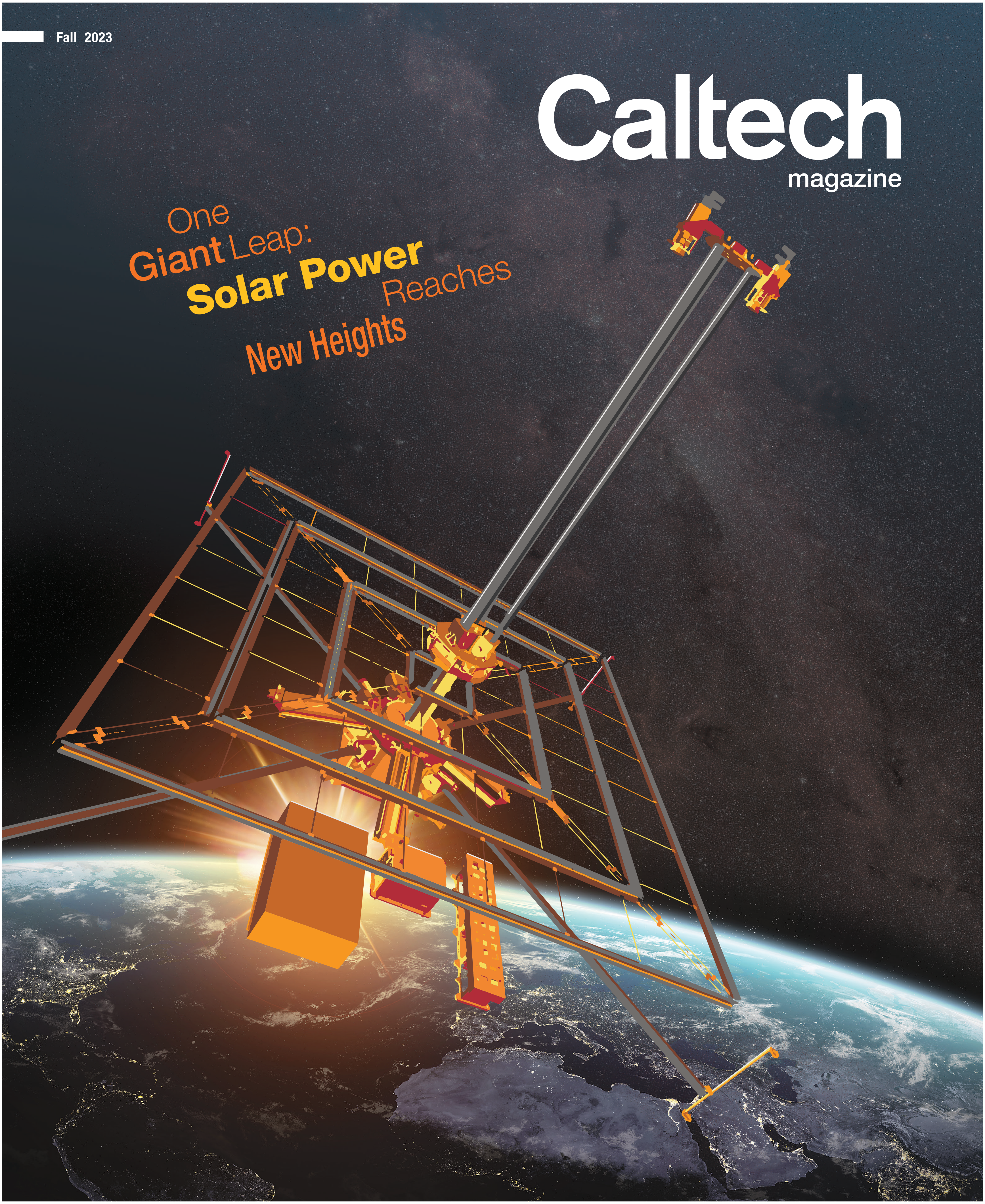
Fall 2023
Caltech
magazine
One Giant Leap: Solar Power Reaches New Heights

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The Professor of Musical Comedy

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EDITOR IN CHIEF
Lori Oliwenstein

SENIOR EDITOR
Omar Shamout

ART DIRECTOR
Jenny K. Somerville

MANAGING EDITOR
Sharon Kaplan

ONLINE EDITOR AND
SOCIAL MEDIA COORDINATOR
Andrew Moseman

CONTRIBUTING WRITERS
Elise Cutts, Lori Dajose, Chris Daley, Julia Ehlert, Andrew Moseman, Katie Neith, Omar Shamout, Ker Than, Emily Velasco

DESIGNER
Jenny K. Somerville

ONLINE DESIGNER
Sergio Solorzano

ILLUSTRATION, PHOTOGRAPHY, VIDEOGRAPHY
Lance Hayashida, Peter Holderness, Jon Nalick, Eric Nyquist, Sergio Solorzano, Jenny K. Somerville

COPY EDITORS
Sharon Kaplan, Carolyn Waldron

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

Weilai Yu (PhD '21) took this photo from the roof of the Beckman Institute in 2018.

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Letters

Trailblazer

The Spring 2023 issue warmed my heart and prompted me to write. Here's why: I was awarded a Caltech MS in environmental engineering science in 1972. I was one of the first students in this breakthrough program. Now I'm 74, living in Sequim, Washington, and retired from a 38-year career as a California attorney. Why the switch to law? Because Caltech and I were trailblazers and too early for start-ups, a much less mature job market. So, I switched to law school at USC.

But because of my Caltech degree, I had the opportunity to work on the professional staff of the National Materials Policy Commission and as a script advisor to Dirk Summers, the producer of a film financed by the United Nations titled *Survival of Spaceship Earth*, which is still viewable on YouTube. So, I was amazed to see and read the "Sea Change" and "Out of Thin Air" articles! Way to go, Caltech!

—Nelson (Nick) Brestoff (MS '72)
SEQUIM, WA

Water Log

The article by Ker Than in the spring issue of *Caltech* magazine about Professor Bethany Ehlmann's Lunar Trailblazer experiment to characterize water in lunar polar regions prompts me to tell a story regarding an early failed attempt by my JPL-Caltech lunar sample investigation group to detect, through nuclear magnetic resonance spectroscopy, water greater than the 0.0001 percent weight level in the Apollo samples. This failure led some of us to carry out detailed analyses of the very strong lunar ferromagnetic electron spin resonance (ESR) signals in all our lunar samples. Upon working out the theory for this ferromagnetism, we found we could measure the lunar sample Fe and Ni contents. Additionally, we could detect and

measure the paramagnetic $MN(H_2O)_6^{2+}$, which was suggestive of water contents of 20–140 parts per million in all our lunar samples.

The significance of our ESR results caused the Lunar Receiving Lab folks to immediately acquire ESR instruments and look for ESR-trained staff. The goal became to record the ESR profile of every lunar sample. My two collaborators in the ESR work were JPL–Caltech NASA research fellow Fun-Dow Tsay and Caltech professor Sunney Chan [George Grant Hoag Professor of Biophysical Chemistry, Emeritus]. I can only hope that Professor Ehlmann and Lunar Trailblazer are successful.

Stanley Manatt (BS '55, PhD '59)
LA CAÑADA FLINTRIDGE, CA

On the "Origins"

Your story on the LGP-30 brought back memories. Besides the one found in Germany, I bet there is one in a basement somewhere at Caltech. At least one was there, already obsolete, when I was an undergrad, and anyone with permission from Carver Mead [BS '56, MS '57, PhD '60, Gordon and Betty Moore Professor of Engineering and Applied Science, Emeritus] could use it. My physics lab partner Alan Hindmarsh [BS '64] and I wrote machine language code (no Fortran yet!) to run on it to calculate results from a physics lab experiment. If I remember right, we ended up doing the calculations the regular way, with our slide rules, because getting data in and out of the teletype was too clumsy.

I learned a lot about designing efficient code that was useful throughout my career when I wrote code for protein crystallography and then neuronal network simulations. Every instruction in the LGP-30 had a memory address field that specified where on the memory drum to read the next instruction. So, if you knew how long different operations took and the rotational speed of the drum, you could place your instructions, and sometimes your data, where they would come around on the drum to the read head just when needed. Maybe a little like planning where data will end up on memory cache lines in today's machines.

George Reeke (BS '64)
NEW YORK, NY

Your story on the LGP-30 brought back fond memories. In the fall of 1959, as a junior majoring in math, I took EE 180, Digital Computer Design. As part of the course, we studied the complete logical structure of that computer, showing the details of how each instruction was executed. We even put the system into tiny infinite programming loops, each executing just a single instruction, so we could view the electrical activity on an oscilloscope to monitor the execution. My project was to write a Monte Carlo method to integrate a function that could be submitted as a subroutine. That was pretty heady stuff back in those days! But it was good enough to get me a summer job in 1961 on the CPU design team at JPL for the first general purpose computer to be taken on a spacecraft: the Mars Mariner B, later the Mariner 3 and 4.

Dick Norman (BS '61)
GREENBRAE, CA

I enjoyed the article "Origins" about the LGP-30. We learned about it in a computer course and got to work with it a little. The developer, Stanley Frankel, went on to develop the electronic calculator at a company called Electrosolids.

Bruce Wilkinson (BS '58)
ESCONDIDO, CA

Members of Ali Hajimiri's lab prepare to detect a signal from the Microwave Array for Power-transfer Low-orbit Experiment (MAPLE) on the roof of the Gordon and Betty Moore Laboratory of Engineering. See story on **page 14**.

SoCaltech

- A monument for a mascot
- A birthday for BBE
- Winging it around campus; and more

Fun with Fungi

Aelin Hunt (BS ’23) served as Dabney House president—and its unofficial painter—before they graduated last summer. They fell in love with making murals during their first year at Caltech after taking a class with drawing, painting, and silkscreen art director Jim Barry. Hunt, who graduated with a degree in materials science and chemistry in June 2023, explains the peace they found while adorning several walls in Dabney House, and why it is so fun to paint mushrooms.

“I learned to do watercolors and then a little bit of acrylic painting. Over the next couple of years, I had the chance to do more acrylic painting. Then, when I became president of Dabney House, I had the chance to approve murals. The fun part is getting into the flow of a few hours of painting and listening to music. It’s a good time, and it was therapeutic also. Coming back from COVID, we had just returned to the house, and the mural policy was being revamped. Being able to paint something on the wall was, I don’t know, sort of poetic. ...

“I like mycology, and I think mushrooms look cool. I spent most of my summers in Maine in the woods where there is quite the variety of mushrooms, and I was also a summer camp counselor teaching campers how to survive in the woods. A lot of the counselors knew things about mushrooms and could identify them, so I picked things up along the way. I’ve done a lot of mushroom art. I painted this over winter break in 2022–23. It’s a pretty tall stairwell, and it was quite challenging to get a ladder to fit into it properly. I had to build a small platform so that I could balance the ladder between the stairs and the platform, and then stand carefully on the ladder to paint the top. It was a pretty involved project but one that I found to be a fun challenge.”

Three Questions for:

Richard Thai

Richard Thai joined the Caltech Archives and Special Collections team in March 2023 as the Institute's first digital archivist. Thai came to Caltech from Cal State Northridge, and he previously held archivist positions at the LA84 Foundation and the Natural History Museum of Los Angeles County. Here, he explains what his job at the Institute entails.

1. What does a digital archivist do?

The role of a digital archivist can vary from institution to institution. At Caltech, I am working primarily with "born-digital" materials. As you can guess, those are materials that were created on a computer and not digitalized from a physical counterpart. So, instead of preserving letters and newspapers, I am preserving emails and websites. More importantly, I am developing the policies and workflows for preserving digital content and making it accessible.

2. What led you to a career as an archivist?

I like organizing stuff; I have a fondness for history, and I enjoy helping people. I thought I wanted to pursue a career in museums, but the only department that had an opening was the history department. They had a western U.S. history collection that needed processing, and the archivist needed help. Like many archivists, getting a taste of working in an archive was what sent me on my archives journey. I did not set out to be a digital archivist but, with things becoming increasingly digital, it is where the exciting new developments in the field are happening.

3. What about the field do you find challenging, and what excites you?

Digital archiving is a relatively young field, so we do not have a deep history of professional practice to fall back upon. Many of my digital archivist colleagues have told me that they are learning on the job. At the same time, we are not held back by decades-old professional dogma, and there are a lot of opportunities to be a pioneer in the field. It is daunting but also a very exciting time.

Koji Arai, a senior scientist at Caltech's Laser Interferometer Gravitational-wave Observatory (LIGO), loves hamburgers. He also loves math. So, in the grand Caltech tradition of cross-disciplinary research, Arai decided to investigate whether the basic shapes of a hamburger could be described by a single mathematical function. As it turns out, they can, and Arai has dubbed his delectable creation the "Burger Function." Arai, who likes to paint watercolor portraits of burgers, explained that his wife challenged him to draw a burger in a CAD (Computer Aided Design) program, which he uses to design mechanical parts for LIGO. Arai thought that was too easy a task, so he opted instead to devise a single "grand unified" function for burgers in which each of the seven layers of the burger—the two buns, onion, tomato, cheese, patty, and lettuce—are essentially spheres that get squeezed in different ways by changing the parameters of the function. "Seeing a burger expressed in math is like tapping into its pure essence," he says. "For a physicist like me, this is very satisfying."

Join us at the 2023–24 Watson Lectures and hear from scientists and engineers on the forefront of discovery and invention, who are tackling society's most pressing challenges. Lectures begin at 7:30 p.m. in Beckman Auditorium, and are free and open to the public. Arrive early to purchase food and beverages, and to enjoy music and other activities. Here are the remaining Watson Lectures in 2023:

November 8: Richard Andersen

James G. Boswell Professor of Neuroscience; T&C Chen Brain-Machine Interface Center Leadership Chair; Director, T&C Chen Brain-Machine Interface Center

Learn about neural prosthetics to help paralyzed people.

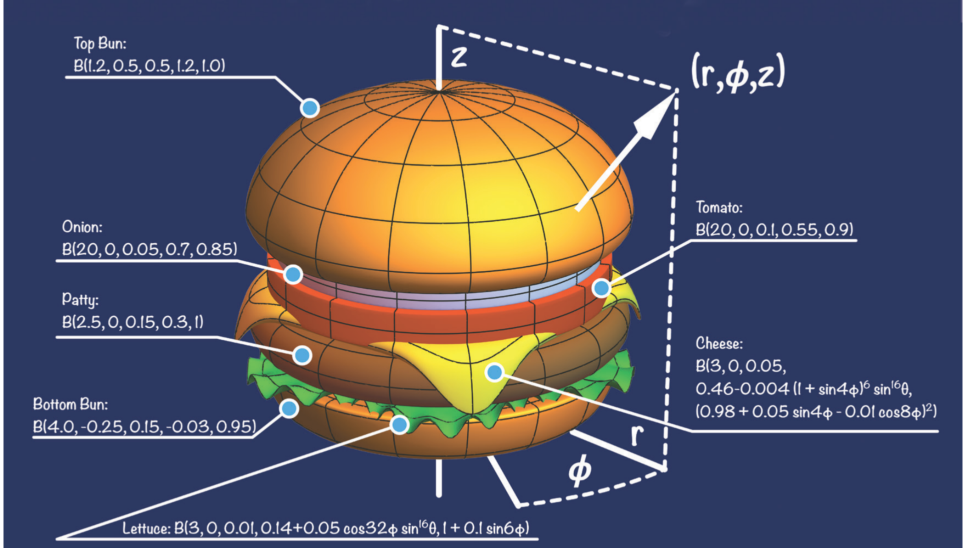
December 13: Wei Gao

Assistant Professor of Medical Engineering; Investigator, Heritage Medical Research Institute; Ronald and JoAnne Willens Scholar

Learn about wearable sweat sensors that more accurately monitor health.

Visit **Events.Caltech.edu/Watson** for the full schedule and to register. Watch previous lectures on Caltech's YouTube channel:

BURGER BY NUMBERS



$$\textbf{Burger Function} : B(a, b, w, v, r_0)$$

$$= \left(r_0 \sin\theta,\ \phi,\ v + \frac{2w}{\sqrt{\pi}} \int_0^{a(\cos\theta - b)} e^{-t^2} \mathrm{d}t \right)$$

$$(0 \leq \theta \leq \pi)$$

The Many Moods of Bernoulli

The new face of Caltech Athletics is fierce, industrious, and quite loveable. Bernoulli was revealed as the new name of Caltech's beaver mascot in May 2023 following a poll conducted by the Caltech Student-Athlete Advisory Committee in which more than 700 votes were cast. Bernoulli was the most popular name among over 100 nominated. Sculptor Walter Horak crafted the beaver statue, which was unveiled outside Braun Athletic Center just before the polling began. The Institute first adopted the beaver as its mascot on October 21, 1921.

Betsy Mitchell, director of athletics, physical education and recreation, said at the naming event that the sculpture connotes "the reality of our sports teams—strong, persistent, smart, and loyal to each other." Since its unveiling, members of the community have left good luck charms for Caltech's sports teams in the statue's arms and at its (webbed) feet. The athletics department also adorns Bernoulli in festive gear for holidays and other special occasions throughout the year.

10 YEARS *of* BBE

This year marks a decade since the Division of Biology voted to incorporate the growing discipline of bioengineering and to change its name to the Division of Biology and Biological Engineering (BBE).

The transformation combined the division's traditional academic concentrations—genetics, biochemistry, developmental biology, immunobiology, microbiology, molecular biology, and neurobiology—with its newly established strengths in the fields of bioengineering, genomics, synthetic biology, and computational biology.

As a result of this reorganization, the number of faculty members in the division grew considerably, with 10 joint appointments awarded to researchers in other divisions whose work had a bioengineering focus. "Modern research in biology is increasingly intertwined with technological advances," says Richard Murray (BS '85), the William K. Bowes Jr. Leadership Chair of BBE. "Those technological advances in turn allow the possibility of providing new solutions to societal problems, ranging from human health, to sustainability, to new materials and devices."

Thomas Henning (third-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.***

Thomas Henning is a graduate student in social and decision neuroscience whose research focuses on neuroforecasting (the practice of using neurophysiology to predict population-wide behaviors from small groups of people), and on understanding how humans interact with AI agents. He is also the co-president of the Black Scientists and Engineers of Caltech (BSEC). In his free time, Henning enjoys video games, political discussions, film, and the NBA.

"I majored in business during undergrad, then I worked as a trader at Goldman Sachs for two years. During my tenure on Wall Street, I found myself spending all my free time on academic Twitter, browsing research papers, and thinking about various fundamental questions related to decision-making. I heard of this field called neuroeconomics where I could learn about human behavior and how it impacts the economic world from a basic science perspective. While working as a trader, I started working on research at night and on the weekends remotely with Professor Gregory Russell Samanez-Larkin at Duke after connecting on Twitter. Then I recognized that I liked research a lot more than my job. So, I applied to Caltech, and I've been here ever since.

My research focus now is a field called neuroforecasting, which is, basically, adding neural-imaging data to a focus group. Say a musician has multiple versions of a song, and you bring in a focus group of 30 people to ask their opinion. You're trying to predict which is going be the biggest hit. Neuroforecasting researchers have found that if you conduct this focus group while recording each subject's neuronal activity in a functional MRI or electroencephalogram, you can predict how well that song is going to perform on Spotify better than asking the subjects themselves what they like the most."

For more #SoCaltech, go to **tinyurl.com/MagSoCaltech**

Flocking Together

Five bird-watchers paused on Wilson Avenue, binoculars trained on a bright yellow goldfinch. The group's leader, a man with a handlebar mustache and NASA baseball cap, earnestly marked the find on his checklist.

Alan Cummings (PhD '73), a senior research scientist in the Space Radiation Laboratory at Caltech who celebrated 50 years of service at the Institute earlier this year, is one of the founders of Caltech's bird-watching group, which has been going on weekly walks since 1986. "We've done over 1,700 walks now," says Cummings, who has developed experiments, analyzed data, and managed projects for various space missions, including NASA's long-running Voyager program, throughout his career.

On Tuesdays around noon, the group convenes to trek across campus and look for birds. Cummings diligently tracks each walk's data, noting walk attendees and how many acorn woodpeckers and red-whiskered bulbuls are spotted, among other avian varieties.

"Each walk is about 2 miles, so it's not for everybody," he says. "I can quite understand when people come and then they leave after a few walks. But once you start going, it's hard to stop. You've got a huge amount of data that you've collected, and you just feel obligated to keep it going. It's almost like Voyager."

Object Lesson:
Exquisite Corpse Totem Sculpture

This sculpture, titled *Scale vs. Size: The Exquisite Corpse*, was built by Caltech students in winter 2022 for a visual culture course called Relative to You: Representing Scale in Art and Science, taught by former Caltech visiting professor and artist-in-residence Lia Halloran. Students used accumulated knowledge from their academic disciplines to address the challenges of each project and create pieces that were meaningful to them. For this assignment, Halloran had students create a 3D-printed piece roughly 10-inches-by-10-inches in size that represented something either very big or very small. The pieces were then assembled into a single totem sculpture according to the "exquisite corpse" model, in which each person does not know what the others are creating until they all connect the parts as a group. "The project prompt was open-ended enough for students to think about the difference of scale versus size within their disciplines," Halloran says. "It was exciting when the students brought in their components and worked together to determine the placement order and how the piece worked together visually."

Dungeons, Dragons—and Chemistry?

In the far-flung town of Terensby, seven adventurers were summoned to solve a mystery. Locks had been stolen, streetlamps smashed, and shovels, crowbars, and weapons taken—but no money was missing.

Skyler Ware, a chemistry graduate student at Caltech, set this scene for the Dungeons and Dragons (D&D) players she had invited to join her at Odyssey Games Pasadena. For the next four hours, the group tracked down the culprits: monsters that were corroding the town's iron into rust and eating it. The mystery—and the game module itself—were designed by Ware to share science knowledge through D&D, a fantasy tabletop role-playing game.

Ware's unusual approach to science outreach was inspired by the STEM Ambassador Program (STEMAP), a public engagement training program funded by the National Science Foundation (NSF). Ware completed a 10-week course with STEMAP as a requirement of NSF's Center for Synthetic Organic Electrochemistry, which funds her research. During the course, she developed her first engagement project: a D&D game incorporating elements of her research on battery science in the lab of Kimberly See, assistant professor of chemistry at Caltech.

"The STEM Ambassador Program has this focus on doing outreach in places where we don't typically think about doing outreach," Ware says. "A lot of folks think of doing outreach in schools, libraries, museums, science festivals, and that's all very important. But there are people who don't go to those spaces, who can't go to those spaces."

STEMAP encourages open-minded exchange and dialogue between scientists and members of the public rather than one-way communication. Ambassadors engage communities they are members of, and with which they have shared interests, experiences, or identities. Ware says she focused her outreach on the D&D community because she had organized games for several years and knew her friends were curious about her research. In her first project, she created a D&D game in which players had to figure out how to charge their battery-powered teleporters during the adventure. Afterward, Ware handed out a sheet that described the "anatomy of a battery" and the chemistry that makes it work.

Graduate student Skyler Ware, standing back center, leads players through a science-inspired Dungeons and Dragons quest.

Her second outreach game encouraged players to think about chemistry through rust and iron while solving a mystery and tracking down monsters. After the game, she gave each player a handout that described the chemical reaction that creates rust and speculated how a monster could use electricity to corrode iron.

"This is one of the more unique D&D adventures I've been on; it was very cool," said one of the players, Victoria Bian, who teaches English as a second language.

Dennis Lui, a K–12 educator who also participated in the game, said the role-playing experience lends itself naturally to scientific principles. "You're doing a lot of investigation using logic and using all the tools at your disposal like lightning, the elements, and acid," he said. "You can try to imagine the effect of what you're using in the real world."

In addition to their newfound chemistry knowledge, the participants said they valued the connections, fun, and inspiration that came out of the experience. "To people who didn't have science long ago, the things that we do in the real world now are like magic," Lui said. "So in a lot of ways, it's fun to explore both magic and science in D&D."

—Julia Ehlert

Origins

Department of Medical Engineering

Ten years ago, Caltech became the first institution in the country to launch a department with the name "medical engineering." On its 10th anniversary, the department has become a leader in the development of micro/nano medical technologies and devices, medical nanoelectronics, biomedical materials and biomechanics, fluidics and bioinspired design, and medical imaging and sensing. Here, some of the department's influential faculty members talk about how it began, and where it is going.

Ares Rosakis, chair of the Division of Engineering and Applied Science (EAS) from 2009 to 2015 and the Theodore von Kármán Professor of Aeronautics and Mechanical Engineering, *on introducing academic departments in place of teaching options:* "The things that were in my mind when I became chair had to do with making the division nimbler and more capable of responding to emerging interdisciplinary opportunities while addressing urgent societal needs. So, I introduced a well-defined departmental structure allowing us to increase the internal and external visibility of EAS and to focus our fundraising activities. The effectiveness of this approach became evident with the creation of the new medical engineering department."

YC Tai, the Anna L. Rosen Professor of Electrical Engineering and Medical Engineering, *in an oral history with the Caltech Heritage Project:* "There were many faculty who thought their research could expand into medicine. We started the effort to start a department, including a preparation to present this idea to the faculty board. That was in 2013."

Tai, *on the voting to create the department:* "During the faculty board meeting … unanimously, they voted yes, not a single abstain or no vote."

Rosakis, *on the significance of the achievement:* "It was the first department ever created in the country carrying the name 'medical engineering.' We chose this name intentionally to highlight EAS's many connections to medicine and medical technology. I believe that this name choice has excited prospective students, faculty, and donors."

Andrew and Peggy Cherng, co-founders and co-CEOs of Panda Restaurant Group Inc., *on why they chose to fund the department in 2017:* "Supporting efforts to help medical professionals diagnose and treat patients in more efficient ways was the perfect way to make a difference in our local community and around the world. We felt this department at Caltech was uniquely positioned to succeed in this endeavor due to the strength of its faculty and its willingness to support forward-thinking and interdisciplinary research."

Tai, *on the effect of the $30 million gift to name and endow the Andrew and Peggy Cherng Department of Medical Engineering at Caltech:* "Because of the Cherngs' endowment, which we decided to spend mostly on graduate students, we're creating opportunities for the smartest students to come to Caltech and work out the research they want to do. We don't lock them into something even before they come."

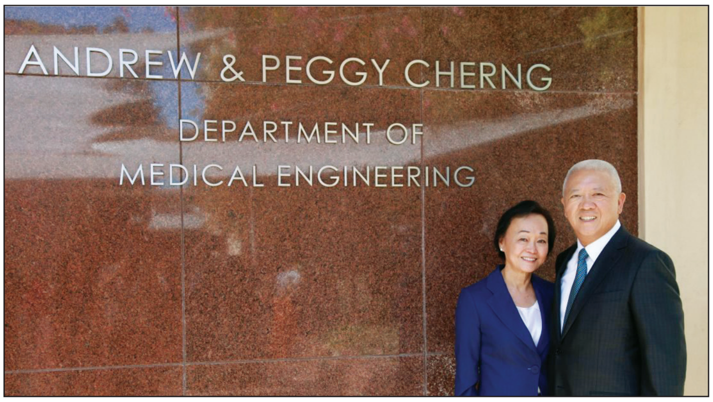
Tai, *on recruiting faculty to the department:* "It was suggested we should look at Professor Lihong Wang [who was then] at Washington University in St. Louis. … He realized the first in vivo or functional photoacoustic tomography machine. … He's really strong."

Rosakis, *on recruiting Wang in 2016:* "I was on vacation in Scotland speaking to him over the phone continually. Eventually, we got him."

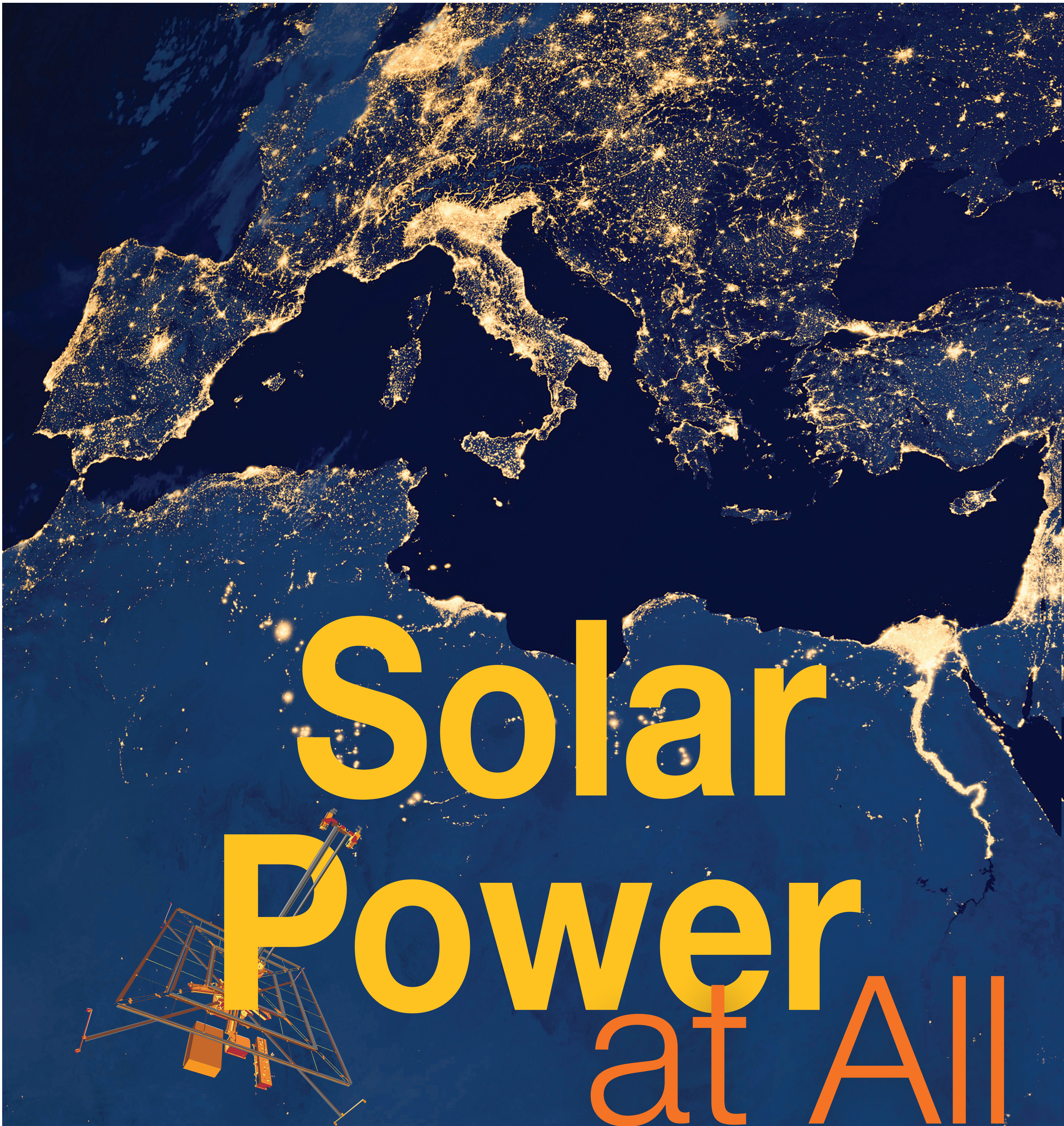
Lihong Wang, the Bren Professor of **Medical and Electrical Engineering, who became the Andrew and Peggy Cherng Leadership Chair of the Department of Medical Engineering:** "Dr. Tai has laid the foundation for the department to grow. In 2014, we started with four students. Right now, we recruit around nine per year. In 2012, we inaugurated with 10 faculty members. Now, we've got 20 outstanding members. Our department has created about 20 startups. That's a lot."

Wang, *on the future:* "People are the most important factor when you want to do first-rate research, and Caltech provides an outstanding research environment. The core of our department is applying engineering to solve medical problems, and we have no shortage of expertise in terms of engineering. There are a lot of opportunities for collaboration. ... Harry Atwater [Otis Booth Leadership Chair, EAS] puts it nicely: Caltech engineering works at the leading edges of fundamental science to invent the technologies of the future. We want to be a step ahead of everybody else."

—Omar Shamout



Peggy (left), and Andrew Cherng, who endowed the Cherng Department of Medical Enginnering in 2017.



Solar Power at All

Hours

By Ker Than

Caltech researchers hope to **harness the sun's energy** and **power the planet** from **300 miles above.**

On a cool, clear evening in May 2023, Caltech electrical engineer Ali Hajimiri and four members of his lab gathered on the roof of the Gordon and Betty Moore Laboratory of Engineering to await a signal from the heavens.

In preparation, the researchers had strewn portable floodlights across the floor and erected a collapsible canopy in a corner of the roof to shelter instruments and monitors stacked atop a small folding table. Two antennae perched nearby on heavy-duty tripods, their electronic gazes steadily tracking an invisible target drifting more than 300 miles overhead. The signal—if it came—would arrive in the form of a weak microwave beam transmitted from the Space Solar Power Demonstrator (SSPD-1), a 110-pound set of Caltech payloads that had launched into space five months earlier aboard a SpaceX rocket on the Momentus Vigoride-5 spacecraft. SSPD-1 is the first spaceborne prototype from Caltech's Space Solar Power Project (SSPP).

The source of the evening's anticipated signal was the Microwave Array for Power-transfer Low-orbit Experiment (MAPLE), a series of flexible lightweight microwave power transmitters built in Hajimiri's lab that make up one of SSPD-1's three main experiments. Hajimiri, an SSPP co-director and principal investigator, and others have estimated that space-based harvesters founded on the technology demonstrated by MAPLE could one day provide access to eight times as much solar energy on average as their terrestrial counterparts.

"This is a system able to provide stable power over time," adds aerospace engineer Sergio Pellegrino, an SSPP co-director and principal investigator, whose lab worked on SSPD-1's ultralight deployable structure. "There is potential for a breakthrough in the provision of clean renewable energy."

That harvested energy could then be dispatched to any place on Earth, including areas devastated by war or natural disaster, or regions with poor energy infrastructure, explains nanophotonic and solar-energy expert Harry Atwater, who is also one of SSPP's principal investigators. "You could imagine in places like that, where you want to bring power to a large city, you could immediately do that without building a large power grid," Atwater says. "The thing that's really transformative about space solar power is that, unlike solar power on Earth, it has potential to eliminate the need for storage. You get power continuously, 24 hours a day, and you don't have to come up with day-to-night storage, like in the form of batteries, or season-to-season storage."

The May rooftop experiment was long planned but had to be rapidly executed on short notice. The Caltech engineers had just three hours to haul their equipment to the roof, having received the green light from Momentus to conduct their experiment only that evening. "It wasn't like we had everything set up, and we were just sitting around waiting," recalls Raha Riazati, an undergraduate researcher in Hajimiri's lab who designed the receiving antennae for the test. "It was definitely a mad rush, and I remember being very stressed and thinking, 'I really hope we can get everything ready in time, because if we don't, this will be a wasted opportunity.' It was pretty nerve-racking."

Around 10 p.m., the team paused its various activities to huddle around a single monitor. From where they were on the rooftop, there was only a seven-minute window in which the signal could be detected, and the countdown had begun. "In the beginning, we weren't seeing the signal," Hajimiri recalls.

A minute passed. Then a few more. Before the team's apprehension could turn into alarm, a digital peak heralding the signal appeared on-screen. The growing spike carried the precise power level and frequency shift the team had predicted based on the beam's travel from orbit. "It took a few seconds for it to sink in that, yes, this is happening," Hajimiri notes. MAPLE's demonstration marked the first time that power was transmitted and received in space, directed toward Earth, and then detected, according to Hajimiri. "The level of energy, of course, is very small at this point," he says. "This was mostly about detection, but it is a first step."

Despite lasting only 90 seconds, the microwave signal detection at Caltech on May 22 marked a major milestone toward realizing a century-long dream to harvest solar energy in space and beam it wirelessly down to Earth. The experiments on SSPD-1 are designed to test key technologies that could enable Caltech's unique take on this vision, which involves deploying a fleet of nimble, modular spacecraft, each equipped with a flexible ultralight membrane that can function as both solar panel and energy transmitter. Like a starling murmuration, the spacecraft will come together as a "flock" to create enormous floating power stations above Earth, but each spacecraft will also be able to operate independently.

In addition to MAPLE, SSPD-1 has two other main experiments: Deployable on-Orbit ultraLight Composite Experiment (DOLCE), a structure designed and built in Pellegrino's lab that measures 6 feet by 6 feet and that will test the architecture, packaging scheme, and deployment mechanisms of the spacecraft; and ALBA (Italian for "dawn"), a collection of 32 different types of photovoltaic (PV) cells, some built in Atwater's lab and at other Caltech labs, and some sourced from other researchers around the world. Atwater's team is conducting tests to determine which of these cells operate best in the punishing environment of space.

In total, about 35 faculty members, postdocs, graduate students, and undergrads at Caltech worked on the SSPD-1 project.

With the May test successfully concluded, Hajimiri's team erupted in cheers and high-fived one another before beginning the laborious task of dismantling the equipment and clearing off the roof. It was only later when she was back in her room that Riazati could reflect on the night's achievement. "That was when it clicked in my head that this project I'd been working on for over a year and a half had finally worked, and that we'd gotten this groundbreaking result," she says. "I was like, 'Wow, that was pretty awesome.'"

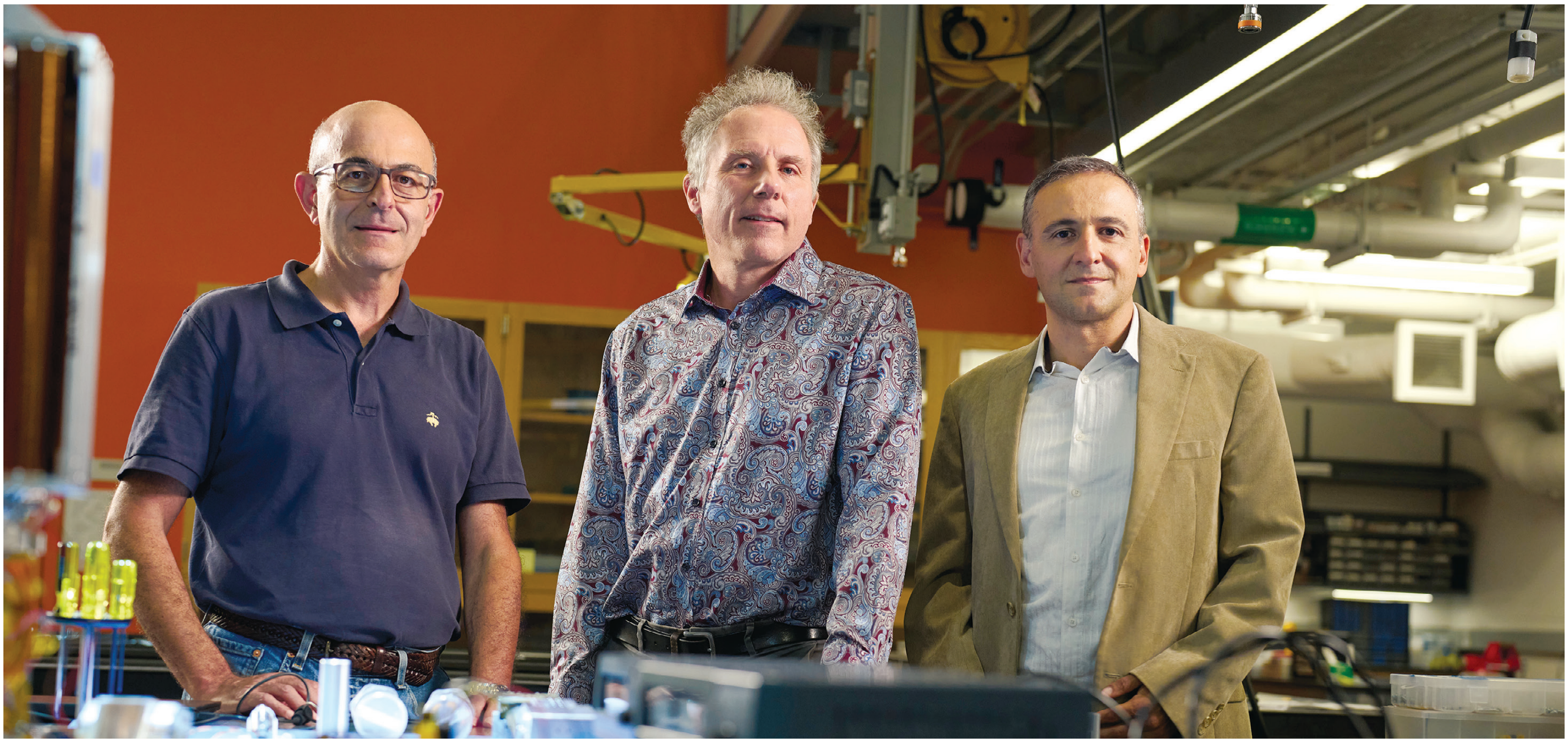
Space-based solar power may also one day power rovers on the Moon or Mars.

A Long Journey

The idea of space-based solar power dates back to as early as 1923 when Russian theorist Konstantin Tsiolkovsky proposed using mirrors in space to concentrate a strong beam of sunlight down to Earth. Years later, the science-fiction writer Isaac Asimov, in his 1941 short story "Reason," imagined solar-powered satellites beaming energy in the form of invisible microwaves to Earth and human settlements across the solar system. Learning of this for the first time, Asimov's robot character asks, "Do you expect me to believe any such complicated, implausible hypothesis as you have just outlined? What do you take me for?"

The first patent for a microwave-based method of transmitting power from orbit was granted in 1973 to NASA engineer Peter Glaser, who also outlined the engineering concepts for his proposal in an influential 1968 *Science* article titled "Power from the Sun: Its Future." Glaser's ambitious plan called for massive satellites equipped with solar-panel arrays capable of harvesting sunlight in space, converting the sunlight into energy, and then beaming that energy wirelessly toward 5-mile-wide receiving antennae on Earth. "It is an incredibly complex piece of infrastructure. It needed to be giant to make sense," Pellegrino says.

Glaser also articulated the rationale for harvesting solar energy in space: high above the atmosphere where the sun never sets, sunlight can be collected around the clock, irrespective of clouds, weather, or nightfall. This prospect so intrigued the U.S. government that it spent $20 million to investigate the technology (inspired by the shift toward reducing dependence on fossil fuel due to the oil crisis of



Left to right: Sergio Pellegrino, Harry Atwater, and Ali Hajimiri, the principal investigators of the Space Solar Power Project.

the 1970s), only to deem it too complex and expensive a few years later. But thanks to recent advances in photovoltaics, materials engineering, and electronics, combined with decreasing launch costs and urgent calls for more clean energy sources, space-based solar power is enjoying a new moment in the sun.

The European Space Agency recently approved two concept studies of a European space-solar network as part of its SOLARIS initiative, which aims to establish the technical, political, and programmatic viability of space-based solar power. The China Academy of Space Technology plans to launch its own power-beaming satellite prototype by 2028, and the U.S. Naval Research Laboratory recently tested technology to convert sunlight into microwaves in space, although it did not actually transmit that energy anywhere. India, Japan, and the United Kingdom have also expressed interest in developing their own technologies.

Of these global efforts, Caltech's is arguably the furthest along: SSPD-1 is the first space-based solar power demonstrator to reach orbit and demonstrate wireless energy transfer in space. "Demonstration of wireless power transfer in space using lightweight structures is an important step toward space solar power and broad access to it globally," Atwater says.

The Caltech Concept

The Caltech effort began after philanthropist Donald Bren, chairman of Irvine Company and a life member of the Caltech community, first learned about the potential for space-based solar energy manufacturing as a young man after reading an article in *Popular Science* magazine. Intrigued by the potential for space solar power, Bren approached Caltech's then-president Jean-Lou Chameau in 2011 to discuss the creation of a space-based solar power research project. In the years to follow, Bren and his wife, Brigitte Bren, a Caltech trustee, agreed to make a series of donations (which ultimately amounted to a total commitment of $100 million) through the Donald Bren Foundation to fund the project and endowed professorships.

"The hard work and dedication of the brilliant scientists at Caltech have advanced our dream of providing the world with abundant, reliable, and affordable power for the benefit of all humankind," Donald Bren says.

In addition to the support received from the Brens, Northrop Grumman Corporation also provided Caltech $12.5 million between 2014 and 2017 through a sponsored research agreement that aided the development of technology and advancement of science for the project.

Bren charged Caltech with making solar power feasible and—equally as important—economically viable. The Institute responded by asking Hajimiri, Pellegrino, and Atwater's teams to invent the necessary new technologies, materials, and manufacturing processes. "You could characterize our work at Caltech as a component-led

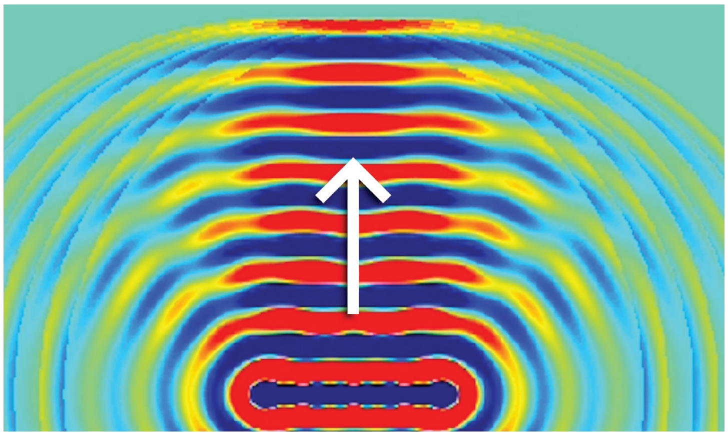
Fact:
Modern terrestrial solar panels are about 20 percent efficient at converting sunlight into energy. Space solar panels are about 30 percent efficient.

revolution," Atwater says. "In the solar-energy-technology part of SSPP, we need to achieve a kind of photovoltaic technology that does not exist today that is ultralight, efficient, low cost, and resistant to radiation."

The Brens approached Hajimiri due to his work in electronics and photonics that laid the groundwork for 5G communications and radar sensors in cars. But at first Hajimiri had reservations. "The way that space solar power had been envisioned previously, it was not practical at all," Hajimiri remembers.

Atwater had a similar initial reaction. "It took me a long time to overcome my own skepticism," he recalls. "But it's one of those things: you start thinking about how you might do it, and it really gnaws at you, and you can't let go of it."

The more Atwater, Hajimiri, and Pellegrino began chewing on the problem together, the more realistic it began to seem. "It became clear that we needed to replace the basic components that other people had imagined being part of the system," Atwater says. "If you change the components, suddenly you can have a much higher power-to-weight ratio, and that reduces the mass to orbit and, therefore, the launch cost."



Space Solar Power Project transmitters are designed to direct power toward Earth using the physical phenomenon of interference.

The trio eventually came up with a design plan now known as the Caltech Concept, which is radically different from the one Glaser outlined decades earlier. "The Caltech Concept is not a giant monolithic object. It is a collection of spacecraft—many, many, many spacecraft—that are all identical," Pellegrino explains. "They're synchronized, and they provide energy to Earth."

As initially envisioned, each spacecraft will carry a square-shaped membrane measuring roughly 200 feet on each side. The membrane is made up of hundreds or thousands of smaller units, called tiles, which have PV cells embedded on one side and a microwave transmitter on the other. The tiles are arranged into long strips suspended between four telescoping booms that provide structure and tension for the membrane. The strips are folded and coiled for launch and unfurl once the spacecraft reaches orbit. Each spacecraft would operate and maneuver in space on its own but also possess the ability to hover in formation and configure an orbiting power station spanning several kilometers with the potential to produce about 1.5 gigawatts of continuous power.

Since each power station would consist of individual spacecraft operating collectively, there would be no need for complex wiring and a heavy central antenna. "This is a paradigm shift," Hajimiri says. "The analogy I use is going from one big elephant to an army of ants."

Ali Hajimiri's team is developing algorithms that will allow a spacecraft to determine the current configuration of its transmitting-antenna flexible-array elements and make real-time corrections to them.

Ants Versus Elephant

The ability of each tile to transmit energy wirelessly through space is based on a physical phenomenon called interference, which arises due to the wave-like nature of light. To understand interference, Hajimiri says, imagine sitting at the edge of a pond and putting both of your hands in the water and moving them up and down. Each hand makes a wave, but because of how the waves and their energy interact, some waves will be bigger and others will be smaller. Like big waves in water, synchronized light waves overlap, their peaks meet and create a greater peak; this is called constructive interference.

"If you have multiple sources that are operating in concert, in the same phase, you can actually direct energy in one direction so all of them will only add in one direction and will cancel each other out in all other directions," Hajimiri explained in a recent video that accompanied an announcement of SSPD-1's launch. "The same way that a magnifying glass can focus light into a small point, you can actually control the timing of this in such a way that you can focus all of that energy in a smaller area than the area that you started with."

The upshot of being able to control direction by manipulating timing is that no moving mechanical parts are required, and energy can be redirected in mere nanoseconds to a receiver in space or on the ground. "It's as if you have an army of ants that are working in perfect synchronization, and each one of them contributes a little bit of energy, but as a whole they send it to the right place," Hajimiri said in the video.

Engineering "Backward"

If the Caltech Concept is ever to be realized, everything about current PV-cell technology will need to be rethought and vastly improved, Atwater says. The PV cells used in space to power satellites and the International Space Station are about 32 percent efficient at converting sunlight to energy. They weigh about 2.1 kilograms per square meter and have a power-to-weight ratio, or specific power, of 200 watts per kilogram. They cost about $10,000 per square meter to manufacture.

SSPP aims to develop a PV cell with an efficiency level of 25 percent that is 100 times less expensive ($100 per square meter), 40 times lighter (0.05 kilograms per square meter), and with a specific power 33 times greater (6.6 kilowatts per kilogram) than current space PV cells.

Another way to think about it: An SSPP spacecraft with a 60-meter-by-60-meter surface area made using today's space PV-cell technology would cost $36 million and weigh nearly 9,000 pounds, or almost as much as a Ford F-450 truck. With the ultra-lightweight PV-cell technology Atwater envisions, it would cost just $450,000 and weigh about 300 pounds, or about as much as an IKEA three-seat sofa.

To achieve these lofty goals, Atwater's team is investigating novel manufacturing techniques and exotic materials for the creation of its PV cells. "We're inverting the normal methodology that you use to make solar panels," Atwater says. "What we said was, 'We have to make this very cheap, so we're going to start with the economic analysis that says it has to cost $100 a square meter. Then we're going to design the cell-manufacturing process, and out of that we're going to make the cell.' It's completely backward."

Atwater's team is using a simple method called spalling to create highly efficient PV cells made from gallium arsenide and indium phosphide. Spalling involves peeling a layer of ceramic material from a bulk crystal to create a film layer that is thinner than the thinnest piece of plastic found in your home. Crucially, spalling doesn't require a vacuum environment, and the PV cells can be baked in a furnace comparable to a consumer oven. "We're using the same kind of processing that we teach Caltech first-year students," Atwater says. "It's very inexpensive."

The ALBA tests, which began in June, have so far shown that gallium arsenide cells perform well in space even though they do not have a protective coating. "It's a point of validation that these low-cost cells we made with processing that you can do in your kitchen will work in space, and they work nicely," Atwater says.

The two other solar-cell technologies being tested by ALBA include PV cells made from thin-film perovskite, and semiconductors known as quantum dots that utilize nanotechnology and quantum mechanics to convert sunlight to energy. In total, 32 PV-cell samples, each made using a variation of one of these three technologies, make up ALBA's science payload. "We're testing their current voltage characteristics and how they perform as a function of temperature," Atwater explains. "This is the first time these kinds of PV cells have ever been tested in space."

Delivery and Deployment

The third SSPD-1 experiment, DOLCE, demonstrates the packaging and deployment mechanism for the flexible membranes populated with PV and radio-frequency components that, although not included in DOLCE, will be required in a complete space-based solar-power spacecraft. The first stage in the deployment occurred in May 2023, and the process was completed in September.

Pellegrino's team has developed a novel method called slip wrapping that packages large membranes tightly and efficiently by first dividing them into precise strips that are compactly folded into a star shape and then carefully wrapped around a central axis to form a tight cylindrical package. DOLCE is the first engineering-scale demonstration of the slip-wrapping technique in space.

The edges of the membranes aboard SSPD-1 are reinforced with deployable "longerons" that are the result of extensive research in Pellegrino's lab. They consist of two tape-measure-like sections of ultrathin composite material made of glass and carbon fiber that are bonded together on one side. The longerons' curved cross section is thin walled and provides high bending stiffness, which allows the longerons to store energy during packaging; this "strain energy" is then used to self-deploy the structure in space.

When combined, the longerons and the slip-wrapping technique allow each membrane strip to be tightly stowed in a cylindrical mechanism. Deployment occurs in two steps: first, the folded strips with the membrane uncoil from a central spool into a star shape, and then the star unfolds into a flat structure. The uncoiling step is controlled by a motor, whereas the unfolding process is driven by the stored strain energy of the longerons.

"We discovered that this is a highly repeatable process, very robust," Pellegrino says. "In fact, we've never broken any of the structures we built by folding and unfolding them, but it took much study to develop the technique for packaging, and even more study to acquire the courage to let the structure deploy by itself."

Photovoltaic cells were invented by Bell Laboratories in 1954 to power the first U.S. satellites.

Looking back, Hajimiri acknowledges it has been a long journey to get to this point, and there is still much ground—and space—left to cover. "Movies often portray a direct path to success. The real path to success has a lot of meandering and a lot of dead ends. But people don't talk about that. There are a lot of things that can go wrong. The key is to learn from each of them and take the next step." [C]

Harry Atwater is the Otis Booth Leadership Chair of the Division of Engineering and Applied Science; Howard Hughes Professor of Applied Physics and Materials Science; director of the Liquid Sunlight Alliance; and a principal investigator of the SSPP.

Ali Hajimiri is the Bren Professor of Electrical Engineering and Medical Engineering, and a co-director and a principal investigator of the SSPP.

Sergio Pellegrino is the Joyce and Kent Kresa Professor of Aerospace and Civil Engineering and a senior research scientist at JPL, which Caltech manages for NASA. He is also a co-director and a principal investigator of the SSPP.

Mars, Texas:

My Year in Simulated Space

Alumnus Ross Brockwell is living on the Red Planet—in Houston.

By Elise Cutts (BS ’19)

In June, structural engineer Ross Brockwell (MS ’01) stepped into a 1,700-square-foot, 3D-printed complex at the Johnson Space Center in Houston to start a yearlong mission for NASA. Since the doors swung closed behind him, he has been physically cut off from his friends and family and bombarded with stressful tasks, and has eaten a copious amount of freeze-dried astronaut food. He could not wait to do it.

The space agency tapped Brockwell, who earned his Caltech master’s degree in aeronautics, to serve as flight engineer for the first of three planned Crew Health and Performance Exploration Analog (CHAPEA) missions. Along with three crewmates, he will ultimately spend a year inside the Mars Dune Alpha habitat coping with challenges like equipment failures and resource shortages as the team tries to accomplish its mission. All the while, NASA scientists are monitoring the crew’s mental and physical health to learn how to keep astronauts healthy and performing to the best of their ability during future long-term missions to Mars.

At Mars Dune Alpha, Brockwell is effectively on another planet. His messages to the outside world are even slowed by a simulated communications delay. We reached Brockwell before he headed to Houston to ask about the mission selection process, his role as flight engineer, and what was on his mind as he prepared for a year on “Mars.”

What made you think, *I want to do this?*

I’ve always been interested in the space program and the Mars mission in particular, and I got into structural engineering thinking I might be able to design space stations, habitats, orbiters, rockets, and things like that. That’s why I was so interested in going to Caltech, and why I got into city planning and infrastructure. I’ve always thought that community design will be a part of the space program someday.

What was the selection process like?

There was a medical exam, and then I went to Houston for a week or so. There were psychological evaluations and various exams, tests, and interviews. They presented us with a few mission-realistic tasks both individually and as a group, which was super cool. I mean, it was at the Johnson Space Center in Houston!

There was also a virtual reality component to this, so we got to try that out. We also took part in this expedition over the mountains in Wyoming for almost two weeks as a small group with an expedition leader and a psychologist from NASA. We did a little adventure up in the backcountry. It was amazing.

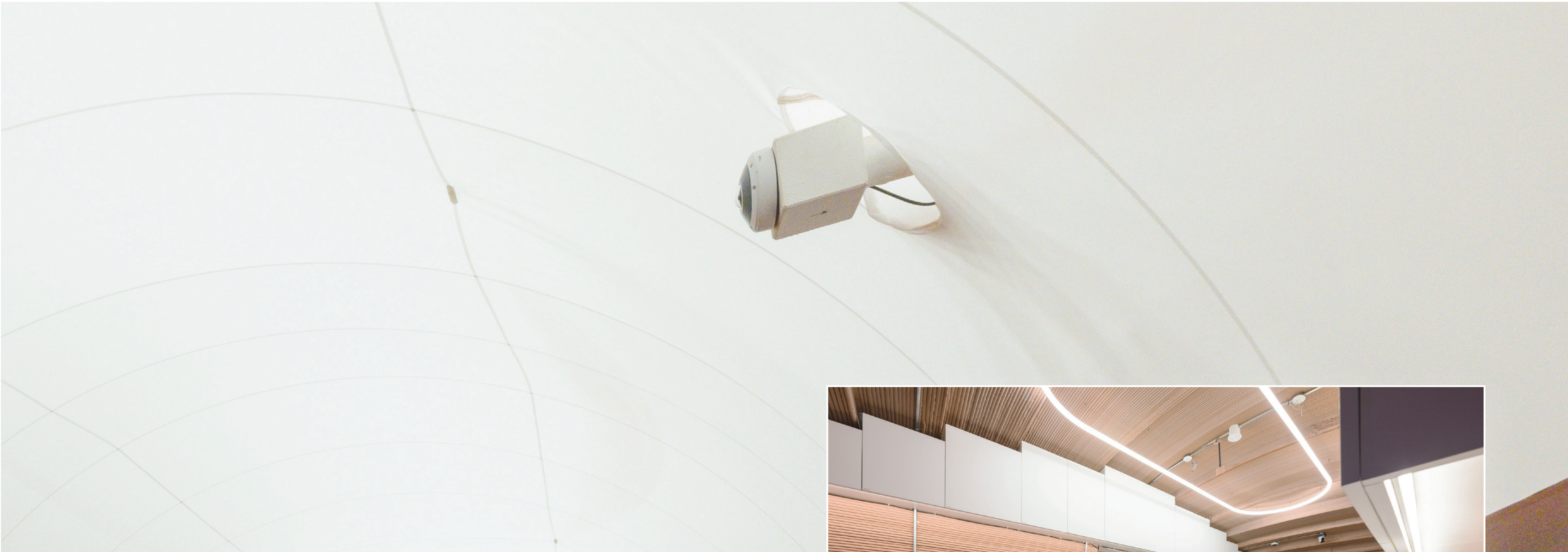
What do your responsibilities entail, and how do they differ from what you are used to as a structural engineer?

Maintenance of the structure and its systems are things that I’ll probably be expected to take the lead on. Some of the problem-solving aspects are universal, and some of the management parts are, too. But I can imagine there’ll be something related to solar panels—that wouldn’t be a surprise. It’s obviously going to be a big part of a real mission. I don’t do that in my day-to-day, but it’s something I’ve always been interested in.

Did anything about your experience at Caltech help prepare you for this mission?

The whole experience at Caltech is incredible for someone interested in this line of work. I got to tour JPL [which Caltech manages for NASA] a couple of times and did a few things in the lab that were directly relevant. I saw facilities where they tested tiles for the space shuttle, and I did research on shock loading of metal plates, which is relevant to space missions.

It was also really fascinating to connect theory to practice. You learn that some theory applies to fluids and solids and microbes and all sorts of things—patterns that



emerge that math can trace. Sometimes you are faced with a problem that is an unfathomable mystery at first glance, and you somehow manage to break it down and come up with a solution that works on the other side. I hope I can tap some of that on this mission. I can't say enough how appreciative I am for my experience at Caltech. I hope I can do them proud.

Are you going to miss anything specific from the outside world during the mission?

I'll miss fresh seafood, for sure! I was actually just talking about that the other day. I can literally walk down the street in Virginia Beach, where I live, and have some of the best seafood you can get.

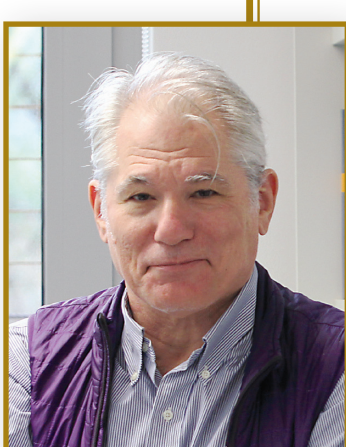
As the start date approaches, what has been on your mind the most?

I would hope that this mission could help spread some excitement and build some appreciation for the value of the space program in general. There's been some debate over it. To me, it's so obviously important and useful and beneficial to mankind. I hope that starting to talk about the exploration of the Moon and Mars will help society keep things in perspective and foster a healthy discussion about the value of these unified projects and exploration efforts. There's sometimes a discussion like it's Earth versus Mars, and I really hope we can bridge that gap to where the desire to reach out into space and explore Mars only adds to the appreciation and understanding of the value of our home planet. It's not either/or. [C]

Top: The Mars Dune Alpha habitat's kitchen and lounge area. **Middle:** A crop-growing station. **Bottom:** Private living quarters.

Undergraduate members of Caltech's LATTICE (Lunar Architecture for Tree Traversal in-service-of Cable Exploration) Team demonstrate a deployable robotic zipline they developed to shuttle materials across the jagged surface of the Moon.

The 2023 Distinguished Alumni



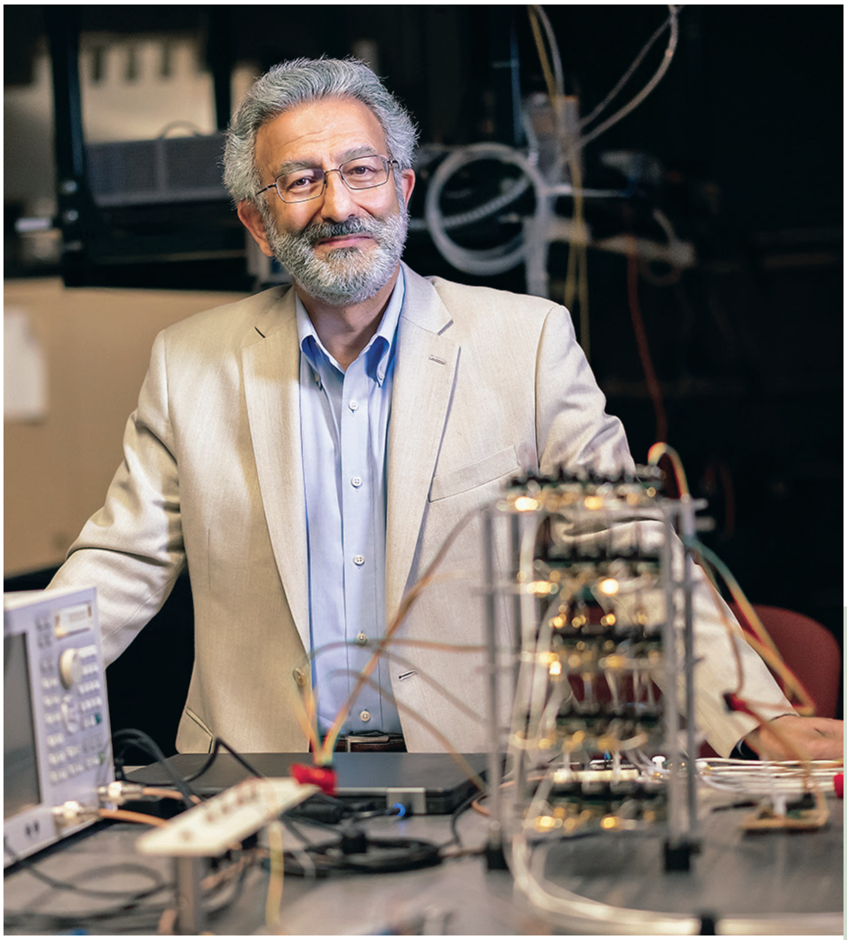
Caltech's annual Distinguished Alumni Awards—the highest honor the Institute bestows upon its graduates—recognize "a particular achievement of noteworthy value, a series of such achievements, or a career of noteworthy accomplishment." The 2023 luminaries include an optics expert who invented near-zero-index optics, optical nanocircuits, and wave-based analog computing based on nanomaterials; a leader in obstetric and gynecological care who broke barriers at Caltech; a bioinformatics pioneer who managed a team that mapped the fly, human, and mouse genomes; and a trailblazing chemist who helped develop the cancer-treatment drug Abraxane.

By Katie Neith

Nader Engheta

MS ’79, PhD ’82, Electrical Engineering;
Electrical Engineer and Physicist

For his pioneering advancements in optics, including optical nanocircuits and metamaterials, which have brought a new understanding to how light and materials interact at the nanoscale.



Nader Engheta has long been intrigued by waves. When Engheta was a teenager in the 1970s in his native Iran, his older brother taught him how a battery-operated transistor radio worked. “I instantly became fascinated with the waves we cannot see,” remembers Engheta, the H. Nedwill Ramsey Professor at the University of Pennsylvania. “That fascination and curiosity really pushed me into trying to find out what waves are and what properties they have.”

His wave quest led him to pursue a bachelor’s degree in electrical engineering at the University of Tehran. He continued his studies at Caltech and, for his doctorate, earned a degree in electrical engineering with a minor in physics. Now, with decades of groundbreaking research to his name, Engheta is still energized to discover more about what scientists can build with waves. “I’m passionate about the physics and engineering of waves because to utilize waves in order to achieve new and useful functionalities, we need to manipulate and control them,” Engheta says. “And for that we need materials.”

Engheta has spent his academic career at the University of Pennsylvania, where he holds a primary appointment in electrical and systems engineering, and secondary appointments in physics and astronomy, materials science and engineering, and bioengineering. His work has revolutionized how specialized materials can sculpt light, which has led to numerous novel phenomena and technologies such as near-zero-index photonics, wave- and material-based analog computing, and invisibility cloaks.

His research has also led to fundamental and transformative contributions to the electrodynamics of light–matter interactions including the development of optical nanostructures that are analogous to microelectronic circuit elements, and it has assisted in the creation of many other innovations in optics, electromagnetics, and materials science. These include optical structures that can bend light in unusual ways and have applications in photovoltaics and spectroscopy. In addition to optics and nano-optics, his current work also spans photonic computation and more. For example, Engheta has been working on a system that uses light waves instead of electric currents to perform analog computations.

“Doing analog computations with light waves at the nanoscale can bring us to another paradigm of information processing that can be done much faster than the current information processors and at a much smaller volume and lower power,” he says.

Engheta traces his many achievements—and how he arrived at them—to his time at the Institute. “Caltech taught me the way of doing science: how to be curious, how to think critically and creatively, how to be courageous and go down different paths,” he says. “I am indebted to Caltech, because I learned how to push the frontiers of knowledge and how to explore and develop new scientific domains.”

This willingness to break boundaries bore fruit at Penn when he collaborated with a colleague in the psychology department to examine the retinas of green sunfish to find out if they have photoreceptors that allow them to see the polarization of light, a visual aspect imperceptible to the human eye. “Together, we actually created a new research field we called bioinspired polarization imaging,” Engheta says. “I’m not a biologist, but I was able to read and learn from that field and apply what I know about light waves in my field to a different one. And this type of philosophy—not being afraid to go into a new field—I learned from Caltech.”

Karen Maples, MD

BS ’76, Biology; Physician

For her trailblazing role as one of the first Black female undergraduates at Caltech, and for her outstanding accomplishments as an obstetrician, which include delivering the world’s first surviving octuplets.

Karen Maples does not shy away from a challenge. Her math skills were so advanced in high school that she tutored her peers. As a teenager, she helped her mom canvass in Berkeley during the political upheaval of the 1960s and early ’70s. When it came time for college, Maples chose Caltech without visiting campus and without knowing what to expect when she got there, including that there were only a few women enrolled, and that she would be in the first class of Black undergraduate women. “When you come from a place where you’re at the top of your class and find out that college is quite different, that was an eye-opener,” Maples says.

Maples was recruited to Caltech by the late Lee Franke Browne, a Caltech employee and lecturer who dedicated his career to efforts that expanded students’ access to STEM. “I didn’t know a thing about Caltech, but my mother, who was an educator, thought it sounded like a great opportunity,” Maples says.

While Maples intended to pursue math, the late Ray Owen, professor of biology, emeritus, helped set her on the path toward medicine. “Ray was an incredible teacher and a wonderful mentor,” she says. “He really supported me through my years at Caltech.”

With no pre-med option at Caltech, she studied for the MCAT without much guidance and was accepted to the UCLA School of Medicine. Thanks to the foundation for learning she had built at the Institute, Maples says the world of professional medicine “clicked” for her when she got the chance to interact with patients. “Caltech taught me the value of critical thinking and how to put the whole picture together, which helped guide me in patient care so that I don’t just evaluate the individual details of a case,” she says. “That thinking process helped me become very successful as a physician.”

It also earned her the residency of her choice, first at Los Angeles County Women’s Hospital, then at Harbor-UCLA Medical Center, where she did a rotation at Kaiser Bellflower. Maples spent 39 years with Kaiser Permanente as an obstetrician and gynecologist, retiring recently after nearly four decades that included safely delivering Nadya “Octomom” Suleman’s octuplets. “As chief of the department, Suleman was my patient for the duration of her care,” she says. “It was quite a feat—I think they are still the only surviving octuplets in the world.”

Maples’s contributions at Kaiser Permanente include establishing a teen obstetrics clinic, promoting laparoscopic gynecological surgery, and creating obstetric content for the electronic medical record. As chief of service, Maples managed 40 physicians, 20 nurse practitioners and midwives, and 15 rotating OB/GYN residents. She oversaw the opening of a high-risk labor and delivery unit and provided staff training that led to a significant improvement in patient safety outcomes. Maples has also served on the Food and Drug Administration’s Obstetrics and Gynecology Devices Panel and as an advocate for the American College of Obstetricians and Gynecologists.

However, Maples is most proud of her time as the assistant area medical director of Kaiser’s Downey Medical Center from 2011 to 2019 as well as her mentorship of countless medical professionals and young women pursuing a STEM career. “I try to talk to any woman interested in medicine or the sciences,” Maples says. “Similar to being a lifelong learner, I like to think I’ve become a lifelong mentor.”

Eugene Myers

BS '75, Mathematics; Computational Biologist

For his transformative impact on the field of bioinformatics. Myers created the Basic Local Alignment Search Tool (BLAST) that revolutionized biological sequencing and continues to be used by scientists throughout the world, and he later developed a whole-genome shotgun method that helped map the human genome.

Although he was born in Idaho, Eugene Myers traveled the world as a child due to his father's career with ExxonMobil. One of the main constants in his life, he notes, was access to books. "Probably the most influential thing in my life is that my parents had a volume of *Gray's Anatomy,*" Myers says. "At 12 years old, I already knew about mitochondria and the endoplasmic reticulum."

After finding one of his dad's college textbooks on linear algebra, he gravitated toward math, earning his bachelor's degree from Caltech in the subject. But those early lessons in biology stayed close to his heart throughout his professional career, including his most recent tenure as director of the Max Planck Institute of Molecular Cell Biology and Genetics in Germany.

Myers became interested in electrical engineering—which he would eventually apply to computational biology—as an undergraduate at the Institute, where, he says, he missed out on earning a dual bachelor's degree because he refused to take a public speaking class. He went on to earn a PhD in computer science from the University of Colorado and then held faculty positions at the University of Arizona and UC Berkeley and served as a group leader at the Janelia Research Campus of the Howard Hughes Medical Institute.

It was at the University of Arizona in the late 1980s that Myers helped create the Basic Local Alignment Search Tool (BLAST)—now one of the most widely used bioinformatics programs—which uses an algorithm to compare biological sequence information with a database of sequences. This kind of information allows researchers to trace genes across multiple species.

Building on what he learned creating BLAST, Myers helped lead Celera Genomics' successful quest to map the fly, human, and mouse genomes in just three years (1999–2002) while serving as the company's vice president of informatics research. Using computer programs to help decipher the chemical makeup of the human genetic code and those of other animal models has helped make many major biological research and medical advancements possible, he says.

"I went into the job with a complex and difficult mission to build a system with a lot of moving parts—thank God I was one unit away from having an engineering degree," says Myers, who credits his undergraduate education for guiding his path. "Caltech helped me view things with a beginner's mind and learn how to be very creative and resourceful in terms of looking for solutions."

Myers retired earlier this year, but he has not stopped working. In fact, he has set up an independent research project to sequence the genomes of every species of bat on Earth. "Bats are fascinating," he says. "There are bats that live 50 times longer than they're supposed to and bats that never get sick. Fruit bats eat sugar all day and never get diabetes. What's going on there?"

Myers says if his team can develop all the sequences and look for differences at the molecular level in bats, they will potentially discover ways to help people live longer. "I'm not going to stop solving problems," he says. "I still write code every morning. I write programs that I think are going to be useful and interesting to other people."

Kenneth Suslick

For profound contributions to sonochemistry (the study of chemical reactions powered by high-frequency sound waves) and chemical sensing, which have advanced the field of medical imaging and facilitated life-saving treatments for cancer and sepsis patients.

BS '74, Chemistry; Chemist and Medical Entrepreneur

Listening to the radio played a key role in the life of Ken Suslick, who grew up in Chicago in the early 1960s, in much the way it did for Distinguished Alumni Awardee Nader Engheta (MS '79, PhD '82).

"It was the era of space exploration, and I still remember begging my dad for a little transistor radio, so I could listen to the NASA launches," Suslick says.

A few years later, a high school teacher turned him on to chemistry, the field he studied as a Caltech undergraduate and later for his PhD at Stanford. He is now the Marvin T. Schmidt Professor of Chemistry, Emeritus, at the University of Illinois at Urbana-Champaign. But when he arrived at Caltech, Suslick figured he would study math.

"After a week, I realized I was definitely going to be a chemist," he says with a laugh. "There were huge differences between a math major at Caltech and somebody who was at the top of his class in high school calculus."

As a first-year student, he worked with analytical chemist Fred Anson (BS '54)—now the Elizabeth W. Gilloon Professor of Chemistry, Emeritus—and then joined the lab of Bob Bergman, an organic chemist who later moved to UC Berkeley. "The lab is where I learned to think critically and creatively," Suslick says.

Creative approaches to research wound up driving his career. After his doctorate, Suslick accepted a position in his home state at the University of Illinois, where he has been for 45 years. During that time, he has worked as a scientist, inventor, and serial entrepreneur, tackling subjects as far ranging as the chemical effects of ultrasound (sonochemistry), the mechanochemistry of inorganic solids, drug delivery, and chemical sensing (most notably of bacteria). "I've always been interested in doing things that others aren't," Suslick says. "The important question for me is: 'Is your research interesting or boring?' Not 'Is your research basic or applied?' And that's one of the reasons why I like going off the beaten path."

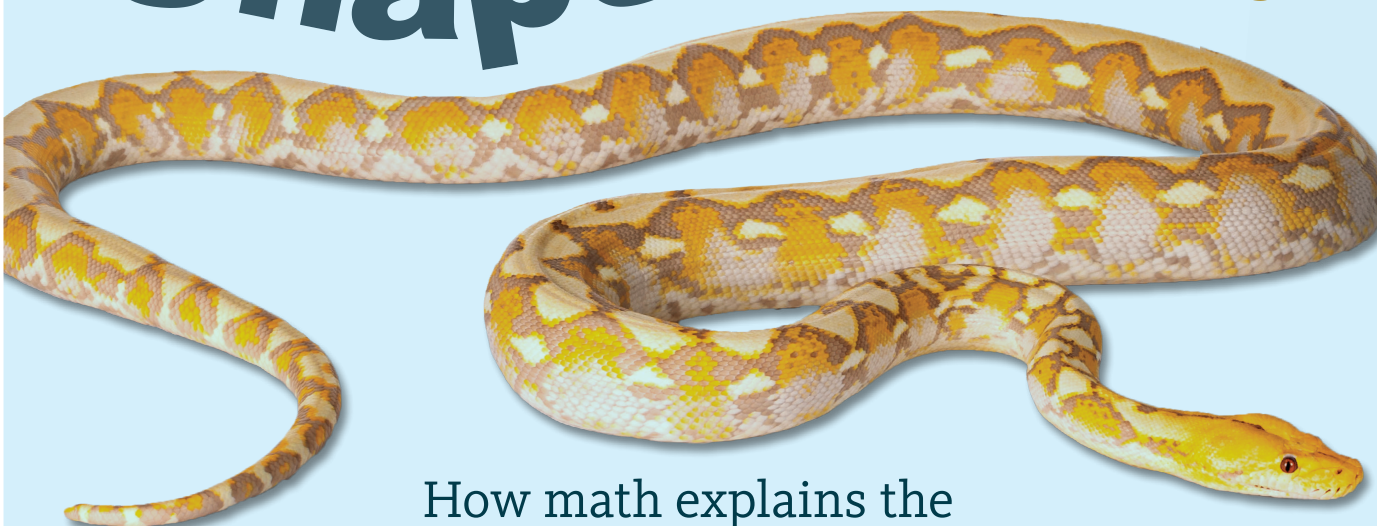
His investigations into sonochemistry led to breakthroughs in the development of the first echo contrast agent for medical sonography, allowing physicians to see ultrasonic images in much greater detail. Suslick's sonochemical research also helped him co-invent the nanopharmaceutical Abraxane, a chemotherapy agent used to treat breast and pancreatic cancers.

Another company launched by Suslick called Specific Diagnostics developed an array-based chemical-sensing platform that can rapidly test for antimicrobial susceptibility. "We discovered that we could rapidly tell bacteria apart based on their smell," Suslick explains, noting the sensors consist of multiple different chemically responsive dyes that change color when exposed to odors. "The pattern of color changes is a molecular fingerprint. We can now use this technology to diagnose sepsis [a dangerous and fast-acting blood infection] in a few hours when it used to take two or three days."

At age 70, Suslick started a company called Iridescent Sensors that makes a handheld, portable "optoelectronic" nose for use by first responders, hazmat workers, and chemists, which can swiftly detect toxic gasses at low concentrations.

"Every step I've taken I trace back to Caltech," Suslick says. His son, Benjamin, is now following in those footsteps: Benjamin earned a bachelor's degree in chemistry from Caltech in 2014 and works as a polymer chemist.

Shape Shifters



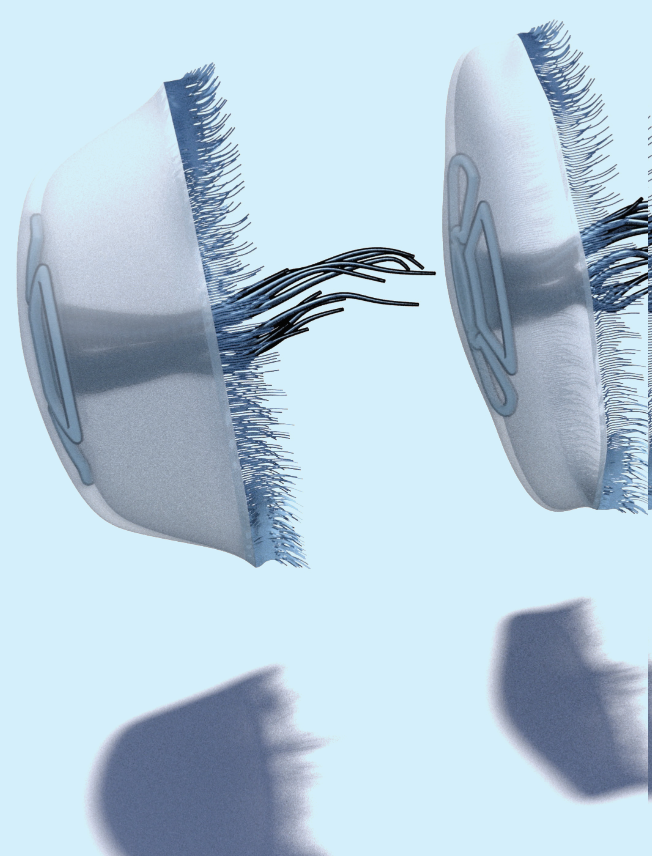
How math explains the movement of snakes, jellyfish, cats, and ... astronauts?

By Emily Velasco

Across the animal kingdom, creatures move through their environments not by walking, running, or climbing but rather by changing the shape of their bodies. This kind of locomotion is found in snakes as they slither, in jellyfish as they swim, and even in cats as they twist themselves to land on their feet.

The contortions of a falling cat and a sidewinding snake have more in common than you might think. A team of researchers led by Caltech's Peter Schröder say they have discovered a single algorithm that describes how this process works in many types of animals.

"One classic example is a single-celled organism," says Schröder, the Shaler Arthur Hanisch Professor of Computer Science and Applied and Computational Mathematics. "How does it move? It doesn't have legs. It doesn't have wings to fly with. The only thing it can really do is change its shape. Once you understand that basic



observation, you see there are all kinds of creatures who move by changing their shape. Astronauts can even turn in zero gravity by doing a dance-like motion that manages to turn them without the need to push off a surface."

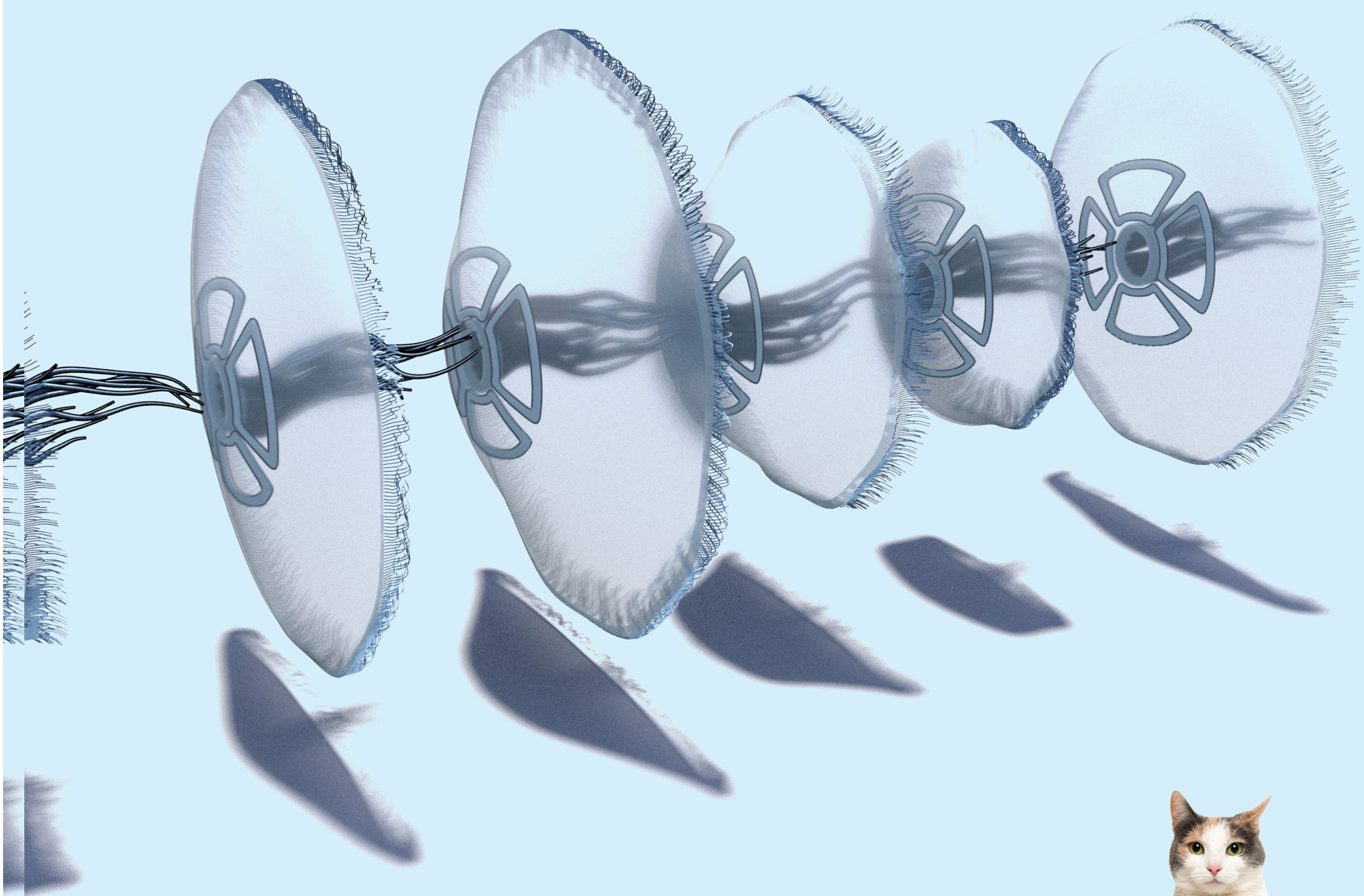
Schröder says this phenomenon can be explained by the principle of least dissipation of energy, which states natural systems will always try to be as efficient as possible. As an example, he cites an ice skate, which can easily slide forward or backward but has great difficulty sliding side to side. If a person wants to skate forward, they push their skates away from the center line of their body. The skates (and the person wearing them) will move forward because forward motion is easier and more efficient than sideways motion. The system consisting of the skater, the skates, and the ice favors forward motion because it wastes the least energy.

The same principle is at work when a snake undulates across a sandy desert. A snake, being long and skinny, can slide forward and backward much more easily than it can slide sideways. The snake moves forward while undulating back and forth because forward motion reduces the energy lost to friction during its side-to-side undulations. Motion along the length of the snake encounters less friction, so the system favors it, and the snake slithers along its scaly way.

Schröder's team modeled these examples of locomotion on computers with the animals rendered as sets of flexible nodes connected by rigid bars. This allowed the researchers to examine how the creatures move in a simulated space and compare it to real-life data. Guided by the principle of least dissipation (and other math), these animal models showed movement remarkably like that seen in their real-world counterparts.

"It's not 100 percent accurate, but it shows remarkable agreement with motion observed in real life, suggesting that it captures a major part of what happens in nature," Schröder says. "There's a certain mathematical beauty when you have a very simple principle that can explain a whole bunch of things at once. That's what gets me up in the morning."

A paper describing the research titled "Motion from Shape Change" appears in the August 2023 issue of *ACM Transactions on Graphics*.



Building Community

The First-Year Success Research Institute aims to forge long-lasting bonds.

By Omar Shamout

Heading to college in a country more than 6,000 miles from home is a daunting journey, as second-year Caltech undergraduate Adelynn Tang can tell you. Tang enjoyed studying math and science during high school in Shanghai but knew that navigating a new language, culture, and environment while also adjusting to American methods of teaching meant she would need a collaborative learning culture, a feature she focused on when deciding on a university. “That’s one of the reasons why I thought Caltech was a good fit,” says Tang, who is studying physics. “I really like being able to collaborate with people on problem sets. That’s a little bit different from what my high school was like.”

When she learned about Caltech’s First-Year Success Research Institute (FSRI), which begins prior to the fall term, Tang felt encouraged and excited by the opportunity. “I thought FSRI would also be a good way to get started with things early, to have a little sense of what the Caltech community is like, and to get in touch with people,” she says.

Second-year undergraduate Adelynn Tang

FSRI is an orientation and academic-support program organized by the Caltech Center for Inclusion and Diversity (CCID). The program is designed to introduce incoming first-year students to Caltech’s research and math curriculum, culture and campus life, and academic and student support services in a collaborative environment that allows students to develop lasting relationships with peers and colleagues.

At no cost to attendees, FSRI provides participants with a summer research experience under the mentorship and guidance of a Caltech faculty member; computing, math, and writing courses during the summer; and leadership, research, and academic skill-building workshops. Additionally, cohort-building activities, which are central to the students’ continued success throughout their time at Caltech, include a service-learning project, group field trips and excursions, and opportunities to build relationships with all Caltech’s undergraduate students, as well as graduate students, postdocs, faculty, and staff.

Thanks to the longstanding support of the 27 Foundation and a 2021 gift from the Gordon and Betty Moore Foundation (see page 34), FSRI has welcomed 52 students each of the past two years, up from 30 in 2021. The goal of program organizers is to reach a total of 60 students every year. And, since last academic year, FSRI’s educational, research, and social engagement opportunities have been expanded beyond the summer to include programs and faculty- and peer-mentoring engagements throughout the entire first year. In addition, FSRI is now led by its first full-time director, Lizette Alvarez, who joined Caltech in spring 2023.

FSRI, formerly known as the Freshman Summer Research Institute, evolved out of the Summer Scholars Program launched in the 1970s by Lee Franke Browne, a former Caltech lecturer and director of secondary-school relations at the Institute. It served incoming students who were from underfunded school districts or had gaps in their science and math enrichment and instruction.

“People ask ‘What’s in a name?’ In this case, I think a lot,” says Lindsey Malcom-Piqueux (MS ’03), Caltech’s chief diversity officer and assistant vice president for diversity, equity, inclusion, and assessment. “The F became ‘first-year,’ which is more gender inclusive. And then the S became ‘success,’ and that’s important because instead of focusing on a finite period like summer, we wanted to ensure these students know the program is committed to their success through support and community building throughout that crucial first year.”

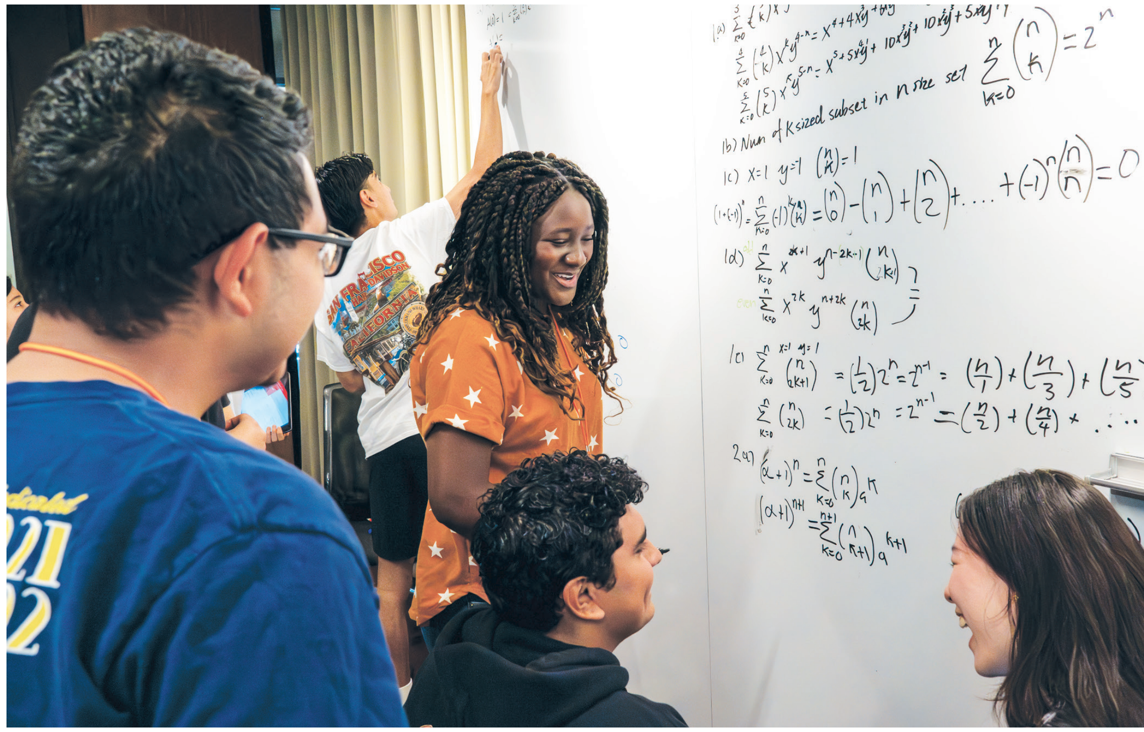
Academics and research

A student’s FSRI experience begins online with a three-week computer-programming prep course. Then, when they arrive on campus in late July, the participants begin a six-week math course taught by lecturer Roberto Pelayo (PhD ’07). The math course prepares FSRI students for Caltech’s diagnostic exam in mathematics, a test that helps inform which core math courses students will be enrolled in their first year. “There are proof problems that we’ve never seen during high school,” Tang says. “So that was helpful, because [then] I already knew a little bit before we learned it in Math 1a.”

Adam Blank, teaching professor of computing and mathematical sciences and FSRI’s academic director, says the virtual component is designed to create a “stepladder” for students before they arrive at Caltech. “This staged process is very important,” Blank says. “It’s too much all at once for in person.”

Once on campus, the students also take a new three-week academic writing workshop through the Hixon Writing Center, and they are given a seven-week research

Incoming first-year undergraduates make moon lamps at an FSRI gathering on campus in July 2023.



Left to right: Second-year undergraduate and FSRI math teaching assistant Mario Solis; first-year undergraduates and FSRI students Steven Romero-Ruiz, Angie Moussambote, Edvar Bautista Flores, and Gabo Zhang.

assignment with a Caltech faculty member, postdoctoral scholar, or graduate student. These research project leaders also serve as their students' FSRI academic mentors throughout the year, checking in with them weekly.

Beginning in 2023, FSRI students who perform well in the computer science class can request to skip Caltech's core CS 1 course. The goal of this is to provide students who have developed a strong foundation in programming the opportunity to progress in that field or explore other disciplines.

"My job is to get them excited about why programming might be useful to them, even if they don't want to be a computer scientist," Blank says. "In the course, they create code for things like a chemical equation balancer, an automatic differentiator, and a rocket simulation. We try to cover every field that computer science might be useful in."

After they complete the math and writing courses, students begin their research project under the guidance of their project leader. Some students choose to work alone, while others work in groups of two or three. The project is meant to align with their academic interests to the extent possible. After seven weeks, the students present their findings to the entire FSRI group. This early exposure to campus research is a defining characteristic of FSRI and an aspect that distinguishes it from other pre-college summer bridge programs. FSRI is designed to facilitate sustained engagement in research and to help incoming students better appreciate and feel equipped to access the extraordinary research opportunities that a Caltech education affords.

Second-year undergraduate Luke Alvidrez

Luke Alvidrez, a second-year mechanical engineering student who participated in FSRI in 2022–23, grew up in rural Jacksonville, Alabama, where there were just over 100 students in his high school graduating class.

"I wasn't able to do any research during my time in high school," Alvidrez says. "I was in an area that was very small, and I just couldn't find any of those opportunities. I knew Caltech was very research based, and I didn't want to fall behind. FSRI got me on track."

Blank led Alvidrez's and Tang's research projects, and mentored three other groups. Blank had students build a robot that could autonomously navigate a room to detect and retrieve certain objects while ignoring others. "Adelynn and I worked pretty closely," Alvidrez says, noting that he had been able to use some of the concepts taught in the FSRI coding class in this research. "We trained the object-recognition algorithm for all of Blank's groups. I had fun trying to make code as short and safe as possible. I even tried doing the assignments in different programming languages."

Life outside the classroom

While summer academics and research are central to FSRI, the program also offers workshops and casual meetups each month throughout the summer and school year. The workshops, which broadly comprise the cohort-building component of FSRI, include Summer Undergraduate Research Fellowships (SURF) proposal training as well as seminars that explore social identity and imposter phenomenon, database search strategies, and healthy sleep cycles, among many other topics. Casual events include board game nights, pottery painting, movie meetups, and trips to Disneyland and Knott's Berry Farm.

"We've been to OinkMoo, which is a bubble-tea place, and we went to get acai bowls. We're planning to go to Target and H Mart using our Metro pass," said Nicole Yang, a 2023 FSRI student who was painting moon lamps at an FSRI gathering on a hot afternoon in late July with three new friends: Hanna Park, Gabo Zhang, and Tuyako Khristoforova. Yang, who is from Hiram, Georgia, and her new friends met at the Discover Caltech event for admitted students in April. They stayed close over the summer and have grown closer since arriving on campus. "I'm so lucky," said Zhang, who is from Las Vegas. "I didn't have this kind of strong friendship bond in high school because there is so much competition."

The four women pointed out that FSRI faculty and staff have done a lot to help them feel at ease in their new surroundings, both academically and socially. "They're very generous," Khristoforova said. "Doing this stuff for us to have fun and de-stress, I think it's very nice. It's not just study, study, study."

"The classes are enjoyable, too," Zhang added. "They want you to work with other people rather than just listen to a long lecture, so even if you're struggling, you're struggling with other people. I find that comforting."

Tang and Alvidrez say the informal meetups and activities were their favorite aspects of FSRI, helping them settle in at Caltech and feel they had found a welcoming community. In the process, they were able to connect not only with their classmates, but also with the faculty, postdocs, graduate students, and CCID staff. "It was really fun because they told us their perspective of Caltech, and it was really different from ours," Tang says. Interacting with faculty members in social environments also helped ease Alvidrez's fears that Caltech faculty members might not be approachable, particularly for a first-year undergrad. "It helped to humanize them," he says. "Yes, they're your professor, but they're just another person who you can talk to."

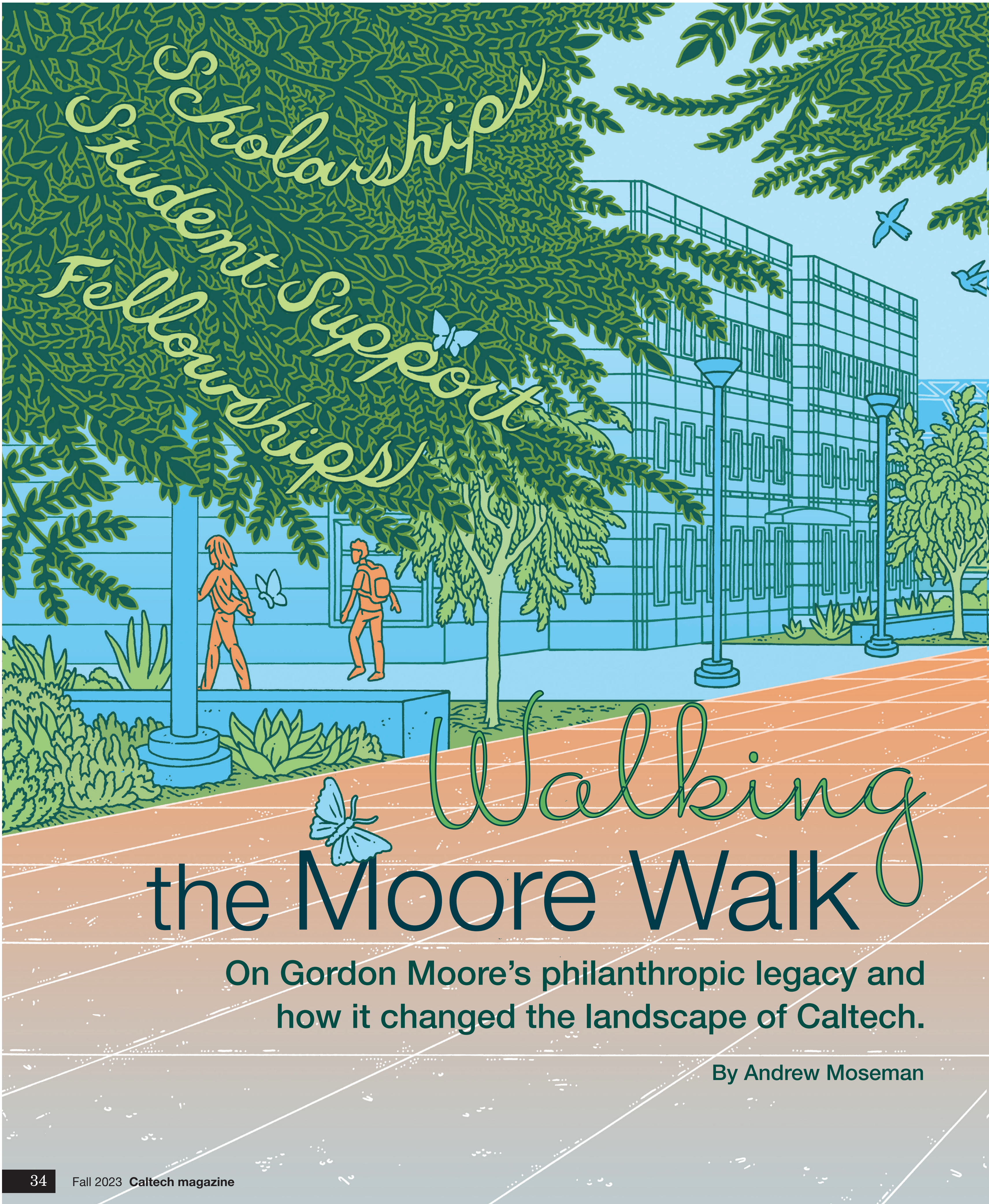
First-year undergraduate and FSRI student Said M. Garcia performs research in Professor Changhuei Yang's biophotonics lab.

Brody Wyman, FSRI's program coordinator, says the social events and cohort-building activities are important steps in FSRI's effort to help students build a support structure and community that they can turn to in the classroom, lab, and beyond. In addition, the events help the staff to assess programming and, in so doing, to better serve students in the future. "Listening to them speak about their experience at Caltech, you really learn more about their personalities and where they're coming from, which helps us as we try to make their FSRI experience as personalized and impactful as possible," Wyman says. "I really value the chance to speak to students about their daily lives."

This type of healthy relationship building is what CCID director Tashiana Bryant-Myrick views as perhaps the most critical component of FSRI. "FSRI helps create a sense of belonging for students, which is a big part of CCID's goals of increasing cultural exchange and ensuring that you show up to Caltech as your authentic self," she says. Bryant-Myrick also highlighted FSRI's kin-group mentors—FSRI alums who make themselves available to current students for advice and guidance—as crucial to the program experience. "We want to create a family feel," she adds. "The kin-group mentors receive Red Door Marketplace gift cards to use during their meetings with their students, and they are invited to all the FSRI activities so that they can continue to build a rapport with the students. That has worked out well."

FSRI program director Alvarez joined Caltech in April 2023 and has been working with Wyman and the rest of FSRI's staff to ensure the programming is intentionally planned and structured to create an even more holistic experience going forward.

"We want to take care of the whole person and make sure we're not just adding to their plate," Alvarez says. "Sometimes that means they'll need academic support or professional development, but other times they might just need to relax. Sometimes they just need that space to be 18 or 19."



Walking the Moore Walk

On Gordon Moore's philanthropic legacy and how it changed the landscape of Caltech.

By Andrew Moseman


Leadership Chairs
Research Centers
Interdisciplinary Research
Moore Lab

Carver Mead (BS '56, MS '57, PhD '60) was just starting a decades-long career as a professor at Caltech in 1959 when his future entered his office carrying a briefcase full of spare parts. The unannounced visitor to the Eudora Hull Spalding Laboratory of Engineering introduced himself as Caltech alumnus Gordon Moore (PhD '54), then working for a new company called Fairchild Semiconductor and keen to meet the man running the Institute's electronics teaching lab.

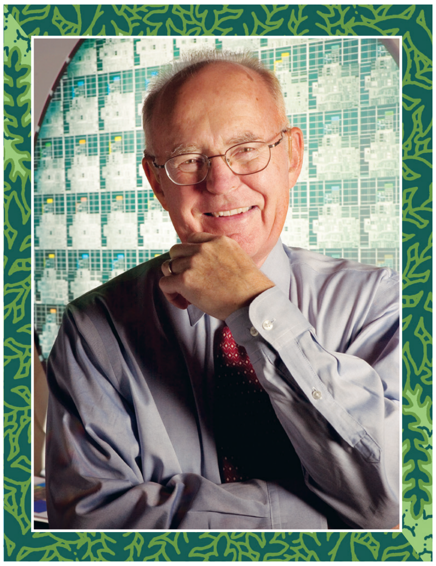
"He asked, 'Are you using transistors?'" Mead remembers. "I said yes. He said, 'Would you like some transistors to use in your class?' And I said, 'I sure would.' So, he opened his briefcase—it was an old-fashioned one, a clamshell—and he pulled out bulging manila envelopes."

Mead recognized the contents: the envelopes swelled with then-state-of-the-art transistors, the 2N697 and 2N706, the latter of which Mead calls "a beautiful little transistor, just perfect for teaching classes." The meeting marked the beginning of a lifelong partnership in which Moore collaborated with the professor as Mead pioneered very large-scale integration, the cornerstone of modern computing; and Mead helped Moore define his namesake law that states that the number of transistors that fit on an integrated circuit will double every two years.

For Moore, who in 1968 went on to co-found the iconic chipmaker Intel Corporation (a company now valued at more than $140 billion), those little transistors offered to a young professor also launched his towering legacy of philanthropy to Caltech. Among those contributions was a 2001 gift in which he and his wife, Betty, personally committed $300 million to Caltech and contributed another $300 million through the Gordon and Betty Moore Foundation. The combined $600 million represented the largest philanthropic donation to an institution of higher learning up to that point.

The Moores also provided two unrestricted gifts during Caltech's *Break Through* campaign: $100 million that the Institute used to match graduate fellowships, which provide individual graduate students with the freedom and flexibility to fully pursue their educational and research interests, and a further $37 million to support student scholarships. Moore believed deeply that this kind of unrestricted funding was the best way for him to support Caltech's signature brand of high-risk, high-reward ideas, especially those that crossed academic divisions or were at too early a stage and too far removed from commercial realization to garner federal funding.

"Those within the Institute have a much better view of what the highest priorities are than we could have," he said at the time of the $100 million gift. "We'd rather turn the job of deciding where to use resources over to Caltech than try to dictate it from outside."



Gordon E. Moore, co-founder of Intel Corporation and the Gordon and Betty Moore Foundation, in 2005.

There are few corners of Caltech the Moores have not touched. The Gordon and Betty Moore Laboratory of Engineering, home to Caltech's electrical engineering department, was dedicated in 1996. Moore Walk, which had its finishing touches completed this year, was named in his honor in 2002. A long list of graduate and postdoctoral fellowships, undergraduate scholarships, and Caltech professorships have benefited from support by the Moores or their foundation, especially when this philanthropy amplified other donors' gifts by providing matching funds. Moore endowed the professorship now held by his old friend Mead, a fellow Distinguished Alumni Award winner who is now the Gordon and Betty Moore Professor of Engineering and Applied Science, Emeritus.

Even after his retirement as Intel's CEO, Moore served as chair of Caltech's Board of Trustees from 1993 to 2000, the year in which he and his wife established the Gordon and Betty Moore Foundation, a private and competitive grant-making organization that continues to expand upon Moore's philanthropic legacy. Moore's son, Kenneth Moore, now serves as a trustee on Caltech's board.

"Gordon Moore is an inspiration for Caltech students, alumni, and leaders," Caltech's Board of Trustees chair David W. Thompson (MS '78) said in a tribute to Moore, who passed away on March 24, 2023, at age 94 (see page 39). "With ambition, ingenuity, and magnanimity, he changed the world and positioned the Institute's scholars to pursue equally transformative goals."

"Gordon and Betty's philanthropy, both personal and through the Moore Foundation, continues to expand the universe of knowledge and will continue to enrich the lives of young scholars for generation after generation," says Caltech president Thomas F. Rosenbaum, the Sonja and William Davidow Presidential Chair and professor of physics. "Gordon's innate curiosity, thirst for discovery, humility, and love for Caltech always shone brightly."

Overall, the Moores' personal commitments totaled nearly $440 million, making them Caltech's most generous alumni donors. The foundation has given another $469 million to the Institute, between the initial Caltech commitment of $300 million and other funding dispersed through competitive programs and grants. The Institute has used the Moores' unrestricted gifts to foster bold new ideas and support one of Caltech's most important resources: its people. To do so, Caltech created a matching program that has had a multiplier effect by amplifying other donors' impacts and, in turn, leveraging additional support. This has led to the creation or continued funding of approximately 100 graduate fellowships, 12 new undergraduate scholarships, and seven leadership chairs that provide unrestricted funding for the holders' discretionary use.

"From his time as a student through his service as chair of the Caltech Board of Trustees, Gordon understood the power and promise of Caltech as a leader in science, engineering, and higher education," says Harvey Fineberg, M.D., president of the Gordon and Betty Moore Foundation. "Through the foundation and in his personal philanthropy, Gordon remained a staunch supporter of Caltech throughout his life."

Idea Accelerator

A few years ago, David Van Valen (PhD '11) had an idea: he wanted to explore a new way to study how single cells process information. But the Caltech assistant professor of biology and biological engineering thought it was too risky to pursue—until he read about the Moore Inventor Fellowships in a departmental email and wondered if his research project, a concept that sits at the interface of technology, biology, and computation, might be exactly what the program is intended to encourage. Still, he had convinced himself the idea was too raw to solicit funding until a nudge from Richard Murray (BS '85), the William K. Bowes Jr. Leadership Chair for the Division of Biology and Biological Engineering, persuaded him to proceed.

In 2021, Van Valen was named a Moore Inventor fellow, and says that the support has been transformative for his project. The Moore Foundation gives each fellow a total of $675,000 over three years to pursue their concept. The idea for the fellowship was inspired by the 50th anniversary of Moore's Law and in honor of its creator's penchant for invention. Van Valen's group wanted to advance a new technique, a kind of optical barcoding in which combinations of spatial and color patterns can assist researchers as they delineate how individual cells respond to specific types of stimuli and which genes prompt those behaviors.

"Without support from the Gordon and Betty Moore Foundation, this story ends here, where it's a cool idea but it's not an actual technology," Van Valen says. "We just didn't have the resources to pursue this risky concept. But the foundation gave us what we needed to go down that path." The foundation supported not only necessary technology and tools but also lab managers and students, including a Summer Undergraduate Research Fellowship (SURF) student who worked in Van Valen's lab. "It's a night-and-day story," Van Valen adds. "Now we have projects. The technology that we set out to build has been built, and it works."

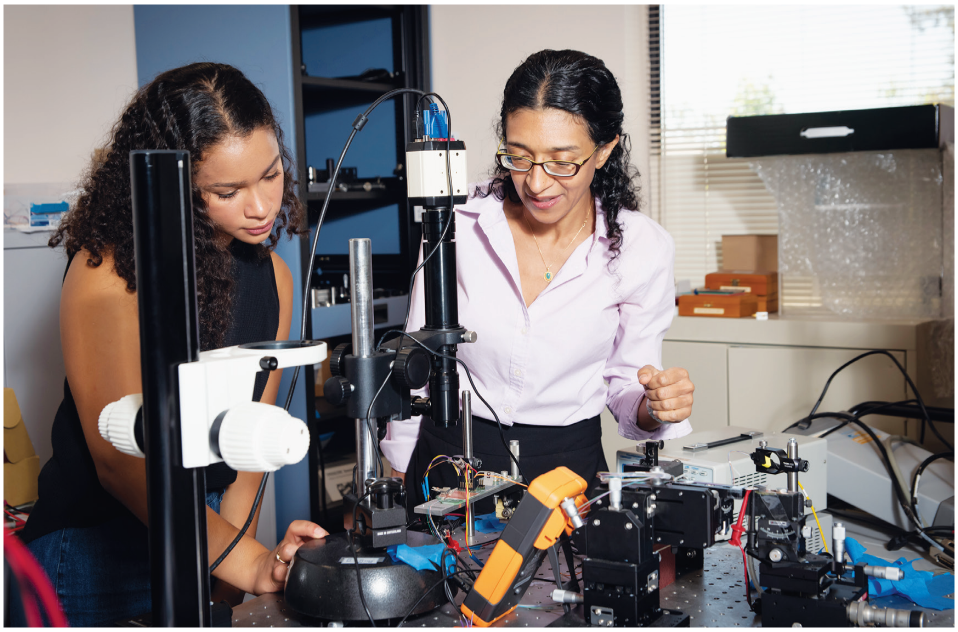
Faculty Benefactor

When Azita Emami, the Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering, joined the Caltech faculty in 2007, she was able to set up her lab, in part, as a result of support from a 2003 Moore Foundation grant. "The startup packages are a marvelous support as we launch our careers, take new directions, and have the freedom at the beginning to define what we want to do," she says.

Emami—whose lab is in the Moore Laboratory, which sits on Moore Walk—says the early financial support meant she could begin her work immediately and did not have to dedicate her first year to seeking grants to support graduate students or purchase equipment for her research: "In my field, because I work on very high-speed data communication systems and optical communication systems, I needed very expensive equipment. So, startup funding helps junior faculty buy those kinds of very specialized instruments and equipment that they need."

Moore's legacy impacted her career in several other ways as well, Emami says. His work at Intel pushed the boundaries of computing power and speed, creating new opportunities in her field. The Moore match funded numerous graduate students who have worked in her lab. And his stature has encouraged many other donors to support the Institute.

Professor Azita Emami (right) with 2021 WAVE student Liliana Edmonds.



"The name Gordon Moore by itself brings a lot of prestige, and donors appreciate that someone like him is matching the funds," Emami says.

And Everything in Between

Mead notes that, although Moore came from a chemistry background, he was eager to invest in big ideas, especially the interdisciplinary ones so common at Caltech. Moore provided matching funds to support not only professorships, fellowships, and scholarships, but also leadership chairs that provide the holders with discretionary funding to jumpstart new initiatives.

One such initiative that was supported with discretionary funding from a leadership chair is the Center for Science, Society, and Public Policy (CSSPP), which was established in 2023 in the Division of the Humanities and Social Sciences. The center, led by professors Michael Alvarez and Frederick Eberhardt, was conceived to provide a forum for research and discussion of issues at the intersection of science, ethics, and public policy.

CSSPP recently welcomed incoming postdoctoral scholars Cong Cao and Ozan Gurcan. Cao's research focuses on the intersection of biology, economics, and artificial intelligence (AI). One of her projects, on climate change and public health, leverages AI models of how pollution spreads under different temperatures, car traffic patterns, and weather trends to predict the locations of outsized respiratory and cardiovascular problems among the people who live and work in the most impacted areas. Gurcan explores questions of moral and political philosophy regarding genetic technologies and hopes to help society think through the ethical dimensions of genetic discrimination.

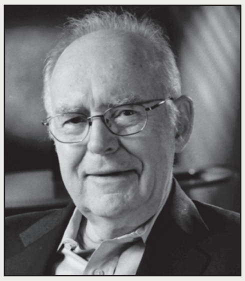
Through its 2001 commitment, the Moore Foundation also supported the Thirty Meter Telescope, Kavli Nanoscience Institute at Caltech, Center for Analysis of Higher Brain Function, Moore Center for Theoretical Cosmology and Physics, Institute for Quantum Information and Matter, Caltech Tectonics Observatory, Center for Catalysis and Chemical Synthesis, and more.

Beyond the Moores' direct contributions, the foundation's investments in science have yielded numerous grants to leading-edge initiatives at Caltech. That includes the Marine Microbiology Initiative, an interdisciplinary effort to better understand the diversity and behavior of marine microbial communities, which received nearly $5 million to support the advancement of research by Victoria Orphan, the James Irvine Professor of Environmental Science and Geobiology and the Allen V. C. Davis and Lenabelle Davis Leadership Chair for the Center for Environmental Microbial Interactions.

Through its competitive grant programs, the foundation has also funded physicist Jamie Bock's BICEP Array project, which seeks to measure the cosmic microwave

In Memoriam

Read more about their lives at **magazine.caltech.edu/post/in-memoriam**

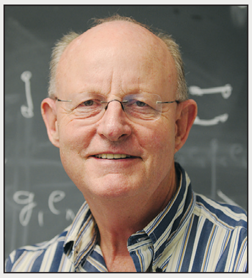


Gordon E. Moore (1929–2023)

Gordon E. Moore (PhD ’54), a Caltech Board of Trustees chair emeritus, visionary philanthropist, and pioneer of the modern electronics industry, passed away on March 24, 2023, at age 94. In 1968, Moore and his colleague Robert Noyce co-founded chipmaker Intel Corporation. Moore served as executive vice president of the company until 1975 and as CEO from 1975 to 1987. In 1965, Moore predicted the number of transistors that can fit on a chip would double every year, a trend he forecasted would continue through 1975, at which point he updated his prediction to once every two years. This principle, now known as Moore’s Law, has become the guiding principle for the industry. Named a Caltech Distinguished Alumnus in 1975, Moore became a Caltech trustee in 1983, a senior trustee in 2001, and a life member of the Caltech community in 2009. He served as Caltech Board chair from 1993 to 2000, the year he and his wife established the nonprofit Gordon and Betty Moore Foundation.

Stanley Deser (1931–2023)

Stanley Deser, a theoretical physicist known for his achievements in general relativity, quantum field theory, and high-energy physics, passed away on April 21, 2023, at age 92. After Deser retired from Brandeis University in 2005, he moved to Pasadena and secured a research appointment at Caltech. At the time of his passing, he served as a visiting associate in theoretical physics at Caltech and was the Ancell Professor of Physics, Emeritus, at Brandeis. Deser and his colleagues Charles Misner and Richard Arnowitt conceived a mathematical description of energy and mass in the context of Albert Einstein’s general theory of relativity, which they called ADM formalism (ADM refers to the first initials of the researchers’ last names). This, together with Deser’s work on supergravity, influenced the development of theories of quantum gravity.



David B. Wales (1939–2023)

David B. Wales, who spent more than 50 years as a Caltech faculty member and administrator, passed away on July 17, 2023, at age 83. In addition to serving on the faculty in the Division of Physics, Mathematics and Astronomy, he was also Caltech’s associate dean of students from 1976 to 1980, dean of students from 1980 to 1984, executive officer for mathematics from 1985 to 1991, and master of student houses from 1991 to 1997. Wales retired in 2008 but remained active in math research. An expert in group theory, algebraic combinatorics, and representation theory, he spent the most time on finite group theory, searching for and studying simple groups. In the same way prime numbers can be thought of as the building blocks of integers, simple groups are the building blocks of finite groups, which are groups with a finite number of elements.

background of the universe; seismologist Zhongwen Zhan’s (PhD ’14) fiber-optic seismology project, which uses old telecommunications infrastructure to detect earthquakes; research toward the ShakeAlert Earthquake Early Warning system; and the Institute’s First-Year Success Research Institute (see page 30).

While the Moores’ philanthropy buoyed promising ideas and inspired a great many people, it also sparked a change in the Institute’s culture, Emami says.

“Caltech realized how transformative it is to have this type of support,” she says. “It allows us to take risks, it allows us to have more freedom and do what we believe in rather than trying to convince others that it’s a good idea, and it allows new projects by new faculty members to take shape. Moore was the person who really changed that paradigm for Caltech.”

Fundamentally, Mead says, Moore loved to support Caltech because he saw it as a place that shared his values, especially his commitments to efficiency, drive, and accomplishment.

“Gordon understood that Caltech was a special place because he had been here; he earned his degree here,” Mead says. “He realized that Caltech is about getting things done, getting things figured out. It’s about excellence, and about the frontier of knowledge. These were values that Gordon fully adopted as part of his being.” [C]

Endnotes

On page 20, we talk with Ross Brockwell (MS ’01), who began a yearlong simulated Mars mission for NASA in June at the Johnson Space Center in Houston.

Besides friends and family, what would you miss most from your everyday life if you took part in such a mission?

My cats.

Dean Gibson (BS ’67)
HAYDEN, ID

I’d miss seeing the seasons change on my morning runs. There’s nothing like that first lungful of crisp air that reminds you fall is on the way!

Helen Foley (BS ’09)
PASADENA, CA

Long load times for Google Street View would be the problem.

Kimberly Gleason (BS ’67)
PORTLAND, OR

Gardening, freshly harvested roses and tomatoes, and being surrounded by green leafy plants.

Martin Goldberg (BS ’78)
MATAWAN, NJ

Physical access to a large library! Hard to replace that real-time access to information, serendipitous discovery, and creative contact with fellow readers.

Mark Zimmermann (PhD ’80)
SILVER SPRING, MD

It is almost certain that, despite the detailed planning that goes into such a mission, I would manage to forget to pack something mundane. All of humanity will be looking on as we put the finishing touches on our habitat. We’re now taking turns staring into the blank camera lens; the other mission members have taken turns, each giving a profound statement beamed back to Earth, heard 30 minutes later. I step up. I hesitate. Then exclaim: “Oh, no! I forgot my toothbrush!”

David Cuthbert (BS ’96)
BAINBRIDGE ISLAND, WA

It has to be rain. There is so much power and something so clean about a good hard rain shower. Makes things right somehow. And the smell of rain hitting the dry ground (petrichor) is a favorite.

Karen Tanaka (BS '83)
TOKYO, JAPAN

I would miss familiar smells: those that arise after a rainfall, those that remind me of my favorite foods, the smell of coffee, and the smell of pine forests. I would also miss some sounds: the sounds of a thunderstorm and the monsoons, or the sounds of wind chimes in a breeze. The feeling of a breeze on my skin. I would also miss people watching.

Nitu Kitchloo (BS '93)
BALTIMORE, MD

Running 9-plus miles per day outside in the Southern Nevada desert. A treadmill is just not the same, very boring. I even love to run in our extreme summer heat of 110-plus degree F temperatures.

Doug Smith (MS '70)
BOULDER CITY, NV

The quiet time in the evening sitting at a small table in the garden with a glass of red wine and a trashy mystery novel.

Larry Oliver (BS '65)
CHARLOTTE, NC

Listening to the Seattle Symphony in person, just letting the notes fill up my ears or watching ballet tell an old story without words.

CJ Beegle (BS '82)
MERCER ISLAND, WA

Raspberries for breakfast and my baby grand piano (the ukulele I could probably bring along).

Virginia Trimble (PhD '68)
IRVINE, CA

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Machine Learning in Nature

"iNaturalist is an app developed by Scott Loarie at the California Academy of Sciences to connect naturalists and amateur field biologists. It allows them to help each other identify plants and animals," says Pietro Perona, the Allen E. Puckett Professor of Electrical Engineering at Caltech. "We have added to iNaturalist the ability to interpret images automatically. This is mainly work by Grant Van Horn (PhD '19), who was a student in the lab. Using your phone, you can grab a picture of [an] animal or plant and have your phone classify it and suggest a number of species that it could be. Among these, you can choose the one that is most likely. Other people who are interested in that species or that location look at your observations, contribute their thoughts, and correct your or the machine's determination of the species."

This brown-throated sloth was identified by an iNaturalist user in Panama.

Find out more: