the Arthur and Marian Hanisch Memorial Professor of Biochemistry.

In addition to such collaborations, CEMI has also launched new careers. Elaine Hsiao (PhD ’18), now a faculty member at UCLA, received CEMI support to become a junior research fellow in the Jacobs Institute of Design Innovation and when she secured a full-time faculty position. "The pilot fund from CEMI was the first grant I received as I was transitioning into my independent scientist position," she says. "It helped me to support a new research project that forms the basis of my lab's current research on how microbes in the gut can affect the brain, and it helped me gain confidence and visibility as I began my professorship role."

Scott Saunders (PhD ’20) took his CEMI research in a surprising direction. His doctoral work under Newman studied Pseudomonas aeruginosa, an important opportunist pathogen. An understanding of how it survives in the absence of oxygen, he knew, could lead to new ways to fight infections. In the course of earning his PhD, however, Saunders became interested in finding better ways to manipulate bacterial genes.

"Now I’m at a medical center, UT Southwestern," he says. "This important, long-term goal is to extend these approaches into a variety of pathogenic bacteria that are related to E. coli and Pseudomonas. These are important pathogens that cause antibiotic-resistant infections that kill lots of people every year. It is very important to understand their basic biology and develop tools to help us understand them more quickly and more deeply."

### Forging Links

Like Leadbetter’s metal-eating bacteria work, CEMI itself owes something to serendipity. A decade ago, Newman says, then-provost Ed Stolper, now the Judge Shirley Huddleston Professor of Biology, noticed that faculty investigating microbiological questions had been hired across several of Caltech’s divisions. This trend was more fortuitous than it was planned, she says, but Institute leadership seized the opportunity.

"What Ed recognized was a chance to have the whole plane sit on the tip of the part," she says, "to bring these people together in a way that allowed for interdisciplinary work and the creation of a community that would enrich the activity of any individual group that was interested in microbes."

Newman, who has been part of CEMI since its inception in 2012, is an exemplar of its ethos. Her lab focuses on the physiologies of bacteria that make it possible for them to survive and thrive in the absence of oxygen. Because of CEMI, Newman’s techniques, strategies, and students have crossed over to help other Caltech research projects get further than they could alone.

For example, biologist Alevi Aravin studies how foreign DNA is detected and how, at a molecular level, it can direct the development of microbes that form on a surface. In particular, she wanted to look at the properties of biofilms whose cells are oriented in a specific direction, which can create a gorgeous iridescence. "Their unique optical properties are much like what you see with peacock feathers or butterfly wings," she says.

Chittur and Kornfeld sought the expertise of Leadbetter, who suggested researching in Southern California. And, in fact, it was on kelp in the Malibu wetlands where Chittur found samples of the biofilms that became the subject of her CEMI research.

Over the past decade, the center built its own unique culture of collaboration and inspiration. Saunders remembers helping set up food and drink for “MicroMornings,” a series that Saunders credits with making him feel like part of a community and giving him the opportunity to connect with other microbiologists who might have far-flung research interests.

Those informal interactions spark further collaborations. Years ago, one of those talks was given by then-postdoctoral scholar Scott Saunders, now a professor at E TH Zurich. In attendance was Newman lab postdoc Nicholas Shikuma, now an associate professor at San Diego State University. Shikuma now in Leadbetter’s cryo-electron microscopy work a direct connection to his own research in bacteriology. Together, they discovered a new class of molecular synapses, which are natural structures released by bacteria. These molecular synapses then interface with an animal and inject a protein into it that triggers its metamorphosis.

“Most of the most thrilling scientific moments in my life actually came one afternoon when Grant Sawyer (professor of biophysics and biology), Martin Pillaifer, Nick Shikuma, and I were sitting in my office looking in real time at the data they’d collected,” Newman says. “That’s the things we started seeing visually just blew our minds. They were structures no one had ever seen before, and this discovery resulted directly from the creativity of those two postdocs and their matching through CEMI.”

The omnipresence of microbes creates an unlimited array of possibilities for CEMI’s second decade. In addition to continuing to promote collaborations among the center-affiliated researchers, Orphan also hopes to forge new partnerships with similar centers around campus, including the Rosalind Franklin Institute, the Traquair and Christy Chauncey Institute for Neuroscience here at Caltech, and the Merkin Institute for Translational Research, due to microbiology’s deep and powerful connections to those burgeoning fields of study. Growing CEMI’s endowment would also help to build its educational program by offering fellowship support for students and postdoctoral scholars alongside the pilot-project funding the center has supplied for 10 years.

“The main currency of success is really the people,” Orphan says. “We have the ability to bring people in and support them and teach them the novel ways we think about microbiology here at Caltech, and then send them off so they can share that with their future universities and careers. If we could expand that bubble out even further, that would be wonderful.”

Jared R. Leadbetter is a professor of environmental microbiology. His work is funded by ONA, the Division of Geology and Planetary Sciences, and the NAGA Ecology program.

Dianne Newman is the Gordon M. Binder/Angel Professor of Biology and Geology and executive officer of Biology and Biological Engineering. Her work is funded by the National Institutes of Health, the National Science Foundation, the Swiss-American Collaborative Science Program, the David and Lucile Packard Foundation, the Reemtsma Foundation, the Kenneth and Jeanne J. Coffin Charitable Foundation, and the Canary-Rumors Cancer Research Foundation.

Victoria Orphan is the James Irvine Professor of Environmental Science and Geobiology and the Allen V. C. Davis and Lorraine Davis Leadership Chair for CEMI. Her work is funded by the Department of Energy, the National Science Foundation, the National Geographic Society, the Gordon and Betty Moore Foundation, the Simons Foundation, the New York State Energy Research and Development Authority, the Simons Foundation, the Donors’ Fund, and the Norman Family Foundation.

Nearby, a massive protein-protein interaction. What Ed recognized was a chance to have the whole

Watch a video about the research CEMI director Victoria Orphan (above) does to understand the microorganisms that play critical roles in oceanic ecosystems.
The payoff—personal, scientific, societal—is enormous.

Support Caltech.
The payoff—personal, scientific, societal—is enormous.

In Memoriam

Roy W. Gould (BS ’49, PhD ’56), Caltech’s Simon Ramo Professor of Engineering, Rmertitus, passed away on February 19, 2022, at age 94. Gould joined the Caltech faculty as an assistant professor of electrical engineering in 1955, a year before earning his doctorate. His research focused on plasma physics and thermonuclear fusion, and he served from 1970 to 1972 as director of fusion research at the Atomic Energy Commission, the federal agency created in 1946 to manage the development, use, and control of nuclear energy. He was recruited to serve as a deputy science advisor to President Richard Nixon, but returned to Caltech instead. Back on campus, Gould constructed a tokamak, a device that uses a magnetic field to confine plasma and study its chaotic mechanics.

Eugene N. Parker (1927–2022)
Distinguished Alumnus Eugene Parker (PhD ’51) passed away on March 15, 2022, at age 94. Parker was a pioneer in the field of heliophysics, the study of the sun and how it affects Earth, the planets in our solar system, and space beyond. In 1958, Parker correctly predicted the existence of the solar wind, a flow of charged particles that stream off our sun at speeds faster than sound. NASA named its Parker Solar Probe, a mission currently traveling around the sun, in his honor. The mission, which launched in 2018, was the first named by NASA after a living scientist.

Arthur D. Riggs (1939–2022)
Distinguished Alumnus Arthur D. "Art" Riggs (PhD ’66), a pioneering geneticist and world-renowned expert in diabetes, died March 23, 2022, at age 81. Evans studied synthetic organic chemistry at Caltech. After a stint at UCLA, he returned to Caltech as a professor of chemistry in 1974. He stayed with the Institute until 1983, when he joined the faculty of Harvard University. Evans’ most influential work involved what is now known as the Evans acyl oxazolidinone method, which is used in the synthesis of polypeptides, a class of molecules that are useful as pesticides, pigments, antibiotics, anti-cancer drugs, and medications for treating high cholesterol.

Carl V. Larson (1940–2022)
Distinguished Alumnus Carl V. Larson (BS ’52), passed away on March 27, 2022, at age 92. A native of Mercer Island, Washington, Larson enrolled at Caltech in 1948. He initially intended to study chemistry, but he eventually switched to mechanical engineering. Over decades, Larson and his wife, Shirley, engaged actively with the Caltech community—often behind the scenes and anonymously. Larson served as president of the Caltech Associates and chairman of the board for the Summer Undergraduate Research Fellowships program. Larson was also adamant that one should “give good people the resources and get out of the way.” He would often remark—using an aero- dynamic analogy inspired by his time as a weather forecaster in the U.S. Air Force and his enthusiasm for vexillology (the study of flags)—that his only intention was to “increase lift without adding drag.”

David A. Evans (1941–2022)
David A. Evans (PhD ’67), a former Caltech faculty member in the Division of Chemistry and Chemical Engineering, died on April 29, 2022, at age 81. Evans studied synthetic organic chemistry at Caltech. After a stint at UCLA, he returned to Caltech as a professor of chemistry in 1974. He stayed with the Institute until 1983, when he joined the faculty of Harvard University. Evans’ most influential work involved what is now known as the Evans acyl oxazolidinone method, which is used in the synthesis of polypeptides, a class of molecules that are useful as pesticides, pigments, antibiotics, anti-cancer drugs, and medications for treating high cholesterol.

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Caltech

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What do you remember most about your Caltech commencement day?

My immigrant father was always a man of few words; he was not easily pleased, and he was never one for much pomp and circumstance. But on that June day, I think he felt and appreciated what a special place Caltech is, as did I and the rest of my family. This sense of honor and pride has been a source of much happiness from that day until today.

Demetrios Missios (BS '88)

My mother took a picture of the wrong person receiving a diploma!

Robert Murphy (BS '84)

Several of the other electrical engineers had created a new type of audio amplifier. They rented several stadium speakers and set them up on the rooftops of the adjoining buildings. When the band started to play, the engineers poured several kilowatts of “The Ride of the Valkyries” into the courtyard, overwhelming every other sound.

Bruce Casner (BS ’75)

I was very happy! My mother spotted Richard Feynman on the Olive Walk and tried to line up a photo of me so he’d be in the background. I suggested we go over and ask if he would pose with me. Of course, he obliged, even though I am a biologist! She created a poster of the adorable photo, which my dad hung in his office.

Robin Wilson (BS ’86)

My parents were there. They had doubts about me going for a science PhD after I graduated from college with a BA in English. But when I finally received my PhD in physics, they were so proud. They have passed away since, but I’ll always remember that day with them. And the great party we had that evening at my home with so many of my fellow graduates—the relief I felt at achieving my dream was amazing. My parents danced along with my friends.

France Córdova (PhD '79)

We had the first President Bush speak at our commencement. I recall all the extra security. Plus the class president leaning in to ask the president something before giving him a hug. His question? “Can I give you a hug? Or will the Secret Service tackle me?”

Michael Kwan (BS '91)

President Rosenbaum’s smile at each and every degree recipient. Maintaining such a genuine smile for hours is not possible without a certain inner peace!

Harsha Reddy (MS ’18)

Our commencement speaker, Ray Bradbury, turned to the graduating PhDs and told them: “I want you to go home tonight and call up every person who ever told you that you couldn’t do it, and tell them to go to hell.” I carried that energy with me all the way through graduate school.

Sarah Milkovich (BS ’00)

My parents danced along with my friends.

Richard Yeh (BS ’88)

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Jad Abumrad, creator and former co-host of the public radio podcast Radiolab, was Caltech’s 2022 commencement speaker. In his speech, he relayed the story of the monarch butterflies that pass through California on their migration from Canada to Mexico, noting that their journey is so long that it requires three or four generations to complete. “You might not be the first butterfly,” he said. “You won’t know it, but you might be the third. Or more likely the three hundredth, taking the work or the knowledge or the discovery of those that came before you. And, in your lifetime, you are going to move it forward in ways no one can imagine. And you’re not going to get all the way. And that’s OK. Because without your effort, humanity is never going to get there.”

You can find more 128th Commencement coverage on page 8 and at magazine.caltech.edu.