Spring 2024

Caltech magazine

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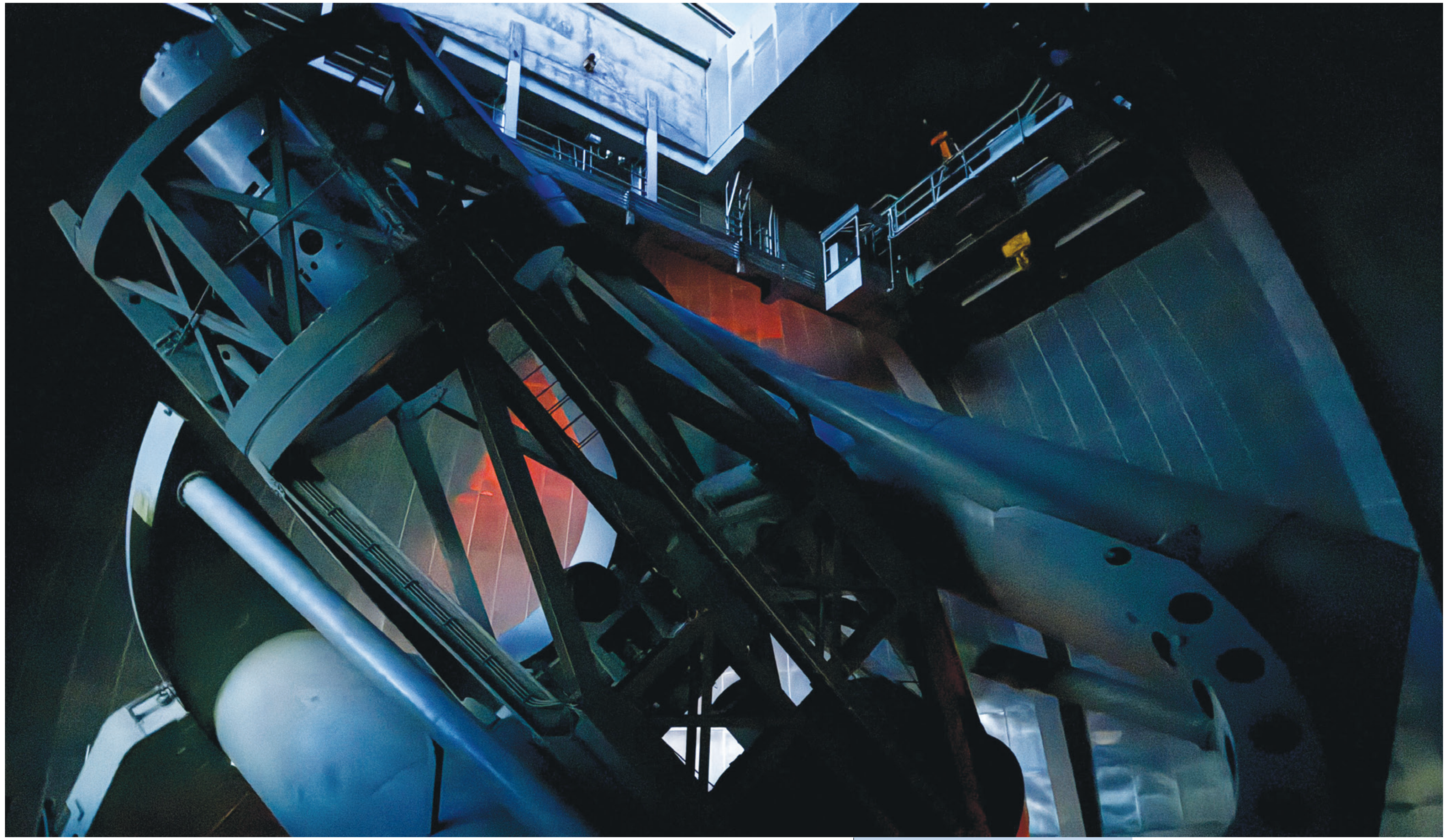

Left: The 200-inch Hale Telescope at Caltech's Palomar Observatory.

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Caltech magazine

EDITOR IN CHIEF
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ART DIRECTOR
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MANAGING EDITOR
Sharon Kaplan

ONLINE EDITOR AND SOCIAL MEDIA COORDINATOR
Andrew Moseman

CONTRIBUTING WRITERS
Whitney Clavin, Elise Cutts, Lori Dajose, Julia Ehlert, Kimm Fesenmaier, Lori Oliwenstein, Benjamin Peltz, Omar Shamout, Emily Velasco

DESIGNER
Jenny K. Somerville

ONLINE DESIGNER
Sergio Solorzano

ILLUSTRATION, PHOTOGRAPHY, VIDEOGRAPHY
Lance Hayashida, Peter Holderness, Jason Holley, Sergio Solorzano

COPY EDITORS
Sharon Kaplan, Carolyn Waldron

PRODUCED BY CALTECH'S OFFICE OF STRATEGIC COMMUNICATIONS
Shayna Chabner, Chief Communications Officer

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Graduate student **Termeh Bashiri** took this photo on campus during the solar eclipse on April 8, 2024, using the space between leaves as a pinhole camera.

Contact *Caltech* magazine at **magazine@caltech.edu**

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Letters

Socially Aware

A roundup of Caltech-related social media posts.

Mike Brown, the Richard and Barbara Rosenberg Professor of Planetary Astronomy, and director and Terence D. Barr Leadership Chair of the Center for Comparative Planetary Evolution, posted the following thread on Bluesky on February 1, 2024:

In Jan 2021, I explained to my family that I was going to channel TSwift, and that I was feeling good ... I was going to rebound from a bleak 2020 and I was going to find Planet Nine. I mapped out a whole program to predict where it is, search old archives, and find it. (1/?) 🔭🧪

In 2021 we developed a new set of mathematical tools to turn measurements of the orbits of distant objects in the sky into statistical predictions of where P9 should be. It was a massive effort of which I am extremely pround. It made 2021 seem ok. Using those predictions, we were off to hunt. (2/)

In 2022 we developed new incredibly efficient algorithms for trawling through years worth of old data and we demonstrated how well it worked on a modest data set from a telescope at Palomar observatory. It was a good algorithm. It was fast. It was accurate. But it didn't find P9 in those data. (3/)

It was ok, because the real data we wanted to look through was the years-long Pan-STARRS survey. There was too much data (and, frankly, too much garbage in the data). Even our nice fast algorithm stalled. We optimized. It [sped] up. The computers cranked through the data for about 14 months. (4/)

And we finished! And the paper is now out ... And... we didn't find P9. Why not? Well, there is still about 22% left in our search area that we weren't able to cover with these two. So there's that. But an obvious reason could be MAYBE IT DOESN'T EXIST, right? (5/)

Interestingly, even as we keep failing to FIND P9, we keep accumulating more and more evidence of its existence. We're just about to submit a new paper showing brand new evidence that you can't explain the positions of objects in the outer solar system without something like P9 (stay tuned). (6/)

So, I guess this is just to say that this new paper out today was a massive effort that I had high hopes for and it would have been fun if it would have been the one. (7/7)

When we published the first #enzyme to MAKE carbon-silicon bonds back in 2016, some people asked us to BREAK them, so these man-made compounds would not persist in the environment. We finally made the first steps toward that.

Frances Arnold, the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry, on X after her lab published a paper in the journal *Science* documenting its work using directed evolution to create an enzyme that can break artificial bonds between silicon and carbon.

After an academic career at U.C. Riverside and Caltech, Chris Birch became a track cyclist on the U.S. National Team. She was training for the 2020 Olympics when she was chosen as an astronaut candidate.

NASA on X after former Caltech lecturer Chris Birch was named to the 2024 astronaut class.

Congratulations to Adoniya Paul! She's a trailblazer as the first African American student from Long Beach Unified to attend Caltech, and today I joined [Southern California Edison] as they presented her a $50,000 scholarship to help her pursue her dreams.

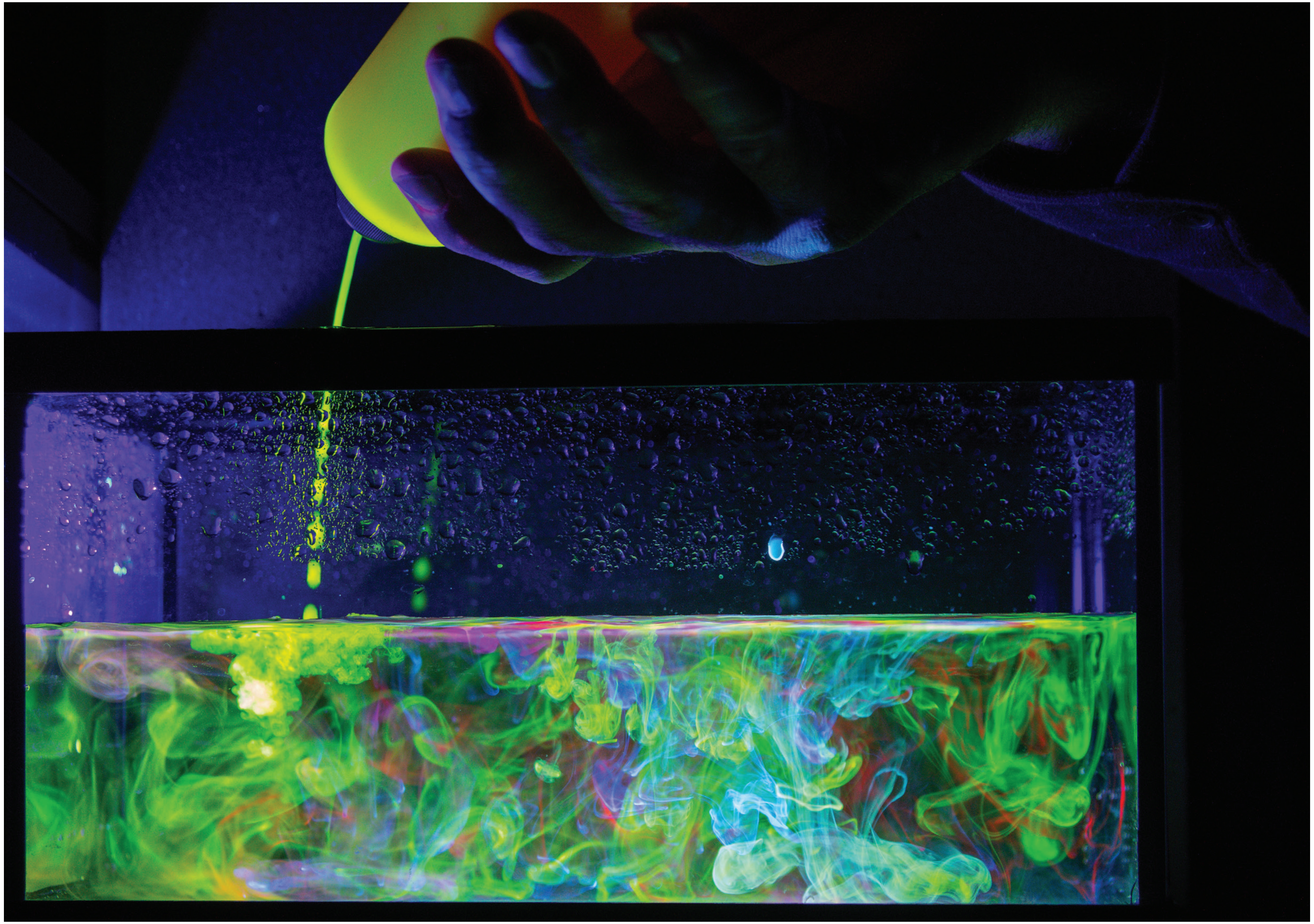
She is inspiring every student who will follow in her footsteps. I look forward to hearing about her future success!

Long Beach mayor **Rex Richardson** on X.

What an amazing individual to be both mindful of the stress the students feel and appreciative of their diversity. Caltech is fortunate to have someone like Vincent.

Juan Ceniceros on Instagram in response to a #SoCaltech profile of **Vincent Lopez**, a barista and cashier at the Red Door Marketplace.

Read the story



- A White House medal ceremony
- Swifties shake up SoCal
- Einstein's legacy lives on in Pasadena; and more

Beauty in Chaos

Aeronautics graduate student Tanner Harms studies turbulence. While many people might associate the word with a bumpy airplane ride, Harms says that is not exactly right. "That's the effects of turbulence more than turbulence itself," he explains. "Turbulence is actually the chaotic and unpredictable movement of fluids."

Harms demonstrated this phenomenon in his lab with some water and dye. "Every time I put a drop of dye in the water, it's not going to be the same. I do the best I can to replicate each drop, but no matter what I do, it's going to look different. Like a snowflake."

Among many other real-world applications, studying turbulence can help researchers figure out the best way to contain oil in the ocean following a spill and to better understand how garbage accumulates in the Great Pacific Garbage Patch, a floating pile of plastic that is twice the size of Texas.

Without turbulence, Harms adds, there would be no life on Earth—something to think about the next time you hear the familiar "ding" on an airplane warning you to buckle up. "Because mixing is largely driven by turbulence, a world with no turbulence might have pockets of dense oxygen and dense nitrogen, but they wouldn't mix together," he says. "It would be very difficult for there to be anything that could sustain life as we know it."

One of the things Harms says he loves most about his work is its inherent beauty. He notes that he learned to appreciate the aesthetic qualities of science from his mother.

"My mom was an art teacher and a graphic designer," he says. "Growing up, I really developed an appreciation for the artistic and creative side of science. Understanding the world—there's something beautiful in that. I mean, who would think turbulence is beautiful? But then you look at something like the surface of Jupiter, and it's just stunning. You see the swirling, and the Great Red Spot, and it evokes a sense of awe."

Watch Harms's Science Journeys lecture, "Chaos, Turbulence, and the Beauty of Uncertainty in Complex Systems"

'Shake' It Off

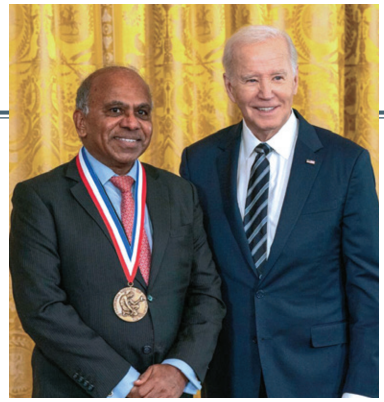
It turns out Taylor Swift concerts are truly seismic events. Following reports of Swift fans generating tremors during a concert in Washington state, the California Office of Emergency Services reached out to seismic network operators in California to see if interesting data could be collected during Swift's concerts at Inglewood's SoFi Stadium in August 2023. Monica Kohler (PhD '95), research professor of mechanical and civil engineering at Caltech, and her colleagues at the Institute's Seismological Laboratory and UCLA responded.

The team tapped into an existing regional network of seismic sensors reaching as far as about 6 miles from the stadium. They also temporarily installed 10 sensors within SoFi and one more across the street. The stadium sensors were inexpensive accelerometers made of off-the-shelf parts, like the kind that researchers regularly build and deploy for the Community Seismic Network, a distributed network of more than 1,200 strong-motion detectors in California.

The researchers found the stadium and its surroundings shook during the show, though the readings were akin not to an earthquake but to a harmonic tremor, characterized by bursts of energy at specific frequency intervals over longer periods of time. The data also showed that the concertgoers' dancing, rather than the music, caused the waveforms.

The work appears in a paper titled "Shake to the Beat: Exploring the Seismic Signals and Stadium Response of Concerts and Music Fans," published in the journal *Seismological Research Letters* in March 2024.

The study also showed that the inexpensive accelerometers used by the Community Seismic Network could be used to measure small vibrations within a stadium and relay those measurements in real time to scientists during emergencies when those facilities might be used as shelters. "It would be really important to be able to monitor the motions of these structures before, during, and after a large-scale event like an earthquake to determine whether the structure is still safe, reliable, and sound," Kohler says.



National Medal of Science Winners

President Biden awarded the 2023 National Medal of Science to Barry Barish, Caltech's Ronald and Maxine Linde Professor of Physics, Emeritus; and Subra Suresh, a Moore Scholar and former visiting professor.

Barish, who shared the 2017 Nobel Prize in Physics, was honored "for exemplary service to science, including groundbreaking research on subatomic particles. ... He has broadened our understanding of the universe and our nation's sense of wonder and discovery."

Suresh, professor at large at Brown University, was director of the National Science Foundation from 2010 to 2013 and has served as president of Singapore's Nanyang Technological University and as president of Carnegie Mellon University. He was honored "for pioneering research across engineering, physical sciences, and life sciences. A transformative educator, he has advanced the study of material science and its application to other disciplines."

"Einstein was not a big lover of history, but I think he would have appreciated that this work is being done now, and it's being done here, where so many scientists are actually continuing avenues and questions that he asked 100 years ago."

– **Diana K. Buchwald**, director and general editor of The Einstein Papers Project and Caltech's Robert M. Abbey Professor of History, on her group's work to delve into the famed physicist's correspondence, notebooks, diaries, lectures, calculations, speeches, and interviews.

Watch Buchwald's Watson Lecture, "Einstein in Pasadena: Between Two Worlds"

"In a very pleasantly unsurprising way, the dynamic with this crew is pretty much exactly as I had expected. Four people living in a small space will have its challenges, of course, but this crew got pretty tight very quickly."

– **Ross Brockwell** (MS '01), on life inside Mars Dune Alpha, a 1,700-square-foot 3D-printed habitat at Houston's Johnson Space Center, the site of a yearlong NASA mission to simulate the psychological and physical demands of living on Mars.

Read more

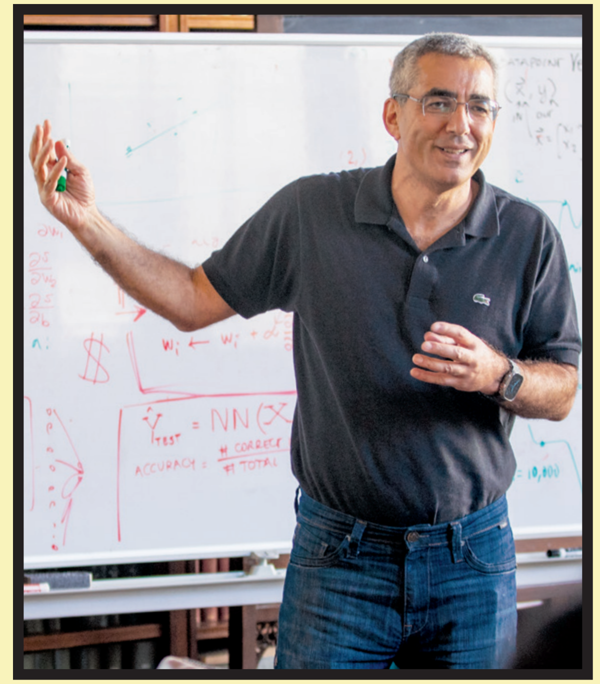
"Many of the core questions we struggle with today are present in these much earlier periods of history but reveal themselves in different ways—some familiar, some radically distinct."

–**Jennifer Jahner**, professor of English, dean of undergraduate studies, and a 2023–24 Fletcher Jones Foundation Distinguished Fellow at The Huntington Library, Art Museum, and Botanical Gardens, who is using the library's manuscript collection to explore how astrology and applied sciences in the Middle Ages helped people navigate uncertainty.

Read more

Three Questions for: Reza Sadri

Reza Sadri, the director of the new AI Bootcamp in the Division of Engineering and Applied Science, joined Caltech in 2023, bringing with him 30 years of experience in software development, including as head of machine learning infrastructure at Instacart. He hopes to bridge the gap between academia and AI technology through a series of eight to 10 workshops a year aimed at Caltech graduate students, postdocs, and researchers. Here, Sadri provides some more details about that effort.



1. What is the AI Bootcamp?

The main goal of the bootcamp is to help participants understand when and how to effectively use AI within their research as well as to identify its appropriate contexts and limitations. Forty years ago, there were a lot of physicists and chemists who could benefit from using a computer, but they didn't know how. AI is at the stage that the computer was 40 years ago. We must bring scientists on board to be able to use AI effectively.

2. What are some ways AI is used ineffectively in industrial and research settings?

First, sometimes, you don't need AI. There are some applications where you can get by using simple mathematical models or statistics. The second mistake is sometimes people use a complicated model when a simple model will work just as well. The third is mishandling data. Effective use of data requires clean, relevant, and non-leaky datasets—data leakage is when information from outside the training dataset is inadvertently included in the model, leading to unrealistic performance. Misusing data like this leads to wasted efforts such as publishing papers based on incorrect data assumptions.

3. What is the long-term vision for the bootcamp?

In the past decade, AI has expanded significantly into various branches and applications, and some AI applications are well suited to specific fields or problems. We will offer specialized bootcamps for these applications, such as reinforcement learning, graph neural networks, and large-scale data processing. The broader application of AI across diverse scientific disciplines inherently enriches AI and machine learning. Scientific research often tackles unconventional problems that are not mainstream, presenting unique challenges. Addressing these issues with AI and machine learning necessitates innovative approaches, pushing the boundaries of the field in unexpected directions.

KNI Celebrates 20th Anniversary

Just how small is a nanometer? Whatever you are thinking, think smaller. *Nano*, Greek for "dwarf," signifies one billionth of a meter (or 10^{-9} meters). A single sheet of ordinary paper is 10,000 times thicker than a nanometer, as is the diameter of a single strand of human hair.

With the advent of sophisticated microscopy instruments, objects only several nanometers in size can be measured by researchers such as those at Caltech's Kavli Nanoscience Institute (KNI), which celebrated its 20th anniversary March 7–8, 2024, with a symposium and a fireside chat between Caltech President Thomas F. Rosenbaum and chemist George M. Whitesides (PhD '64), the 2022 Kavli Prize laureate and the Woodford L. and Ann A. Flowers University Research Professor at Harvard University.

"It is exhilarating to think about everything that is possible at the nanoscale and how many more challenges remain," says Julia R. Greer, the Fletcher Jones Foundation Director of the KNI and Ruben F. and Donna Mettler Professor of Materials Science, Mechanics and Medical Engineering. "We are getting really close to fabricating, manipulating, and imaging samples at the atomic level, which propels new discoveries just about every day."

"I remember from my own time at Caltech, there was a class called E 10. It was engineering presentations and public speaking. I had never spoken in public before. It was terrifying for me, but it was very valuable. This experience of taking an idea of yours, clarifying it down so it's simple and understandable, and communicating it to someone else—that's a valuable skill independent of whether you ever plan to start a business."

– **Bill Gross** (BS '81), an entrepreneur, start-up evangelist, and Caltech trustee, on teaching his new class: E/SEC 102, Science and Technology Entrepreneurship.

Read more

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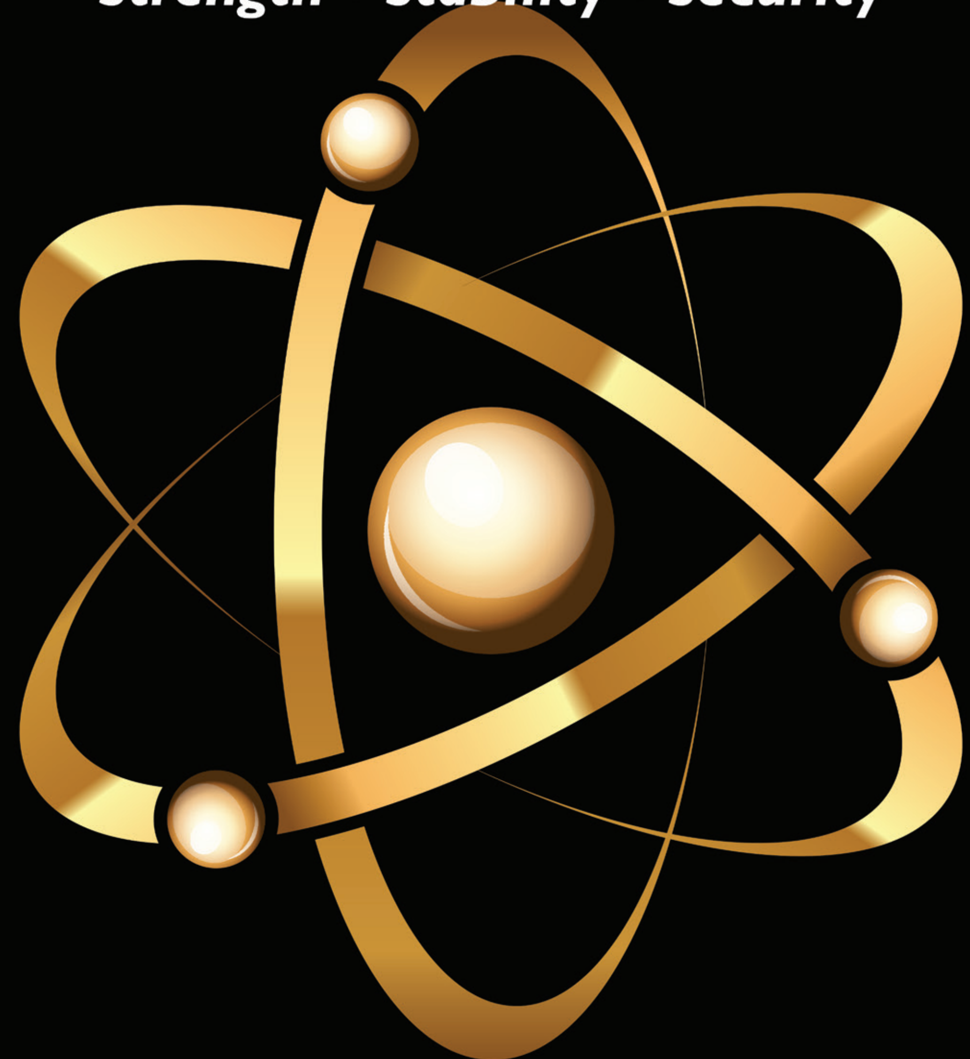

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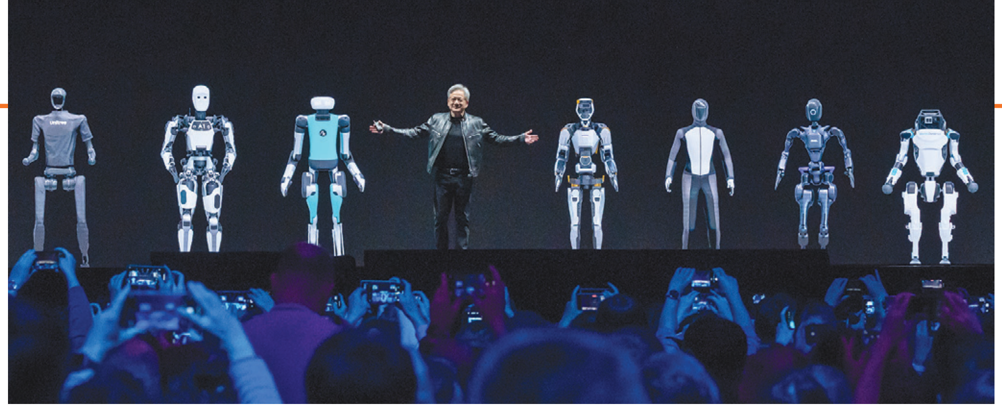


NVIDIA CEO to Deliver 130th Commencement Keynote

Jensen (Jen-Hsun) Huang, founder and CEO of technology company NVIDIA, will deliver the keynote address at Caltech's 130th Commencement ceremony on June 14, 2024.

Named the world's best CEO by *Fortune*, *The Economist*, and *Brand Finance*, Huang led NVIDIA to become a pioneer in accelerated computing and the fourth-most valuable company in the world.

Huang co-founded NVIDIA in 1993 with Chris Malachowsky and Curtis Priem to take advantage of the growing demand for 3D graphics and visualization technology that accompanied the rapidly expanding PC and gaming industries. Huang's sights are now set on combining NVIDIA's computer graphics research with its generative AI research to create the "Omniverse," a platform capable of simulating the real world to create "digital twins" that could be used to safely train robots and self-driving cars, among other applications.

"As NVIDIA's CEO, Jensen Huang has led a revolution in computation and artificial intelligence," said Caltech President Thomas F. Rosenbaum. "His personal story underlies these accomplishments and provides a touchpoint for our students as they embark on the next stages of their careers."

The Commencement ceremony will be streamed live here

Laura Luebbert (fifth-year graduate student)

#SoCaltech *is an occasional series celebrating the diverse individuals who give Caltech its spirit of excellence, ambition, and ingenuity. Know someone we should profile? Send nominations to* ***magazine@caltech.edu.***

Laura Luebbert, a biology PhD student, recently won a prestigious award from the German Federal Ministry for Education and Research and the German Aerospace Center for her work on gget, an open-source software tool for analyzing RNA sequencing data, which has received roughly 100,000 downloads. Luebbert received her bachelor's and master's degrees from Leiden University in the Netherlands.

"I was a wet lab biologist who would spend an hour on her computer per week. Leiden did not teach advanced math or programming as part of its biology curriculum at the time, so I was thrown into the deep end regarding these skills when I arrived at Caltech.

However, I was determined to learn and spent a significant amount of time on YouTube, Codecademy, and Stack Overflow teaching myself to code in Bash, Python, and C++. I started writing code to analyze all my wet lab data—and then the data from other lab members. There was a massive gap between computer scientists with the coding skills to handle and analyze large complex datasets and biologists with a deep understanding of the intricate biology underlying the experiment required for its interpretation. So, I started writing more general software to make complex analyses more accessible for novice programmers. I fell in love with this work so much that I completely switched research fields three years into my PhD."

In the Community

PST ART: Art & Science Collide

Clockwise from far left: Images from *Crossing Over, HomeCare, Blended Worlds,* and *HUANG YI & KUKA*.

While objectivity may rule the day in science, it takes a sense of imagination, wonder, and creativity to see beyond the limits of our current knowledge. In September 2024, Caltech will take part in the landmark arts event, PST ART: *Art & Science Collide*, presented by Getty.

PST ART will span dozens of institutions across Southern California with exhibitions featuring more than 800 artists. Caltech entities on campus and at JPL received grants from the Getty Foundation for three separate projects that will explore the event's theme in unique ways.

Opening Doors

CaltechLive will present *Opening Doors*, a series of dance, music, and theater performances, including *HUANG YI & KUKA*, a dance show featuring Taiwanese choreographer Huang Yi, and Kuka, an industrial robot programmed by Huang; *Turing Tests*, *Apples, and Queens: Collective Storytelling Through Fairy Tales and Artificial Intelligence*, a performance by Invertigo Dance Theatre exploring the life and work of mathematician Alan Turing; *HomeCare*, a concert by Los Angeles-based choral ensemble Tonality about climate change; and *Tesla: A Radio Play for the Stage* about Nikola Tesla, Thomas Edison, and the monetization of scientific research.

"For centuries, the performing arts have played a pivotal role in the public's understanding of scientific, political, and social issues," says Michael Alexander, Caltech's campus arts and culture liaison. "We have engaged four incredible performing ensembles to demonstrate the truth in that statement."

Following each performance, a moderated discussion will engage the artists, Caltech scientists, and audience members in conversation around the topics explored.

Crossing Over: Art and Science at Caltech, 1920-2020

Presented by Caltech Library, *Crossing Over* will feature rare books, scientific instruments, molecular models, historical paintings, drawings, photographs, and films on display across four campus exhibits, as well as installations featuring contemporary art by artists Lita Albuquerque, Lia Halloran, Shana Mabari, Hillary Mushkin, and Helen Pashgian. The project will be accompanied by a visual catalog with 13 original essays about science history and visual culture at Caltech available online and in print.

"*Crossing Over* began in the Caltech Archives, with Caltech's collections of our own history and the history of the science and engineering done here," says Peter Collopy, university archivist and head of archives and special collections. "How, we asked, can Caltech's history help us understand how art and science contribute to each other, both now and over the last 100 years?"

Blended Worlds: Experiments in Interplanetary Imagination

JPL, which Caltech manages for NASA, in collaboration with the City of Glendale, will present *Blended Worlds* at the Brand Library and Art Center in Glendale. This exhibit explores the landscape of human relationships with nature and questions how empathy and connectedness can reveal new worlds and inspire innovative ways to nurture them. Twelve artists—including sculptor Larry Bell and performance artist Moon Ribas—will invite us to rethink our growing disconnection from nature and foster a renewed sense of wonder with our planet and the cosmos. *Blended Worlds* will also include a new stage production called *Earth Data: The Musical* directed by Caltech Theater Arts director Brian Brophy, which will be performed in Ramo Auditorium between October 31–November 3, 2024.

"By emphasizing belonging and connectedness, this exhibition hopes to prompt more responsible stewardship of Earth—and the universe—by rethinking traditional scientific methodologies and emphasizing creative ways of knowing," says Lois Rosson, an exhibit consultant and the Octavia E. Butler Fellow at The Huntington Library, Art Museum, and Botanical Gardens in Pasadena.

–Julia Ehlert

Learn more about the upcoming exhibits and performances

Origins

Propulsion, Aeronautics, and Rocket Systems Engineering at Caltech (PARSEC)

An architectural rendering of the new PARSEC facility.

Nearly 90 years ago, a group of Caltech graduate students and amateur rocket enthusiasts known as the "Suicide Squad" began testing rocket engines under the mentorship of aeronautics pioneer Theodore von Kármán. Their achievements eventually led to the founding of the Jet Propulsion Laboratory (JPL), which Caltech manages for NASA.

The Suicide Squad's adventurous legacy lives on in PARSEC (Propulsion, Aeronautics, and Rocket Systems Engineering at Caltech), a team of students reigniting student rocketry at the Institute, who now have the added boost of a multimillion-dollar gift to help them reach the stars.

Aerospace graduate student Jack Caldwell (BS '22) and his former roommate Lewis Jones (BS '20) launched this rocketry revival in 2017, when they conceived of PARSEC as undergraduates. "Lewis and I were talking, and he mentioned another university's rocket team," Caldwell says. "I remember asking, 'Why isn't there a team here?'"

The two, joined by fellow Blacker House members Alexandra Stutt (BS '21), Richard Hamel (BS '20), and Benjamin Cassese (BS '20), co-founded PARSEC with the goal of building a liquid-propellant rocket and competing in a collegiate rocketry challenge. The COVID-19 pandemic, however, scrapped their plans. Upon graduating, the founding members went on to attend graduate school or work for aerospace companies, with Caldwell continuing as a graduate student at the Graduate Aerospace Laboratories at Caltech (GALCIT).

Recently, PARSEC has grown thanks to an influx of members (mentored by Caldwell) who share a fresh aspiration: to compete in the international Lander Challenge, which sees collegiate rocketry teams attempt to build a self-landing rocket that can fly up to 50 meters, hover for 10 seconds, and land in a designated spot. "Our goal is to set people up to go into industry with a lot of relevant knowledge," says undergrad Max Oberg, PARSEC's president.

But building a self-lander requires physical space and resources, which is why aerospace enthusiast Foster Stanback decided to step in and help PARSEC get its rocket off the ground—literally. An investor and philanthropist, Stanback has gifted $7.4 million to the Institute to fund the construction of a new facility for high-speed flight dynamics. "Caltech students are some of the smartest in the world," Stanback says. "I would expect to see them at the top worldwide with the high-performance rockets they'll develop. I wanted to make this gift so they would have everything they need to reach their full potential."

The center will replace the small garage behind the Guggenheim Aeronautical Laboratory, in which PARSEC currently works, with a sleek, two-story building. The ground floor will serve as lab space for PARSEC students to design, manufacture, and test noncombustible components. Engine testing will happen off campus. The second floor will house a multiuse lab and collaborative meeting space. "Having a permanent home for PARSEC is going to be a game changer," Caldwell says.

Stanback's donation will also solidify the Institute's role at the cutting edge of aerospace innovation, says Mory Gharib (PhD '83), the Hans W. Liepmann Professor of Aeronautics and Medical Engineering, who serves as GALCIT's director and as faculty advisor for PARSEC.

"Foster's contribution is a testament to the outstanding vision of the students in PARSEC," Gharib says. "Any collegiate team can fire a rocket and crash it, but Caltech students are interested in a deeper understanding of what can be done, in studying components, and in coming up with a more scientific approach to a problem."

–Julia Ehlert

The Roots of the Matter

By Lori Dajose (BS '15)

Caltech faculty are working to make farming practices more sustainable.

Off the coast of Peru, a group of small islands in the Pacific Ocean sit encrusted with layers of unusual riches: bird dung.

Bird dung, or guano, contains nitrates and ammonia—chemical ingredients that nourish plants—making it a valuable natural fertilizer to help crops grow. In the mid-1800s, countries with burgeoning populations required an ever-increasing supply of crops to feed their people, leading to international conflict over mining rights to the so-called Guano Islands off the Peruvian coast.

The guano gold rush subsided in the early 20th century thanks to a scientific feat that revolutionized the nature of food production: Scientists Fritz Haber and Carl Bosch developed a method now known as the Haber–Bosch process to synthesize ammonia and thereby create synthetic fertilizers. Both researchers won a Nobel Prize in Chemistry for their efforts (Haber in 1918, Bosch in 1931). These synthetic fertilizers greatly improved crop yields, reducing famines and enabling population growth around the world.

While this technological innovation changed the planet and saved many lives, the Haber–Bosch process produces a significant carbon footprint. And with the world's population projected to hit 10 billion by the end of the century, agriculture is at yet another crossroads: Can humanity grow enough food for the growing population in a way that doesn't hasten the planet's demise?

A group of Caltech faculty members, with help from Caltech's own Resnick Sustainability Institute (RSI), have taken on this challenge by tackling innovative projects in the hope of making agriculture more sustainable and revolutionizing the farming practices of the future. At the forefront of these efforts are the quest for a cleaner way to synthesize ammonia for use in fertilizer, a "communication" system that would allow farmers to monitor nutrient levels in plants and soil as a way to make fertilizer application less wasteful, and a genetically engineered plant that can uncover the workings of the underground root environment.

Did you know?

Global fertilizer consumption was expected to grow from 177.2 million metric tons in 2011–12 to 195.4 million metric tons in 2023–24, a 10.3 percent increase over 12 years, per the data firm Statista.

'Clean' Fertilizer?

All crops, from wheat to blueberries to lettuce, need the same basic chemical building blocks to grow. While plants can get certain elements from their surroundings—such as oxygen from the air and phosphorous from the soil—they need nitrogen in a specific form that does not exist in the atmosphere. Analogous to how humans cannot digest uncooked potatoes, plants cannot utilize N_2, the common form of nitrogen found in air. Nitrogen gas needs to be "fixed," or transformed into a usable form to make it edible for plants. Soil bacteria naturally fix N_2 using nitrogenase, an enzyme that transforms the nitrogen into NH_3, or ammonia, which plants then absorb through their roots. But this natural process cannot keep up with the massive scale of agricultural food production required to feed the global population. So, farmers apply fertilizer, be it dung or synthetic ammonia made through the Haber–Bosch process, which helps farmers keep up with demand for their crops.

But fertilizer produced by the Haber–Bosch process has the largest carbon footprint of any human-made chemical product; carbon dioxide emissions from its production make up 1 to 2 percent of the global total. That is because the Haber–Bosch chemical reaction combines hydrogen from fossil fuels like oil or natural gas, with nitrogen gas. Under high pressures and temperatures, hydrogen gas extracted from the fossil fuels is combined with nitrogen to create the usable form of ammonia. However, the process creates the greenhouse gas carbon dioxide. It also requires costly infrastructure, which is why it is performed at only a few hundred industrial sites worldwide. This means transporting the fertilizer to rural farmers is expensive and results in ammonia-based fertilizers like urea costing two to three times more in sub-Saharan Africa than in the United States, says Caltech chemist and chemical engineer Karthish Manthiram.

To address these issues, Caltech researchers, led by Manthiram and Jonas Peters, a Bren Professor of Chemistry and director of the RSI, are working on a project to synthesize ammonia in a clean, more sustainable way. Instead of extracting hydrogen molecules from fossil fuels, the team seeks to use the hydrogen in water: H_2O. Oxygen is the only by-product of this process, which can occur at room temperature and pressure.

"My parents grew up involved in agriculture in India," Manthiram says. "The ability to feed yourself and your family depends deeply on the productivity of the soil and the animals that live off of it, and it gives you a deep respect and attachment to the earth. Enabling farmers to produce their own fertilizer—in a cheap, clean, local manner—is a major motivation for our project."

However, this cleaner chemical reaction between air and water does not occur spontaneously: It needs a catalyst to start. That is why researchers in the Manthiram lab are developing an electrochemical cell that contains a recyclable catalyst to enable the process. The device at present is a lab-scale prototype and uses lithium to drive the reaction forward.

"With distributed ammonia production, a farmer could synthesize their fertilizer right where they need it instead of importing it from far away," Manthiram says. "This helps food production to be resilient against geopolitical strife as well. For example, fertilizer prices quadrupled at their peak since the war in Ukraine began, as natural gas from Russia was a major source of the hydrogen required to synthesize ammonia."

Meanwhile, chemist Doug Rees and Steve Mayo (PhD '87), the Bren Professor of Biology and Chemistry, are looking at nitrogen fixation through a biological lens, examining how bacteria use the enzyme nitrogenase to transform N_2 into NH_3 at normal temperatures and pressures. The triple bond between N_2's two nitrogen atoms is one of the strongest bonds in nature, hence why the Haber–Bosch process requires such high temperatures and pressures to break it. But nitrogen-fixing bacteria, including those that have symbiotic relationships with plants, can cleave this bond using only the enzyme nitrogenase.

For decades, Rees has been a leading expert on deciphering the complex structure and workings of the enzyme. With Mayo's protein engineering expertise, the two are attempting to engineer a version of the nitrogenase enzyme in the lab that is more effective and efficient at fixing nitrogen. The ultimate goal would be to develop biologically inspired methods of nitrogen fixation that do not require the extreme temperatures and pressures of current technologies. "Nitrogenase is essential for life," Rees says. "The goal is to learn from nature's own nitrogen-fixation methods to possibly develop our own."

Karthish Manthiram holds a prototype of his lab's electrochemical cell for cleaner ammonia production. Behind him, from left to right, are graduate students Channing Klein, Michael Yusov, and Anukta Jain.

The Overfertilization Problem

When farmers apply too much fertilizer to their soil, ecosystems can become damaged. Eutrophication is a phenomenon that occurs when runoff from agricultural systems enters nearby water environments, causing an excess of nutrients to inundate the aquatic ecosystem. This creates a sudden proliferation of plant life, like algae, that suffocates other life-forms and throws off the delicate ecosystem balance.

Eutrophication has been present in California's Salton Sea for decades, killing fish and birds, including endangered species.

Runoff is also an issue because fertilizer is not an infinite resource. In addition to nitrogen and potassium, one of fertilizer's three major components is phosphorous, which must be mined from ever-shrinking deposits around the world. Experts estimate that farms waste 9–14 million tons of phosphorous each year through agricultural runoff, so the judicious application of fertilizer is crucial both for protecting ecosystems and for managing the globe's limited phosphorous supplies.

To help farmers know exactly when and where to fertilize their crops, researchers are developing methods to monitor the complex underground ecosystem of the rhizosphere, the place not far below ground where plant roots, soil, and microbes converge. On average, there are a billion bacterial cells per gram of soil in the rhizosphere all battling one another for coveted niches near a plant's roots. In addition, plants secrete chemical signals and nutrients into the soil, hoping to attract beneficial microbes and repel harmful ones. With such a complex environment, there are still many unanswered questions about this underground frontier.

Now Caltech researchers are beginning to uncover some of those answers. "The study of the rhizosphere was lacking real-time methods for data acquisition," says microbiologist Dianne Newman. "There was a large unmet need in the field where Caltech expertise could really make a difference."

If Plants Could Talk

Newman is combining her microbiology expertise with the skills of Azita Emami, the Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering, and director of the Center for Sensing to Intelligence; Changhuei Yang, the Thomas G. Myers Professor of Electrical Engineering, Bioengineering, and Medical Engineering; and Julia Kornfield (BS '83), the Elizabeth W. Gilloon Professor of Chemical Engineering, to develop technology that can measure phosphorous levels in soil in real time. In a project led by postdoc Reinaldo Alcalde (who works in Newman's lab), the interdisciplinary team has created a biosensor roughly the size of a quarter that can be buried underground and contains soil bacteria genetically engineered to produce fluorescent proteins when the bacteria experience certain conditions, such as low phosphorous levels. When the device detects the fluorescent glow, it sends a wireless message above ground to a receiver that alerts the farmers, who can then make informed decisions about whether to apply additional fertilizer.

The device is currently in the assembly stage: The team has generated fluorescent biosensors and is assessing their activity when contained in polymers, as they will be in the finished product. In parallel, a complementary metal-oxide semiconductor device has been designed to interface with the bacteria in order to translate their fluorescent signal into one that can be received by Bluetooth. By next fall, the team hopes to bring the two components together and begin testing the performance of the device in soils.

"Our long-term goal is to plant these biosensors throughout a field and get information on when and where you need fertilization," Alcalde says. "That would be the dream. But there are many fundamental scientific and engineering challenges we are currently working on: For instance, how long can engineered bacteria encased within a polymer remain metabolically active without growing? There are all sorts of interesting questions."

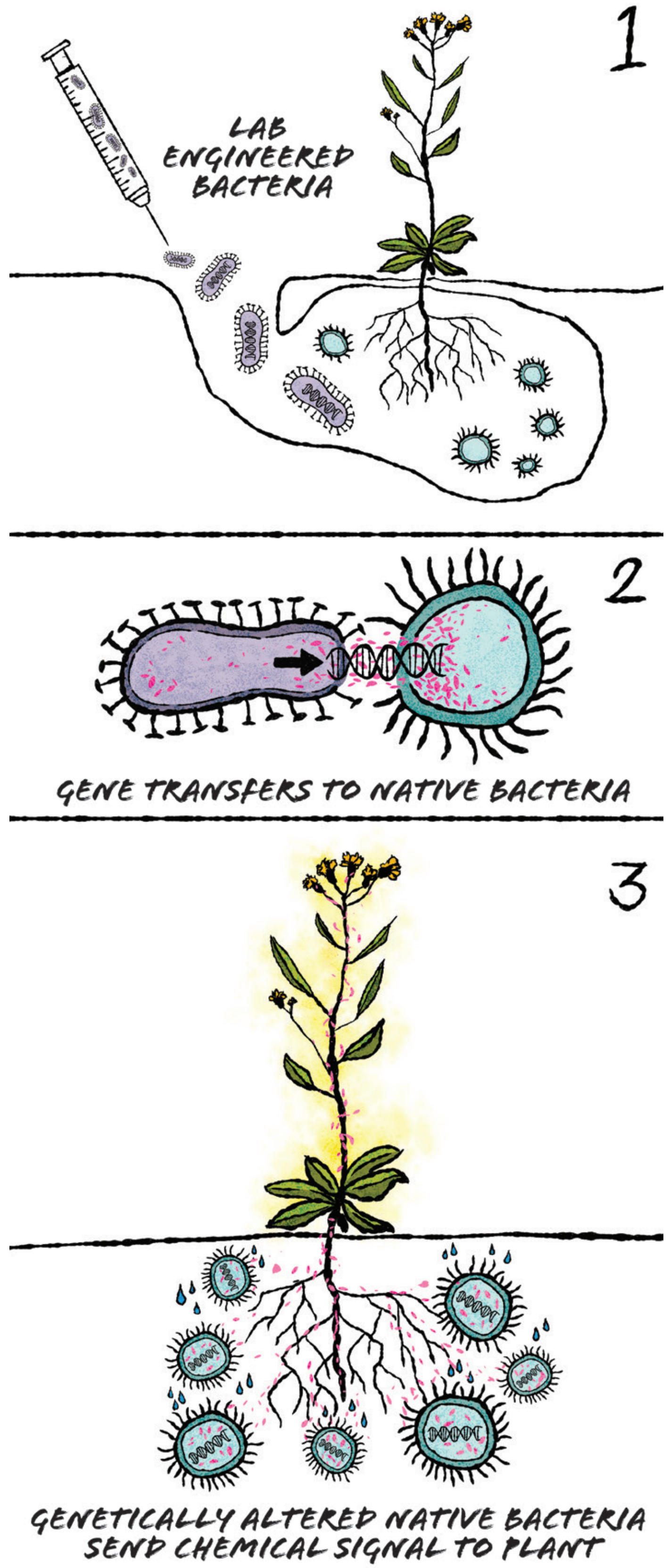
Meanwhile, postdoc John Marken and his colleagues at Caltech are designing a fluorescent system to observe conditions in the rhizosphere, but their version is geared toward scientists rather than farmers. Utilizing genetic engineering expertise from the labs of Niles Pierce, the John D. and Catherine T. MacArthur Professor of Applied and Computational Mathematics and Bioengineering, and Gözde Demirer, the Clare Boothe Luce Assistant Professor of Chemical Engineering, along with plant and microbial biology knowledge from the labs of Bruce Hay, professor of biology (in which Marken is a postdoc), and Elliot Meyerowitz, the George W. Beadle Professor of Biology, the team is developing a noninvasive system that will allow researchers to study the basic biology of root systems and the complicated relationships between microbes in the rhizosphere.

"The challenge with studying the rhizosphere is that it's all underground," Marken says. "You can't see what's happening inside, but you want to monitor what's happening in real time without having to disturb the system."

One way to do that is to monitor the natural signals a plant's leaves convey about the plant's underground conditions. For example, a houseplant's leaves may turn yellow, indicating that its roots are receiving too much water. In this project, the team took inspiration from such natural processes to design genetically engineered "sentinel" plants that can keep watch over the rhizosphere, delivering signals to researchers through their leaves in the form of a fluorescent glow that occurs when the microbes in the rhizosphere experience specific conditions.

The system is crafted so that the fluorescence can be coupled with the exact traits a researcher would like to study. For example, a sentinel plant could be designed such that its leaves will glow when rhizosphere bacteria nearby are expressing genes involved in nitrogen metabolism.

The *Science* of Sentinel Plants



1. Laboratory bacteria are engineered with a genetic program that causes them to secrete a signal compound (such as a plant hormone or a bacterial communication compound) if a specific target gene (such as *nosZ*) is being expressed. These bacteria are inserted into the soil, where the sentinel plant has already been planted.

2. Once in the soil, the lab bacteria pass on this ability to the native root bacteria through a natural process known as horizontal gene transfer.

3. When the native bacteria secrete the chemical signifying that the gene of interest is being expressed, the chemical is taken up by the sentinel plant's roots and travels to the leaves. There, the signal compound activates an engineered genetic reporter in the sentinel plant that causes its leaves to glow. The system can be designed to detect any gene of interest, enabling researchers to learn about multiple bacterial processes in the rhizosphere.

Postdocs Reinaldo Alcalde, front, and Hannah Jeckel inspect a plant and soil sample in the lab of Dianne Newman.

Pinpointing the conditions under which bacteria switch on their ability to metabolize nitrogen is particularly useful in the case of nitrous oxide (N_2O), a potent greenhouse gas. N_2O is produced as a by-product of applying nitrogenous fertilizers to cropland. Some microbes in the soil can convert it into harmless nitrogen gas—provided those microbes are expressing the gene known as *nosZ*. The conditions that drive these microbes to express *nosZ* are not completely understood. If sentinel plants can fluorescently indicate aboveground that *nosZ* is being expressed by root bacteria, then scientists can develop experiments to tweak various rhizosphere conditions and study how they affect *nosZ* expression. Answering basic biological questions like these could ultimately lead to more sustainable farming practices.

"This technology isn't necessarily going into a farmer's field; it's letting us conduct experiments to answer questions about the workings of complex root ecosystems," Marken says. "Just as basic scientific advances in our understanding of cellular biology and human physiology allow us to develop medical treatments to promote health and treat disease, the insights from technologies that let us understand the rhizosphere will empower farmers and policymakers to make informed sustainable agricultural decisions."

While the complex sentinel plant system has many scientific and engineering challenges, its potential rewards are profound. "Once we understand the causal underpinnings of microbial behaviors in the rhizosphere, we can develop new technologies and land-management strategies to promote a more sustainable stewardship of our natural and agricultural soils, simultaneously promoting both human benefits and ecosystem health," Marken says.

Newman says Caltech's multifaceted approach is well designed to redefine the nature of farming in the future. "It's important to have methods for both lab work and field research," she explains. "These high-risk, high-reward projects are pushing the frontiers of certain technologies in the lab. Meaningful research happens all along the continuum from the lab to real-world applications."

Reinaldo Alcalde is a postdoctoral scholar fellowship trainee in biology and biological engineering.

Karthish Manthiram is a professor of chemical engineering and chemistry and a William H. Hurt Scholar.

John Marken is a postdoctoral scholar research associate in biology and biological engineering.

Dianne Newman is the Gordon M. Binder/Amgen Professor of Biology and Geobiology and the Ecology and Biosphere Engineering Initiative Lead with the RSI.

Doug Rees is the Roscoe Gilkey Dickinson Professor of Chemistry and a Howard Hughes Medical Institute Investigator.

All projects in this story received funding from the RSI.

Extra Credit

A company founded by Caltech alum Aadith Moorthy (BS '18) uses artificial intelligence to help farmers get paid for storing carbon in their soil.

By Elise Cutts (BS '19)

The emergence of agriculture changed the course of human history roughly 10,000 years ago. Now, Boomitra, a company founded by Caltech alum Aadith Moorthy (BS '18) in 2016, is using artificial intelligence and remote-sensing technology to help farmers once again shape humanity's future.

Boomitra partners with farmers around the world to help them implement agricultural practices that take carbon out of the air and store it in soil; practices for which the farmers get rewarded. Boomitra's proprietary AI software analyzes satellite observations made by agencies such as NASA and the European Space Agency to accurately determine how much carbon the farmers have sequestered in their soil. For every ton of carbon the farmers store, Boomitra can sell one carbon-removal credit through its marketplace to companies looking to offset their own greenhouse gas emissions.

Boomitra, which means "friend of the earth" in Sanskrit, takes a small cut of each transaction, and the rest of the money is passed on to the farmers. "We get farmers paid for removing carbon dioxide from the atmosphere," Moorthy explains. And, because the amount farmers get paid is tied directly to the amount of carbon in their soil, they are incentivized to store as much as they can.

Thanks to this innovative AI software and carbon-credit marketplace that connects farmers with industrial businesses, Boomitra won the 2023 Earthshot Prize in the "Fix Our Climate" category, which came with an award of £1 million (around $1.24 million today). The contest was launched by William, Prince of Wales, in 2020. "All our finalists remind us that, no matter where you are on our planet, the spirit of ingenuity, and the ability to inspire change, surrounds us all," said Prince William in a press release.

Above: Moorthy, center, with farmers in Kenya in 2023.

Boomitra sells carbon credits to organizations through the voluntary carbon market, with plans to operate within compliance markets (which are driven by government emissions mandates). In the voluntary carbon market, organizations can choose to offset their carbon emissions through the purchase of premium removal credits. Through Boomitra, these offsets are enabled by farmers and ranchers across the world, who receive additional income to adopt regenerative practices, restore soil health, and sequester atmospheric carbon.

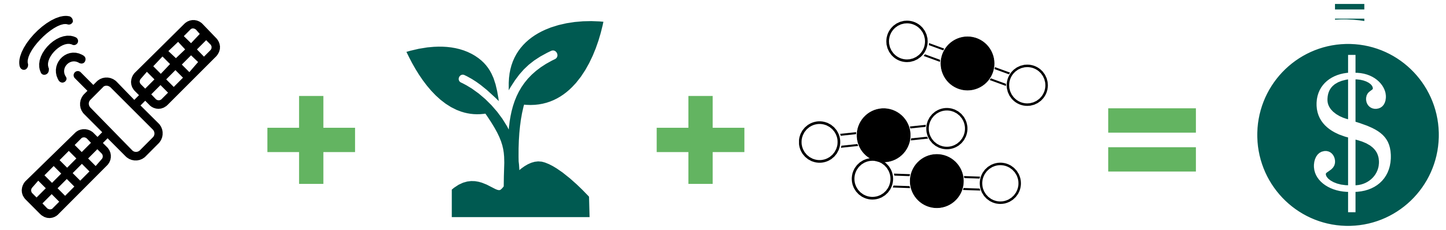
To date, Boomitra has received roughly $6 million in venture capital funding to scale its efforts. "Something holding back the carbon markets in agriculture is how expensive and laborious it is to certify credits in a field," said Erkki Aaltonen, managing director of Norway's Yara Growth Ventures, which invested $4 million in Boomitra in 2021. "Boomitra's remote technology and marketplace have the opportunity to categorically change the way agri-carbon credits are monitored, packaged, and sold. All while enabling small-holder farmers with as few as 2 hectares to make money while sequestering carbon."

Boomitra monitors the farms through satellite data collected via remote-sensing technology because testing soil from every individual farm would be far too costly and inefficient, Moorthy says. Tracking soil carbon capture from space decreases costs by more than 90 percent, he adds, making it possible to monitor far more land than through physical soil sampling alone.

Boomitra, whose continent-spanning team of 56 employees is headquartered in San Mateo, California, also helps farmers learn how to store carbon in the ground by connecting them with nongovernmental organizations such as the United Nations' World Food Programme, as well as with governments, farming organizations, and large agribusinesses that offer this type of educational outreach. In addition to generating carbon credits, storing carbon in soil also helps farmland to resist erosion and hold onto water and nutrients more effectively. "It's a win for the farmers; it's a win for the planet," Moorthy says.

Idea Germination

The idea that eventually grew into Boomitra struck Moorthy when he took a trip to southern India as an undergraduate at Caltech and encountered the funeral procession of a farmer who had ended his own life. The monsoon rains had not come, and the farmer's crops failed. "That got me thinking about why the farmer struggled so much in the face of changing weather patterns, in particular now with climate change," Moorthy recalls. "I wondered if there was anything that I could do with my skills to make some change there."



Moorthy received his bachelor's degree from Caltech in computer science and materials science with a concentration in computer vision and AI. After graduation, he joined the inaugural class of Knight–Hennessy Scholars, a graduate-level scholarship program at Stanford University that prepares students to become leaders in the development of creative solutions to complex global issues.

"At Caltech, I was mostly looking into sustainability," Moorthy says. "From the materials science side, I was doing research on hydrogen fuels and storing hydrogen." But when he returned to Caltech after his trip to India, Moorthy explored whether a satellite's-eye view could help farmers keep better tabs on the moisture in their soil. He built a smartphone app that allowed farmers to pay for satellite data that could help them measure soil moisture more accurately as a means to improving soil quality. While a few thousand farmers began to use the app, Moorthy felt that the company was not scaling up well enough to make the difference he wanted.

Before leaving Caltech, Moorthy realized that the answer might be to shift the focus from soil moisture to soil carbon—and to flip his business upside down: Instead of asking farmers to pay for insights that would help them improve their soil, he would provide the insights for free. Revenue would instead flow from industrial polluters looking to buy carbon credits. The pivot worked. Boomitra now partners with hundreds of thousands of farmers who capture carbon and track their storage levels through Boomitra's smartphone app.

"I'm very proud of the fact that we won the Earthshot Prize; it's a huge validation of all the things that we are doing on a global scale," Moorthy says, noting the company's farmer partners have removed 10 million tons of carbon from the atmosphere so far, storing it on more than 5 million acres of land. "But to truly move the needle on climate change, we need to add two zeros to the end of each of those numbers. By the end of the decade, Boomitra aims to capture one gigaton of carbon in soil—3 percent of the total amount of carbon humans currently pump into the atmosphere every year." [C]

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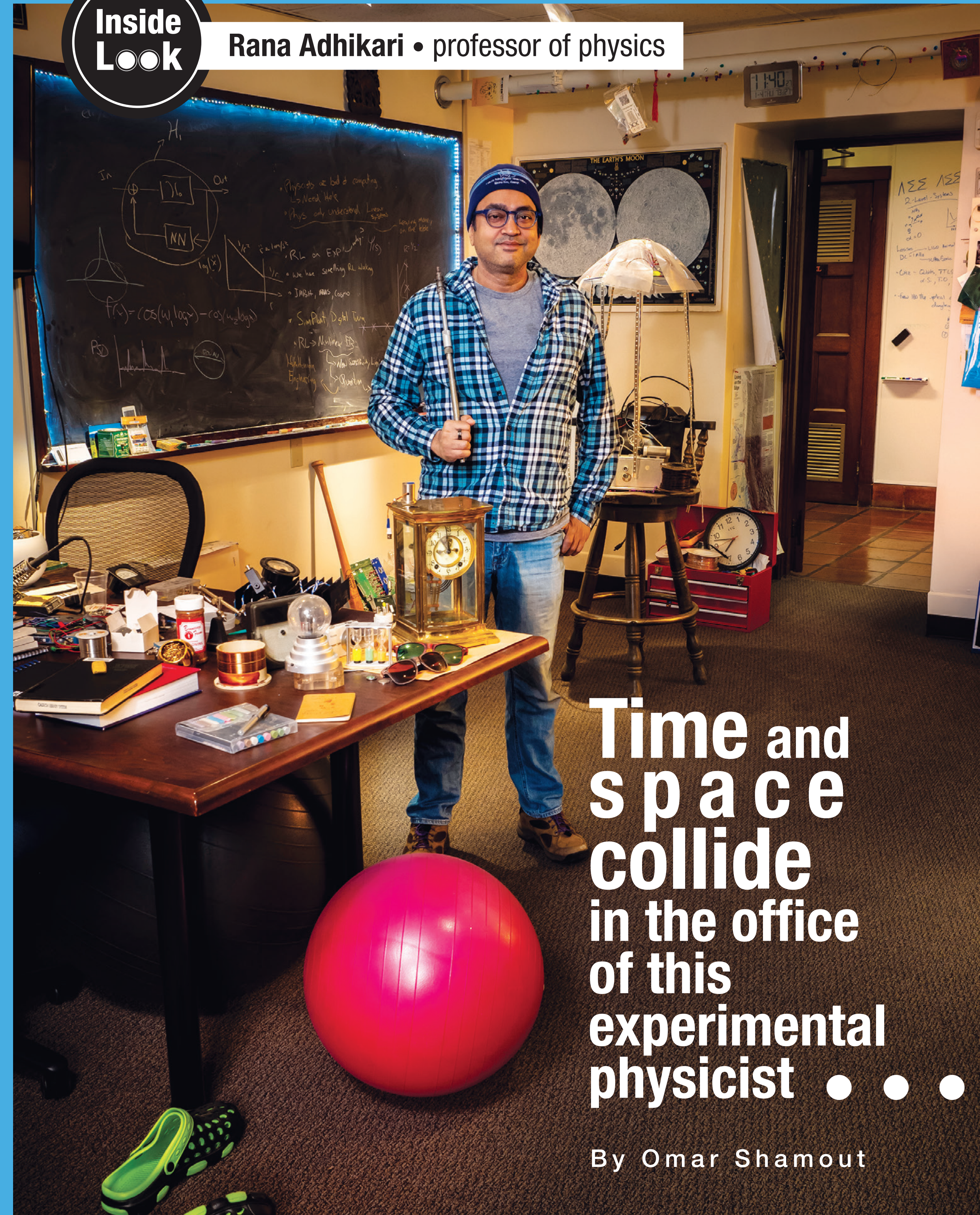
Caltech

Inside Look

Rana Adhikari • professor of physics



Time and space collide in the office of this experimental physicist • • •

By Omar Shamout

Physicist Rana Adhikari was raised in Cape Canaveral, Florida, where his father and many of his friends' parents worked on NASA projects as engineers. When Adhikari grew up, the prospect of following in their footsteps was not an appealing proposition. "It just didn't seem like a cool profession," he recalls.

Still, the Caltech physics professor did not turn his back on engineering. Adhikari arrived at the Institute in 2004 as a postdoctoral scholar working on the Laser Interferometer Gravitational-wave Observatory (LIGO), and he played a key role in optimizing the LIGO detection system, including its mirrors, controls, and lasers, which in 2015 made the first-ever direct observation of gravitational waves. Nearly a decade later, he is still preoccupied with figuring out how to make LIGO's instruments more sensitive. He also wants to solve the mystery of quantum gravity: "Space-time is this fluid, smooth thing that we've all accepted as true. The job of this century is going to be explaining where that comes from and figuring out the real quantum mechanics of space. There's something we haven't found yet."

> "…There's something we haven't found yet."

The decor of Adhikari's office in the Norman Bridge Laboratory of Physics, West, reflects his love of tinkering. Gadgets, some from LIGO and others salvaged from around campus, are strewn around the room. An antique pendulum clock that he found broken in a hallway near his office now sits on his desk. Adhikari, who worked as an auto mechanic after high school, frequently adjusts the gears inside the device to keep it ticking. "It only works when it sits in one exact spot," he notes.

Elsewhere, you can see examples of how Adhikari combines his passion for science with artistic expression. Tucked behind the door is a jellyfish-shaped artwork, which he originally made for an exhibition in Berlin. When activated, the mixed-media creation records a variety of data by sensing the environment around it, including visitors, and then projects different lights based on what it senses. "I wanted to show an early animal and an early AI, and ask, 'What's the difference between people and machines?'" he says.

LIGO may be known best for what it found, but Adhikari says he and other experimental physicists spend far more time "not finding stuff." He compares himself to the Jodie Foster character in the movie *Contact*, who searches the heavens endlessly for signs of alien life. "Most of my life has been about watching this detector give us nothing," he says.

But in a cosmic twist of fate, LIGO made its historic detection at one of the few times Adhikari was not sitting with his headphones on hoping to decipher a signal from colliding black holes over a billion light-years away. "I was on sabbatical," he says. "I just wasn't listening."

Here are some of the objects adorning Adhikari's office:

Los Angeles Dodgers bobbleheads

Adhikari, who became a baseball fan after watching the Red Sox while in graduate school at MIT, has collected these dolls at various Dodgers games during his time at Caltech. In 2008, Adhikari wrote a letter to the club. "I noticed that a bunch of teams were using analytics, or 'Moneyball,' to improve their performance, but the Dodgers weren't," he says. "I offered to do it for them. They never wrote back."

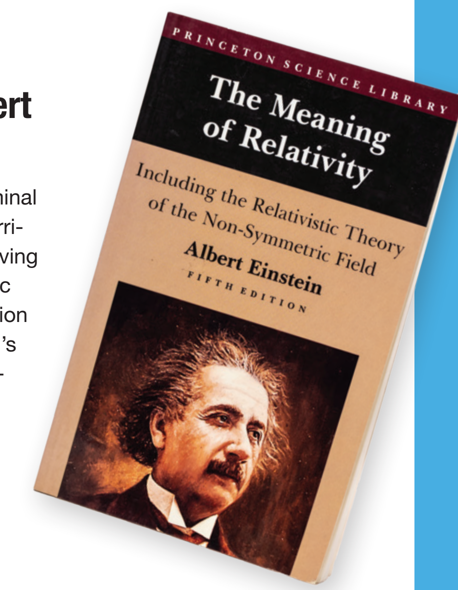
Gravity probe

This probe, which dates back to the early 1980s, was given to Adhikari by the late LIGO co-founder Ronald Drever before he moved back to his native Scotland in 2010. "He left it in his lab with a Post-it that had my name on it," Adhikari recalls. "He knew I would like it." However, Adhikari says he is not sure where the probe came from or if it ever went into orbit. "Like most of these things, it probably didn't detect much of anything," he says. "One of these days, I should open it up to see what's inside."

Rubber toy cars

Adhikari found these mini Datsun replicas in a Caltech meeting room one day and noticed they were the same ones he played with as a child. While talking to a colleague about the cars, he realized the rubber they are made of serves as an efficient shock absorber for experiments. "People have actually tied the cars to the legs of instruments," Adhikari says, adding that the late LIGO co-founder Ronald Drever used them to reduce vibrations in an early LIGO-like prototype.

The Meaning of Relativity by Albert Einstein (1922)



Adhikari first read this seminal book at home during a hurricane in the mid-1990s, having checked it out of the public library next to the gas station where he worked. Einstein's theories piqued his curiosity in physics. "When you read this book, it seems crazy because he says stuff that is obviously not true to our daily experience," Adhikari says. "I showed it to my father and said, 'Do you know about this thing, relativity?' He's like, 'Yeah, but that stuff is hard.' I thought, this is a big scandal if it's true. So far, Einstein is right. But we're still on the same adventure, which is finding that one observation about the universe that does not agree with relativity. That's the holy grail of modern physics."

Cajun seasoning and mask

This Louisiana Cajun seasoning is made and sold by a family member of Adhikari's colleague Danny Sellers at the LIGO Livingston facility. Sellers sent the seasoning as a gift, thinking Adhikari might be missing the bayou. One bottle sits on Adhikari's desk, while another can be found in the second-floor meeting room in West Bridge, where physics faculty, staff, and students often gather for meals. "New Orleans cuisine is the pinnacle," Adhikari says. "Even an average meal there is better than the best anywhere else." The Mardi Gras mask is a souvenir from a trip Adhikari took in 2013.

A New Paradigm *for* Discovery

The **Brinson Exploration Hub** will serve as a proving ground for future space and Earth missions.

By Lori Oliwenstein

To test bold new ideas in space and on Earth, The Brinson Foundation has donated $100 million to Caltech to create The Brinson Exploration Hub. This incubator provides teams of scientists and engineers from Caltech's campus and JPL, which Caltech manages for NASA, with new opportunities to work together to develop novel scientific concepts and instrumentation and deploy them on faster timescales and at lower costs than is possible through conventional means. The overarching goal of the Brinson Hub is to expand our understanding of Earth, the solar system, and beyond.

Brinson Hub projects, formulated by the affiliated researchers, will be selected through a competitive process that seeks to identify new approaches, technologies, and instrumentation that could accelerate the pace of exploration and scientific discovery at a lower cost. Space-based projects might include small satellites and balloons that study the cosmos and the development of technologies to explore phenomena on the Moon and on planets other than Earth. Projects also may be focused closer to home, including efforts such as the robotic exploration of Arctic shelves and other programs to enhance Earth observations, particularly for the purpose of informing and directing response to natural disasters.

These new expeditions and missions will address unresolved scientific problems and may lead to new ways to probe the universe while closing the gap between university research, commercial interests, and national imperatives.

The Brinson Exploration Hub will also provide Caltech undergraduates, graduate students, and postdocs with unprecedented opportunities to participate in space exploration, technology demonstrations, and the engineering and development of instrumentation for small-scale missions. Caltech faculty are also considering ways to augment the undergraduate curriculum to enhance training and preparation of the next generation of space-savvy scientists and engineers.

"The Brinson Exploration Hub will enable a new paradigm that will bridge academia, industry, and government so projects can move expeditiously from ideation and maturation to implementation," says Gary Brinson, founder and chair of The Brinson Foundation.

"The Brinson Foundation's commitment to exploration and discovery will leverage the power of the Caltech campus and JPL in unparalleled ways, for the benefit of science and for all of us fascinated by the mysteries of the cosmos," says Caltech President Thomas F. Rosenbaum.

Through an emphasis on the incubation and implementation of developed concepts, the Brinson Exploration Hub will leverage existing think tanks on campus and at JPL that are focused on early concept development. In addition to working with established Caltech centers and facilities, the Brinson Hub will seek out new relationships with industry partners who could provide additional project ideas, funding, launch services, hardware and software, assembly and test facilities, outside experts, and other forms of support.

"We want to reimagine how we do missions in the future, and this means working with commercial partners to advance the pace and lower the cost of scientific discoveries," says Caltech's Mark Simons, the inaugural director of the Brinson Exploration Hub and the John W. and Herberta M. Miles Professor of Geophysics, who served as JPL chief scientist from 2017 to 2023.

The Brinson Foundation was an early supporter of Caltech's gravitational-wave research, which ultimately contributed to the 2015 observation of gravitational waves; more recently, the foundation has made repeated investments in research related to quantum computing technologies.

"When I imagine the opportunities for new discoveries, advancing innovation, and serving students that will be enabled by the Brinson Hub," says Laurie Leshin (PhD '95), JPL director and Caltech vice president, "I am so grateful for the support of The Brinson Foundation." [C]

Keeping a ‘Big Eye’ on the Universe

Palomar Observatory’s Hale Telescope still delivers discoveries 75 years after its first light.

By Whitney Clavin

In January 1949, renowned astronomer Edwin Hubble rode an elevator at Palomar Observatory up 78 feet to the prime focus cage of the giant, 200-inch Hale Telescope, known during its development as the “Big Eye.” His mission was simple: to capture the machine’s first official picture, known in astronomy as its first light. Begun in 1928 by Caltech cofounder George Ellery Hale, considered one of the greatest telescope builders of all time, the telescope came to life thanks to a $6 million grant (which equates to roughly $106 million today) from the Rockefeller Foundation.

Nearly two decades later, including an arduous 11-year period in which the Hale’s large mirror was ground and polished under fastidiously clean conditions in the Caltech Optical Shop, Hubble slid open a photographic plate holder and exposed the telescope’s first images. Shortly after, he proclaimed to reporters that humanity could at last peer farther into the universe than ever before.

Since then, the Hale Telescope—which was the world’s largest effective optical telescope for more than 40 years—and its sister instruments have collected myriad findings and illuminated details about a host of celestial objects. “I am from a generation that grew up reading about Palomar as this icon,” says Andy Boden, deputy director of Palomar, which is owned by Caltech. “In a quiet moment, I stop and pinch myself because I feel so incredibly lucky to be here.”

Some of the many discoveries made using Palomar telescopes include the first known quasar, identified in 1963 by Caltech astronomer Maarten Schmidt, and the first confirmed brown dwarf, captured in 1994 by former Palomar director Shri Kulkarni, Caltech’s George Ellery Hale Professor of Astronomy and Planetary Science, together with instrument specialist Keith Matthews (BS ’62) and others. Early observations made by Allan Sandage (PhD ’53) of the Carnegie Observatories narrowed in on the age and expansion rate of the universe, validating the scientific legitimacy of observational cosmology. And, in 2005, Mike Brown, Caltech’s Richard and Barbara Rosenberg Professor of Planetary Astronomy, used the 48-inch Samuel Oschin Telescope to discover the dwarf planet Eris, whose similarity in size to Pluto resulted in the infamous demotion of the former ninth planet in our solar system.

The People of Palomar

To prepare the massive Hale Telescope for a night observing the stars, more than 20 Caltech staff members work round the clock to make sure everything is in order. They inspect the instruments being used, chill the equipment with liquid nitrogen, and set the telescope to point in the direction of target stars.

Above left: Edwin Hubble in the prime focus cage of the Hale Telescope in 1950.

When the telescope operators—who align the telescope to the part of the sky an astronomer wants to investigate—start their shift at sunset, they check weather reports and head outside to the catwalk circling the giant white dome. From there, with views stretching out to forests and blue mountains beyond, they assess condensation levels on the dome. If there is too much moisture, they will not open the dome, so as to protect the telescope’s mirror from falling water droplets.

“People call the Hale Telescope the ‘perfect machine,’” says Carolyn Heffner, Palomar’s night operations supervisor. “But it’s really the almost-perfect machine. It takes care and maintenance. Our goal is to provide as much help as possible to ensure that the astronomers can get ‘on sky’ efficiently.” During each shift, the telescope operators work through the night, while Heffner and other support staff work until about 10 p.m.

“We have nicknamed our nightly group the Dark Side because we all love *Star Wars*,” says Diana Roderick, a telescope operator at Palomar who lives in a cottage on the mountain with her husband, Drew Roderick, a grounds and mechanics supervisor. “I love the camaraderie. Everybody pitches in when something needs to get done.”

The Observatory Today

Despite its long history, Palomar remains at the forefront of astronomy. New instruments are continually invented by Caltech astronomers and students and tested on-site. The wildly successful Zwicky Transient Facility (ZTF), a robotic camera installed on the Samuel Oschin Telescope in 2017, has led to many breakthroughs, including the discovery of the first asteroid known to reside entirely inside the orbit of Venus, the first glimpse of a star swallowing a planet, about 10,000 classified supernovae, and more than 100,000 supernovae candidates.

Palomar’s smaller telescopes include Gattini-IR and WINTER (Wide-field INfrared Transient ExploreR), which scan the skies using infrared light to sleuth out objects such as dusty supernovae hidden in optical light. Professor of Astronomy Mansi Kasliwal (PhD ’11), who developed these telescopes with her students, says Palomar is the “best playground for new ideas in astronomy. Even as a grad student, you can do innovative work there.”

The Hale Telescope also serves as the receiving end for NASA’s Deep Space Optical Communications experiment. The mission, run by a team at JPL, which Caltech manages for NASA, is testing a high-bandwidth laser communication system between Earth and the Psyche spacecraft, which launched in October 2023 and is now on its way to a unique metal-rich asteroid, also called Psyche. “Palomar may be old, but it’s a unique place where the old and new come together to advance astronomy,” Heffner says.

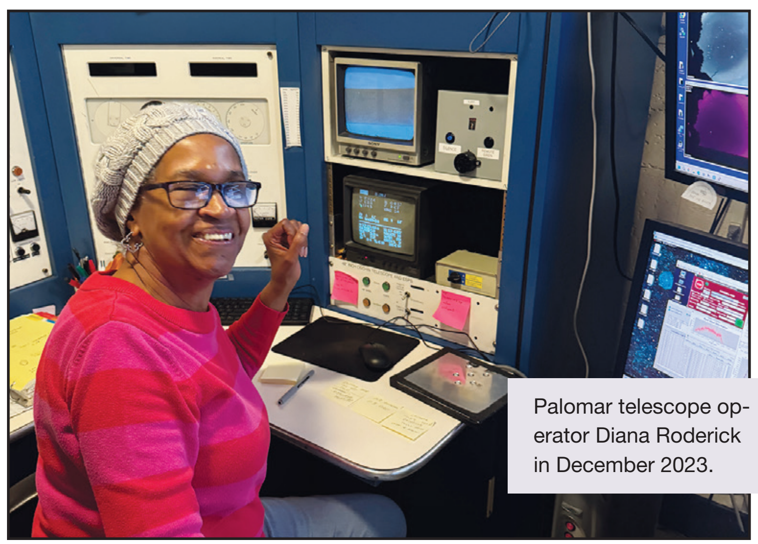
Here are some of the most memorable images captured at Palomar through the years:

Hubble's Variable Nebula

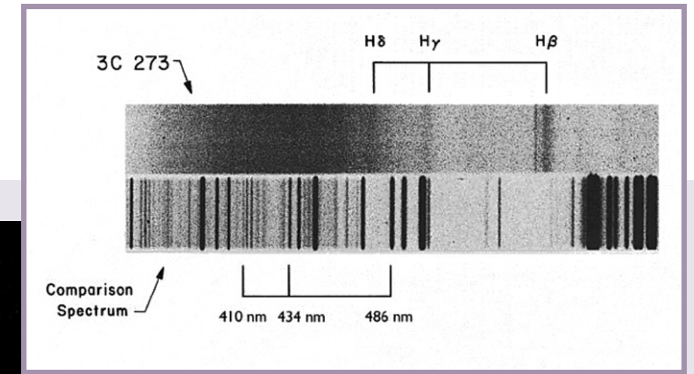
Captured on January 26, 1949, by Edwin Hubble, this is the "first-light" image taken by the Hale Telescope. The billowing fan-shaped cloud the image revealed is now known as Hubble's Variable Nebula, or NGC 2261, and is located 2,500 light-years away in the constellation Monoceros. After taking the image, Hubble announced to reporters that the "200-inch [telescope] opens to exploration a volume of space about eight times greater than that previously accessible for study," according to the book *The Perfect Machine*, a 1994 history of the Palomar Observatory by Ronald Florence. The now-defunct *Collier's* magazine, which secured exclusive rights to the telescope's first images, wrote in its May 7, 1949, issue in an article titled "Behold, the Universe!": "The promise of such vast new information should humble the most arrogant. For, although only astronomers can make these tremendous voyages into space, all of us may gain new spiritual dimensions from what they find."

Dumbbell Nebula

This image of the Dumbbell Nebula (which resides more than 1,200 light-years away in the constellation Vulpecula) was taken by the Hale Telescope in 1961. It is one of the earliest color images of the cosmos. Optical engineer William C. Miller created this image and several others between 1958–65 using a new ultrafast color photographic film known as Super Anscochrome. Miller's photographs, which revealed what could not be seen with human vision alone, made headlines in popular science and news publications in the late 1950s and early '60s. In this image, the outer ejected layers of a dying star glow in dazzling colors. The remaining core of the star, a white dwarf, can be seen as a white dot in the center of the nebula. Also known as Messier 27, the nebula got its common name thanks to its two bright lobes. "This image has extraordinary astrophysical information, showing a rich and complex structure," says Christopher Martin, director of Caltech Optical Observatories and the Edward C. Stone Professor of Physics at Caltech. "It is also one of the first images to show the ineffable beauty of the cosmos. It is both a work of science and a work of art."



Palomar telescope operator Diana Roderick in December 2023.



Quasar

In the early 1960s, Caltech astronomer Maarten Schmidt spent a couple of nights using the Hale Telescope to capture the spectrum of a strange source of radio waves called 3C 273 (the bright blob in the center pictured here). A spectrum breaks light apart into its different wavelengths, revealing signatures of different atoms and molecules. The resulting spectrum's chemical signatures (see inset) remained a mystery until Schmidt ultimately realized that the signatures for hydrogen atoms had been shifted to the red end of the visible spectrum due to the expansion of the universe. That meant 3C 273 was a shocking 3 billion light-years away, yet still incredibly bright in the sky: It turns out that Schmidt had discovered the first-known quasar, distant objects we now understand are ferociously bright and powered by gas falling into supermassive black holes. "With that single finding, Schmidt dramatically expanded the region of the universe that we can explore," says George Djorgovski, professor of astronomy and data science at Caltech.

Orion Nebula

One of the most scrutinized regions of space, the Milky Way galaxy's Orion Nebula is a cauldron of star formation lying 1,500 light-years away in the "sword" of Orion, the famous hunter constellation. The gaseous nebula is bright enough that it can be seen with the naked eye in dark skies. In fact, astronomer Henry Draper took the first image of the nebula in 1880 using only an 11-inch telescope at his observatory in New York. But it wasn't until William C. Miller's 1959 Hale Telescope image that the region's true colors shone through. "Miller's photograph metaphorically opened our eyes to the region's stunning beauty to complement its astrophysical significance," says Andy Boden, Palomar's deputy director.

Ring Nebula and Andromeda Galaxy

In the 1966 *Star Trek* episode "The Naked Time," the starship *USS Enterprise*'s crew becomes infected with an alien virus that causes them to go mad. During one of the episode's frenzied moments, two photos taken at Palomar Observatory can be seen on the ship's bridge. Both pictures, created by William C. Miller, are among the first-ever color images of cosmic objects. On the left in the *Star Trek* photo is the Andromeda Galaxy (2.5 million light-years away), as seen by Palomar's 48-inch Samuel Oschin Telescope in 1958, and on the right is the Ring Nebula (2,000 light-years away), as seen by the 200-inch Hale Telescope also in 1958 (see inset). Because the 48-inch has a much larger field of view than the 200-inch (making it better suited to survey large regions of the sky compared with the Hale's ability to zero in on specific objects), it was able to reveal Andromeda in its entirety like no other telescope had before. "When we look up into night skies and spot the smudge that is Andromeda, that's only its center," says Robert Brucato, Palomar's assistant director from 1982–2003. "The actual diameter of the galaxy stretches across a patch of sky equivalent to a row of six full moons. It is shocking how big the galaxy actually is."

Veil Nebula

The Veil Nebula, a cloud of heated and ionized gas and dust in the constellation Cygnus, can be seen in this image taken during the second Palomar Observatory Sky Survey (POSS II), which operated between 1985–2000 using the 48-inch Samuel Oschin Telescope. The survey served as a fundamental atlas of the sky for many years, leading to the identification of tens of thousands of galaxy clusters, hundreds of supernovae and quasars, and dozens of comets and asteroids. "The Veil Nebula, also known as the Cygnus Loop, is one of the closest supernova remnants to Earth," says Caltech astronomy professor Lynne Hillenbrand. "The ever-expanding emission nebula that we see today will continue to delight amateurs and intrigue professionals, who are still seeking the probable neutron star that was left behind after the explosion."

Palomar electronic technician Greg Van Idsinga in December 2023.

Palomar night operations supervisor Carolyn Heffner in December 2023.

Andromeda Galaxy (ZTF)

Andromeda, our nearest large galactic neighbor, was captured in its full glory by the Zwicky Transient Facility (ZTF) in 2019. ZTF, a robotic camera attached to Palomar's 48-inch Samuel Oschin Telescope, has been scanning the skies every night since 2017 for objects that explode, burst, or otherwise change in brightness. The camera's incredibly large field of view—which is 16 times larger than this image of Andromeda—is the reason it can rapidly scan the skies for such changing, or transient, objects. "You take an image and then come back the next night and compare the two images. The things that change pop out," Kulkarni says. "The sheer volume of data means we need machine learning algorithms to find the objects and classify them. The ultimate goal is to automate the discovery. Once ZTF identifies interesting objects with its wide field of view, we use other telescopes with narrow views to learn more."

Sense of Health

Caltech engineers are developing wearable sensing technologies and materials that could transform the practice of medicine.

By Emily Velasco

Illustrations by Jason Holley

While modern medicine has advanced in ways that would seem miraculous to our ancestors, one key characteristic has remained almost unchanged: The practice of medicine is largely reactive. People book an appointment with their doctor when they feel unwell. They visit urgent care when that nagging pain in their abdomen finally becomes too painful to handle, and they end up in the emergency room when they have trouble breathing.

Studies have shown that preventive medicine—the act of detecting and trying to avert potential health conditions before they begin—vastly improves patient outcomes. Now, several Caltech researchers are working to make preventive medicine more accessible through the development of wearable sensors—small, unobtrusive devices that can provide continuous real-time monitoring of biomarkers related to diabetes, stress, inflammation, heart disease, gout, fertility, and more. The goal: to bring medical care to the patient instead of bringing the patient to the medical care. While a visit to a doctor's office requires an appointment and is just a moment in time, a wearable sensor can monitor the health of a patient as long as it is worn, whether the patient is at home or at work, asleep or awake.

Body parts, clockwise from top: Pituitary gland, female reproductive system, pancreas, toe joint, adrenal glands, heart.

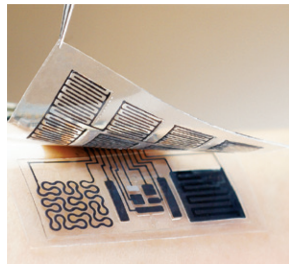
Much of this effort has taken place in the labs of medical engineer Wei Gao, whose sensors detect compounds in sweat that can signify illness; electrical and medical engineer Azita Emami, who uses machine learning and neural networks to detect heart problems; and mechanical engineer Chiara Daraio, who looks to the natural world for inspiration when designing materials with sensing properties.

Sweaty Signals

Gao's noninvasive sensors can be worn almost anywhere on the body and make use of sweat to provide clues about a person's health: If someone's blood sugar is too high, for instance, that can be reflected in their sweat. In addition, when someone experiences stress, their body secretes increased levels of the hormone cortisol, in part through sweat. Also found in perspiration are proteins linked to inflammation, and other biomarkers such as a hormone linked to women's reproductive health, and uric acid, which causes gout.

But because sweat contains lower concentrations of these compounds than are found in blood, Gao and his colleagues have had to invent specialized technologies to detect them. As Gao discussed in his 2023 Watson Lecture, "Wearable Biosensors and the Future of

Personalized Medicine," these new and innovative tools include gold nanoparticles, graphene impregnated with antibodies, and even artificial DNA. Using these technologies, which are precisely tuned to bind to a specific molecule such as cortisol and then generate a small electrical current that can be measured on the skin, the sensors can detect even minute levels of important biomarkers linked to health conditions.



"Wearable sensors give us an opportunity to identify health problems at an early phase, allowing for timely intervention," Gao explains. In addition, he says, "they could play a very important role in monitoring disease treatment. For example, we could monitor therapeutic drug levels in our body."

Machine Learning

Gao's team collaborated with Emami's lab on one of his newer sensors, utilizing her expertise in semiconductor and circuit design to build a chip that can simultaneously measure multiple conditions and biomarkers—a process known as multimodal sensing—and can fit in a compact package measuring only 2 millimeters square. Emami and Gao are also working on sensors that require such a small amount of power they could use the lactic acid found in sweat as a power source, eliminating the need for an external power source such as a battery, or recharging.

Emami and her team have also developed a wearable sensor to detect heart arrhythmias, which are irregular heartbeats that can presage more serious heart conditions. People at risk of arrhythmia are typically sent to a clinic where they undergo an electrocardiogram and have their heartbeat monitored by medical professionals. But since arrhythmias can be unpredictable, they might not occur while the patient is at the clinic. Emami aims to fill this diagnostic gap.

While many people monitor their heartbeat with an Apple Watch or Fitbit, Emami's sensor—which is worn on the chest—does something more complex. In addition to monitoring heart rate, it also detects the heart's electrical activity using a neural network that was trained on a set of heartbeat patterns to look for abnormalities. (Neural networks are AI systems inspired by biological systems such as the brain.)

Left: A sweat sensor developed by Wei Gao's lab. **Below, left to right:** Azita Emami, Chiara Daraio, and Wei Gao, whose labs are developing different types of wearable sensors.

The idea, Emami says, is that doctors could prescribe the sensor for people at high risk for arrhythmia to wear over the course of a week. This interval of time would allow the sensor, which is smaller and consumes less power than current models, to collect data on rare events that might not occur in a clinic, while also alerting the patient to the onset of a dangerous arrhythmia that requires immediate medical attention. "Arrhythmia can happen randomly at different times," Emami says. "If you go to the clinic, everything may look good. Secondly, there are some arrhythmias that are very dangerous, and you immediately have to go to a hospital or an emergency room. This sensor would help to selectively send people either to a clinic or to an ER."

Biomimicry

Daraio has taken another approach to wearable sensors, looking to nature for inspiration. In her 2023 Watson Lecture at Caltech, "Making Wearable Materials Smarter," she discussed how the properties of pectin, a complex sugar found in plants and fruits, led her lab to develop a new polymer that detects changes in temperature and humidity. This polymer, Daraio says, can be woven into fabric that could be fashioned into clothing or directly integrated into wearable sensors that could monitor a person's body temperature for fever, potentially signaling an illness.

Pectin, the molecule responsible for making jams and jellies "set," is so sensitive to temperature changes that a piece of dried mango can be used as a makeshift thermometer, Daraio said in her lecture. She and her colleagues examined the structure and behavior of pectin, particularly its ionic conductivity, to develop the synthetic polymer, which possesses a similar molecular backbone. Yet the polymer represents an improvement on pectin, possessing stronger physical properties and more precise temperature-sensing capabilities. "Pectin as a natural molecule is 300 times more responsive and more accurate than the best temperature sensors available today," Daraio says. "Our synthetic polymer, which is very cost-effective and can be produced in large batches, is even more responsive and more accurate than pectin."

Pectin also tears easily when not dissolved in water. The polymer, however, can be made stretchy and resilient, making it well suited for use in devices that move with the wearer. "Many current wearable sensors are made with rigid electronic components that do not easily interface with soft and conformable fabrics," Daraio says. "However, for all-day wearability,

Wearable Sensors: Looking Ahead

Viviana Gradinaru, the Lois and Victor Troendle Professor of Neuroscience and Biological Engineering, director of the Center for Molecular and Cellular Neuroscience, and the director and Allen V. C. Davis and Lenabelle Davis Leadership Chair of the Richard N. Merkin Institute for Translational Research, discusses the potential role of wearable sensors in preventive medicine.

What is the state of translational research regarding preventive medicine?
For preventive medicine, early diagnosis is critical. Right now, there's a shortage of basic biological understanding of vital health and disease biomarkers, particularly biomarkers that could be accessed easily and frequently. It's difficult to do these kinds of periodic measurements if they're expensive, invasive, or painful, or if they stress you out. Post COVID, there's also been a backlog of access to health care.

Do you believe wearable sensors will play a key part in preventive medicine going forward?
Absolutely. There's a quote that originates with [management consultant] Peter Drucker: "You can't manage what you can't measure." Wearable sensors can play a crucial role because they would allow frequent measurement of factors that can educate healthy humans about what's still to come when changes in course are still possible. There's a lot of talk about lifespan, but wearables could change the conversation from lifespan to "health span." There is absolute value for healthy people to have these frequent measurements, to have a time course and, depending on that time course, to intervene with actionable, helpful behaviors to extend their health span.

What is unique about the wearable sensors being developed at Caltech?
An effective wearable sensor needs to integrate multiple, sometimes complex technologies, and you also need everything to work seamlessly to increase user compliance. Caltech is uniquely good at this type of cross-fertilization due to its small size and pillars of excellence across biology, chemistry, engineering, and data science. And with the Merkin Institute at Caltech, we are excited to connect technology with end users and, as needed, clinicians to inform the best path toward increased health span for all.

sensors should be imperceptible, resilient to washing, and compatible with humid environments because natural fibers like cotton and wool tend to absorb moisture. The new polymers we are developing use changes in ionic conductivity to respond to temperature variations. Such ionic conductors can be integrated in smart threads, for example, that can be embroidered into electronic textiles with new functionalities using conventional manufacturing methods."

The Future

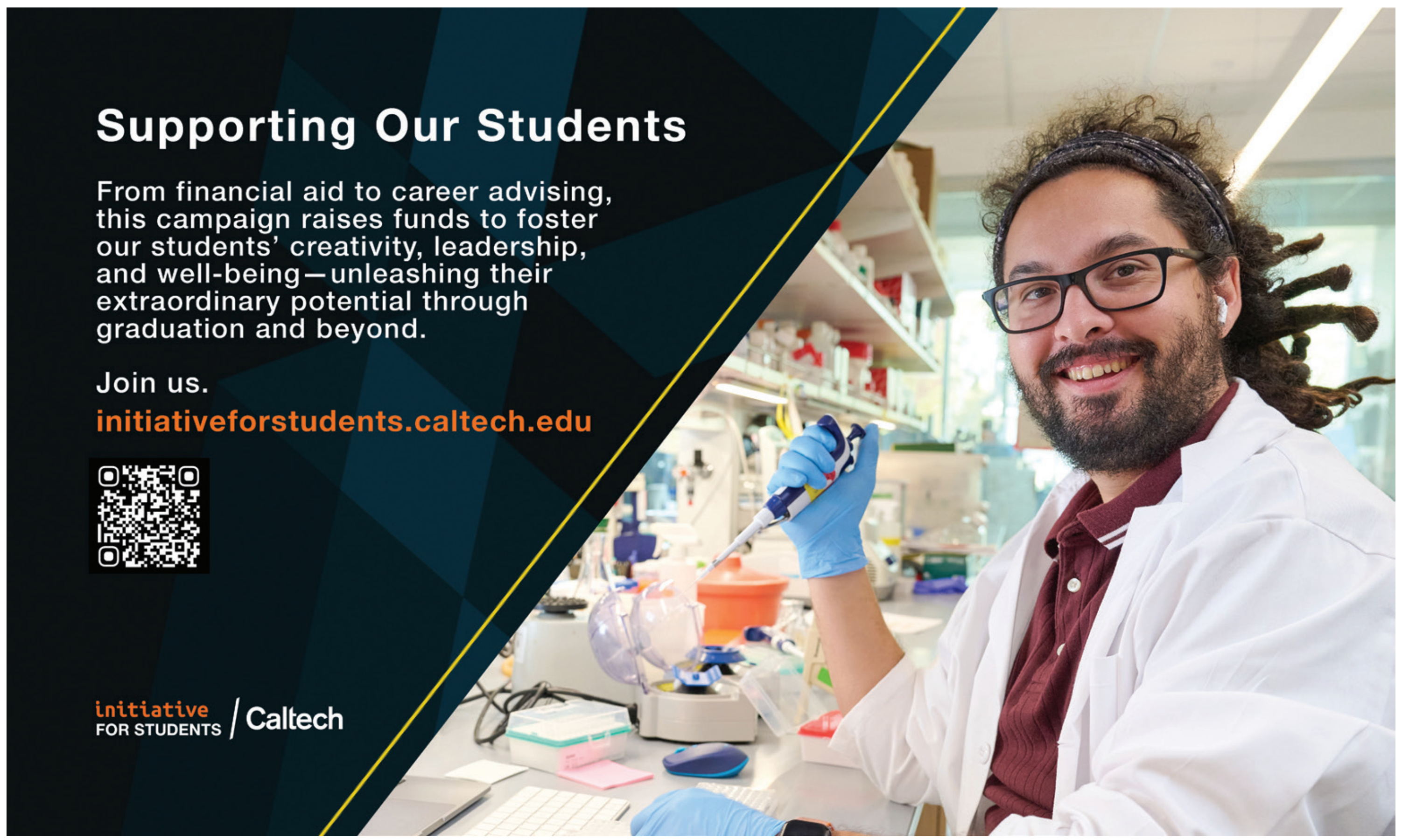
Because the pursuit of wearable sensors benefits from expertise in disciplines such as biology, medical engineering, electrical engineering, computer science, materials engineering, and chemistry, Caltech's focus on interdisciplinary faculty collaboration makes the Institute well suited to be a hub for this kind of research. Though wearable sensors are still relatively new, and their future somewhat unclear, these products may become more commonplace in our lives as computing technology becomes ever smaller, faster, and cheaper, and the novel materials used to make the sensors themselves become more practical and efficient.

"In the future, I think we will have wearable devices that can simultaneously collect a broader range of information from our body," Gao says. "With more comprehensive information, such as physical and chemical information detected with sweat sensors, we could know a lot more about our bodies and our health." [C]

Azita Emami is the Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering; executive officer for electrical engineering; and director of the Center for Sensing to Intelligence, which funds her work along with the Carver Mead New Adventure Fund, Office of Naval Research, and Heritage Medical Research Institute (HMRI).

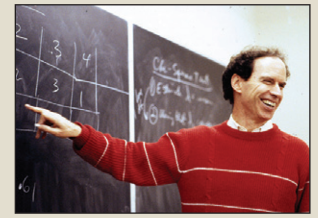
Chiara Daraio is the G. Bradford Jones Professor of Mechanical Engineering and Applied Physics, and a Heritage Medical Research Institute Investigator. She is the Caltech director of the National Science Foundation's IUCRC Center to Stream Healthcare in Place, which funds her work.

Wei Gao is an assistant professor of medical engineering; a Heritage Medical Research Institute Investigator; and a Ronald and JoAnne Willens Scholar. His work is funded in part by the National Institutes of Health, National Science Foundation, Office of Naval Research, and HMRI.



In Memoriam

To learn more about their lives and work, visit **magazine.caltech.edu/post/in-memoriam**.



Gary Lorden
(1941–2023)

Gary A. Lorden (BS '62), a Caltech professor of mathematics, emeritus, passed away on October 25, 2023, at age 82. A statistics researcher, Lorden focused on applications to real-world problems and served as an expert witness in trials. He also worked as a technical advisor to the TV show *NUMB3RS*. Lorden was Caltech's dean of students from 1984–88, vice president for student affairs from 1989–98, and acting vice president for student affairs in 2002. He was also executive officer for mathematics from 2003–06.

Frank Borman (1928–2023)

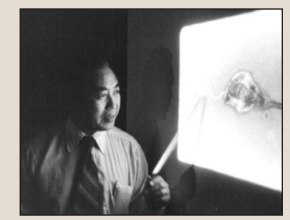
Frank Borman (MS '57), a NASA astronaut who, in 1968, commanded Apollo 8, the first crewed mission to orbit the Moon and return safely to Earth, passed away on November 7, 2023, at age 95. Borman was the first person to be named a distinguished alumnus by GALCIT. A veteran of Gemini 7 and Apollo 8, Borman was a fighter pilot and experimental test pilot in the Air Force, and he served as an assistant professor of thermodynamics and fluid mechanics at the United States Military Academy at West Point. Borman was inducted into the U.S. Astronaut Hall of Fame in 1993.

Fred E. Culick
(1933–2023)

Fred E. Culick, the Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion, Emeritus, passed away on December 11, 2023, at age 90. He joined Caltech as a research fellow in jet propulsion in 1961. Two years later, he joined the faculty as an assistant professor. He was named associate professor in 1966, full professor in 1971, professor of applied physics and jet propulsion in 1978, professor of mechanical engineering and jet propulsion in 1988, and Hayman Professor in 1997. He retired in 2004. Culick's research focused on the dynamics of combustion chambers.

Betty I. Moore
(1928–2023)

Betty I. Moore, co-founder of the Gordon and Betty Moore Foundation and honorary life member of the Caltech community, passed away on December 12, 2023, at age 95. Moore (born Whitaker) became affiliated with Caltech in 1950 after marrying Gordon E. Moore (PhD '54) and moving to Pasadena. (Gordon passed away in 2023.) The Moores, two of the Institute's most significant philanthropists, donated $300 million to Caltech in 2001 alongside a contribution of $300 million from the Gordon and Betty Moore Foundation. The resources supported health and medicine, alternative energy development, information systems, seismology, nanotechnology, and astronomy, among other areas. The Moores also provided two unrestricted gifts during Caltech's *Break Through* campaign: $100 million that the Institute used to match graduate fellowships and $37 million for student scholarships.



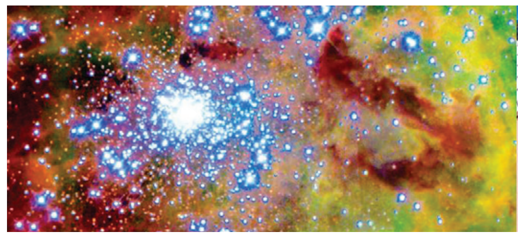
Theodore Y. Wu
(1924–2023)

Theodore Y. Wu (PhD '52), a Caltech professor of engineering science, emeritus, passed away on December 16, 2023, at age 99. Wu was hired as a research fellow at Caltech in 1952 and became an assistant professor of applied mechanics in 1955. He was made full professor in 1961 and retired in 1996. Wu's interdisciplinary research combined aeronautics, mathematics, and fluid physics, covering topics such as the physics of jets and wakes, the energy of ocean currents and wind, ocean waves, the flight of birds and insects, how fish swim, and the locomotion of microorganisms.

Endnotes

On page 23, we introduce a new regular feature called "Inside Look," in which we ask faculty members to tell us about some of the unique items they keep in their office.

What is the most interesting thing you keep in your own office or workspace, and what is the story behind it?



In my first year at Caltech, I bought a red stapler at the Caltech Bookstore. Almost four decades later, I still keep it in use at my office. Years after graduation, when working with Hubble Space Telescope images as an astronomer at the Space Telescope Science Institute, I discovered a nebula and christened it "the stapler nebula" to honor the device it resembled.

Jesús Maíz Apellániz (BS '89)
MAJADAHONDA, SPAIN

A brass-cast bulldog paperweight given to me by my father when I toured his Walworth Valve factory and foundry in high school. I keep it in my workshop as a reminder of his journey from high school to self-taught industrial engineer with no degree. Because he was never able to go to college due to family financial limits, he made sure all five of his kids got to graduate from college.

James Stana (MS '74)
MOUNT DORA, FL

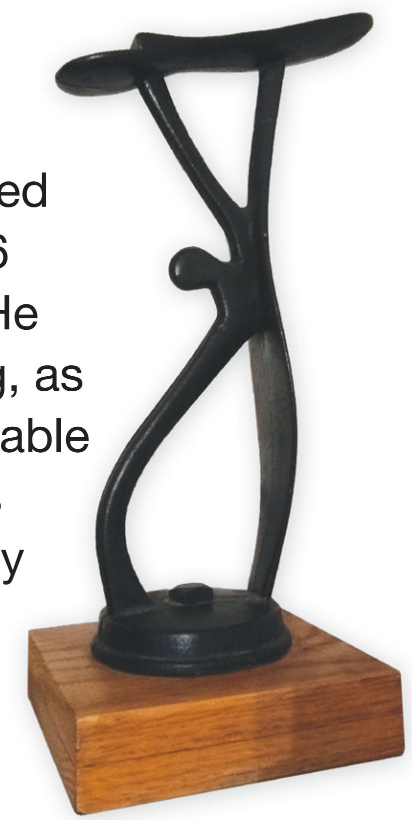
A digital calculator that I built in spring 1972. I had been an electronic hobbyist since junior high school, and when the first Texas Instruments digital calculator chip became available, I bought one, along with eight Monsanto MAN-1 LED 7-segment displays. I also submitted this as a hardware project for the computer design course I was taking.

William Frensley (BS '73)
RICHARDSON, TX

Two envelope-sized acrylic blocks with preserved brain and heart specimens adorn my desk. What drew me in was how simplistically it displays the driver for some of our greatest complexities. It's as though life's secrets are exposed to me every day as I work at my desk!

Tara Gomez-Hampton (PhD '11)
PASADENA, CA

Part of a shoe shiner's stand is in my studio. My great-grandfather, Giuseppe Galante, arrived here from Italy at age 16 and spoke no English. He shined shoes for a living, as that was what was available to him. This stand helps me remain grateful to my ancestors, as their hard work yielded a world of opportunity for me.



Cheryl Forest Morganson (BS '02)
CHAMPAIGN, IL

A braiding of four strands where each interchange is adjacent. It was long conjectured that any number, "n," of strands could be braided in that way. The problem was solved in 1993.

S. Gill Williamson (BS '60)
DEL MAR, CA

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Peruvian Penguin
Julia Tejada, an assistant professor of geobiology at Caltech, explores the past. When she is not hunting for fossils in the Amazon, she pioneers laboratory techniques to study the biochemistry of ancient bones. Tejada's research aims to understand the flora and fauna that populated Earth millions of years ago, on timescales that paleontologists and geologists call "deep time." Here, she is collecting the fossil of a 42-million-year-old penguin found on the coast of Peru. The specimen is covered in a plaster jacket for protection. "That penguin had been buried under very rare conditions, with no oxygen and thus no microbial degradation, enabling it to be so intact," she says.