Fall 2024

Caltech magazine

Chemical Codebreakers

Isotopes help scientists open windows to the past

Contents

Features

Departments

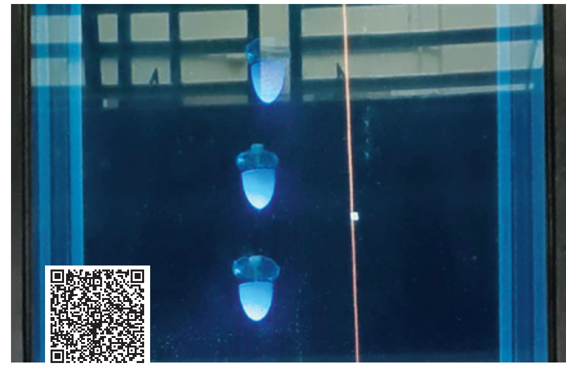
About the cover: Illustrator Charis Tsevis used isotope renderings to create this extinct giant sloth, one of the ancient animals studied by Julia Tejada's lab. See page 14.

Left: The now-retired NASA DC-8 airplane used by many Caltech scientists. See page 36.

Online

What's in a Name?
Feature: **Mineral namesakes**

Innovative Instrumentation
Article: **A jellyfish treadmill**



Veterans in STEM
Story: **DIVE program's new path**

Visit **magazine.caltech.edu**

Fall 2024 Volume LXXXVII, Number 2

Caltech magazine

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
DC Agle, Lori Dajose, Cynthia Eller, Julia Ehlert, Kimm Fesenmaier, Andrew Moseman, Katie Neith, Omar Shamout, Chris Quirk

DESIGNER
Jenny K. Somerville

ONLINE DESIGNER
Sergio Solorzano

ILLUSTRATION, PHOTOGRAPHY, VIDEOGRAPHY
Lance Hayashida, Peter Holderness, Jon Nalick, Sergio Solorzano, Charis Tsevis, Bill Youngblood

COPY EDITORS
Sharon Kaplan, Carolyn Waldron

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

Read *Caltech* magazine on the go at **magazine.caltech.edu**

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

Caltech magazine ISSN 2475-9570 (print)/ ISSN 2475-9589 (online) is published at Caltech, 1200 East California Boulevard, Pasadena, CA 91125.

Image credits: Charis Tsevis: cover, 14-15, 16-17, 19 (illustrations); Ben Douglass: cover concept; NASA/Carla Thomas: TOC (large); Lance Hayashida: TOC (top, bottom right), 4-5, 6 (top), 7 (left), 13, 16, 33, 35; courtesy of John Dabiri Lab: TOC (middle right); Michael Moran: 2; courtesy of Caltech Archives: 3 (top), 9 (top), 39 (Goodstein, Anson); Pranav Patil: 6 (bottom); NASA/JPL-Caltech: 7 (right), 8; courtesy of Emily Silich: 9 (bottom); Jon Nalick: 11; courtesy of Scott Cushing: 12 (left); Sydney Garstang: 12 (right); Max Gerber (image): 15 (right); Christopher Michel: 19 (image); NASA/JPL-Caltech/MSSS: 21 (left); NASA/JPL-Caltech/ASU/MSSS: 21 (right); courtesy of David Brin: 23 (top), 24; photo courtesy of Louise Chow: 23 (second from top), 25; Sequoia Capital: 23 (third from top), 26; Justin Knight: 23 (bottom), 27; Shutterstock/Roman Samborskyi: 28; Bill Youngblood: 29-31; The Graphics Fairy: 32 (heart-colorized); Shutterstock/PhoenixStock (background-manipulated); courtesy of Vivio: 34; Kat Ball: 36; Paul Wennberg: 37; Caltech (right images): 39; Shutterstock/Achira22: 40-41 (background-manipulated); Shutterstock/Photo Melon: 40; Shutterstock/Pumped-Visuals: 41; June Edmonds (back cover).

Printed by Courier Graphics Corporation, Phoenix, AZ

MIX Paper | Supporting responsible forestry FSC® C007548

The newly opened Resnick Sustainability Center will serve as both a hub for sustainability research and as a physical gateway for pedestrians on campus.

Letters

On That Note

When I was a student at Caltech (1959–1964), there was a professor who had built a pipe organ in his home. As I remember it (that was 60 years ago!), there were pipes all over his home, but it sounded really great.

Upon further research (from my journal 5/27/1962):

"Drove over to the late Professor Hunter Mead's home for an organ recital. This 106-rank pipe organ was built over 12 years at a cost of $33,000. It was a beautiful sounding thing with the sounds coming from all sides. Except for a few small living areas, the house is filled with pipes and even the walls have been pushed back and the roof raised to accommodate more pipes."

George R. Cannon, Jr. (BS '64)
SAINT GEORGE, UT

Editor's note: *Hunter Mead, a former professor of philosophy and psychology, and director of musical activities at the Institute, wrote an article titled "The Philosophy of Organ-Building" for the February 1950 issue of Caltech's* Engineering & Science *magazine, which documented his home organ project.*

Read the story

Office Ovation

I love this premise and this story ("Inside Look," Spring 2024)! When I was at Caltech, I loved hanging out in George Rossman's office. Real and not-quite-real minerals to stump the viewer! George's most devious nonmineral was a vial of sugar crystals the color (more or less) of emeralds. (However, it might be too esoteric for nongeologists.)

Mary Johnson (BS '76)
SAN DIEGO, CA

A Time for Joy

One of the biggest successes that my daughter had as an undergraduate student at Caltech was "meeting her tribe." At a time when social-emotional learning and growth was at its most important, she found *joy* at Caltech (due to professors, TAs, housing, her major, etc.).

She and her partner (whom she met at Caltech) are now successful graduate students on the East Coast at prestigious universities—a large reason why I still open your email—because it all started at Caltech.

A part of this email is simply a "thank you" for your newsletter. Another part is for me to say that I would love to read more about the JOY that students, professors, and administrators find and gather at a school as prestigious as Caltech. Few will think about social-emotional growth at a school like Caltech, but I consider myself to be the luckiest mom in the world because Caltech gave my daughter just that—*happiness* and *joy* (among a thousand other opportunities, strengths, talents, and more).

Tricia
ORANGE, CA

A Data-Driven Decade

What an amazing 10 years with @Caltech & @YueLabCaltech! I'm very grateful for the wonderful students, postdocs, and other collaborators I've worked with. Thanks to everyone who attended, especially the alumni who traveled back to celebrate!

Listening to the stories that were told, I was struck by the moments that left lasting impressions for students and postdocs. Many moments were not the ones I thought were important, which again reminded me of the influence and responsibility that comes with being an advisor.

Thanks for all the memories, let's make some more!

Yisong Yue, professor of computing and mathematical sciences, posting on X following his 10-year anniversary party

SoCaltech

Reflecting on *Spectrum Petals*

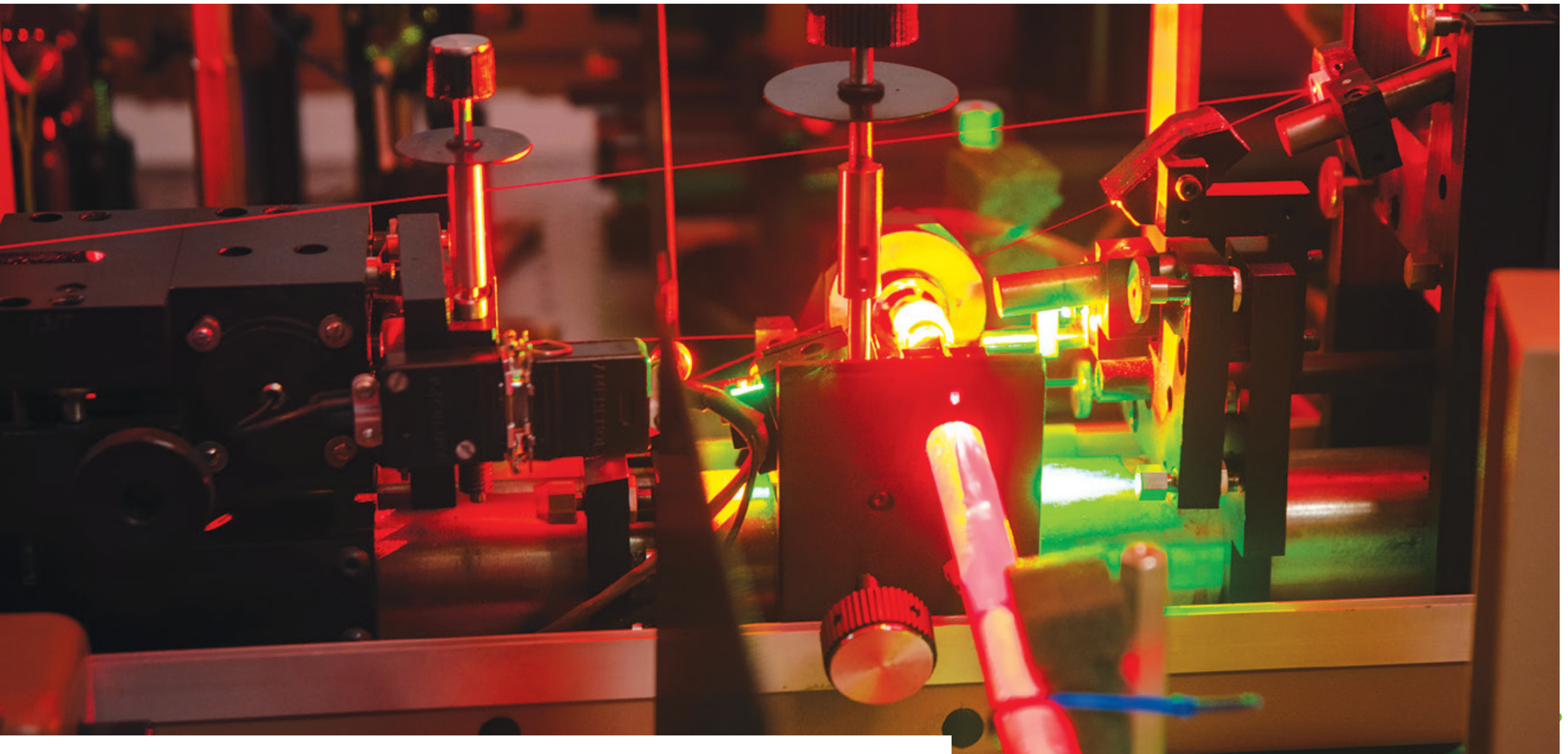
Seven circular acrylic sculptures have brought a playful, captivating presence to Bechtel Mall. They are *Spectrum Petals*, a new art installation by artist Shana Mabari for Caltech's *Crossing Over: Art and Science at Caltech, 1920–2020* exhibition, part of Getty's PST ART initiative. On display through December 15, 2024, *Spectrum Petals* evokes wonder through its dynamic interaction with light and space. The work is sponsored by art organization The Island.

Each sculpture measures 3–4 feet in diameter and has a mirrored surface in a different color of the electromagnetic spectrum. "Color isn't just about aesthetics; it shapes our emotions, perceptions, and even decisions." Mabari says. "The ability to perceive colors from electromagnetic waves in the visible spectrum is a remarkable gift, allowing us to experience the world in rich and nuanced ways."

Mabari cultivated a deep appreciation for the intersection of art and science during a 2004 collaboration with Shinsuke Shimojo, Caltech's Gertrude Baltimore Professor of Experimental Psychology, to develop optical illusion environments. She has also worked with neuroscientist Christof Koch and neuromorphic engineer Tobias Debruck (PhD '93), both of whom spent time at Caltech. These partnerships have inspired her exploration of how humans perceive their body position and movement as well as light and color.

"Mabari's colorful sculptures beautifully activate Bechtel Mall," says *Crossing Over* curator Claudia Bohn-Spector. "Hard-edged and luminous, they sprout like alien blossoms."

The sculptures appear to float effortlessly atop the grass, offering an opportunity for serene reflection—both literally and figuratively. "There is a sense of calm and centeredness in the work," Mabari says. "I hope it offers a meditative quality, an escape from the chaos of daily life that invites people to embrace a more thoughtful experience of joy and harmony."



Shine a Light

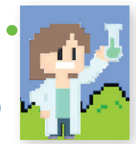
Sometimes, only a 50-year-old laser will do. Nick Hutzler (BS ’07), an assistant professor of physics, says this Coherent 599 tunable dye laser, manufactured in 1977, is a surprisingly useful tool for an initial step in his lab’s analysis of electron excitations in three species of metal-containing molecules: ytterbium, strontium, and radium hydroxide.

Because the dye laser emits light at a broad bandwidth, the team can create a large, yet low-resolution, image that includes a wide range of the electronic excitation spectrum at once. If the team were to use a more popular low-bandwidth laser at this stage, they would have to take a series of images to cover the same range.

Broad-bandwidth lasers have fallen out of fashion, Hutzler says, because researchers often prefer to zero in on a more specific frequency range in higher resolution using lasers that emit light at a lower bandwidth. “It sounds weird, but the reason we like this laser is because it’s really bad,” Hutzler says.

But what happens when the 50-year-old laser breaks? “It’s not a very precise instrument,” Hutzler says. “We’ve had mirrors and mounts on them break, and we just eyeballed it and made a new part, which you couldn’t do for a modern laser. If it really came down to it, we probably could just build a whole new one.”

What is VISUAL ACTIVISM?



“Why do organizers turn to visual culture to communicate demands?” “What are the potential limits of representations?” “Can art help us to understand, enact, or imagine politics otherwise?” These are some of the questions posed by Caltech’s Anna Stielau, the Weisman Postdoctoral Instructor in Visual Culture, during her spring 2024 Visual Activism course.

Visual activism, Stielau explains, “goes above and beyond art. It’s a big-tent term that names a range of practices that employ the visual as a political tool, from livestreaming police violence to snapping selfies that fill a void in mainstream media.”

Stielau came to these questions as a photography student at the University of Cape Town in South Africa in the 2010s, a time when students there were protesting institutional racism and the legacy of apartheid in education. “Student activists were so savvy about social media and the ability of visual materials to broadcast information.”

Stielau assigned her students a project in which they used writing exercises to figure out their stance on a specific issue and then come up with a way to visually express that sentiment. Some designed posters, while others took photographs and created memes. Computer science major Pranav Patil (BS ’24) designed a playable computer game about the impacts of privatized health care. “If I can teach them to be sensitive to questions of audience or to think about form, they can apply these things irrespective of the messages they are trying to communicate,” Stielau says.

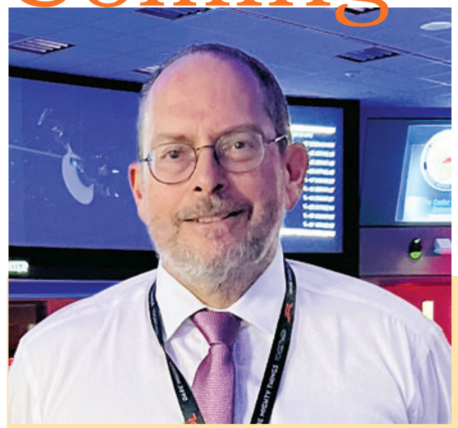
Read more

A still image from *The Price to Live*, a computer game created by Pranav Patil (BS ’24).

Alums Coming Back

“I’m really excited about championing the impact of what KISS has been able to achieve in the past and what we can do in the future. KISS is recognized for its significant impact in many different areas. Through over a hundred workshops, we’ve brought together thousands of people from over 300 organizations representing 27 countries, fostering interdisciplinary collaboration.”

– **Harriet Brettle** (MS ’19) on her new role as executive director of the Keck Institute for Space Studies



“My first experience working with scientists and engineers at JPL was over 40 years ago as a Caltech graduate student. From that time to the present, it has been clear to me that no other institution matches its combination of scientific breadth and engineering capability. I am thrilled to be able to play a leadership role on the science side of this remarkable institution.”

– **Jonathan I. Lunine** (PhD ’85) on his new role as chief scientist at JPL, which Caltech manages for NASA

"Farewell, Dear Friend"

On April 19, 2021, NASA's Ingenuity Mars Helicopter made history when it completed the first powered, controlled flight on another planet. Though it was expected to make no more than five test flights over 30 days, Ingenuity soared higher and faster than ever imagined by its team at JPL, which Caltech manages for NASA. The aerial scout for the Perseverance rover touched down for the final time on January 18, 2024, after its 72nd flight in just under three years. Here are some of the well wishes sent to Ingenuity and its team throughout its mission.

"It's an honor to share this lifetime with you. Thank you for dreaming, daring, and doing!"

"Anything is possible when a group of dedicated people work together. Congratulations on a successful mission and for making history."

"You are an amazing helicopter, and I love you."

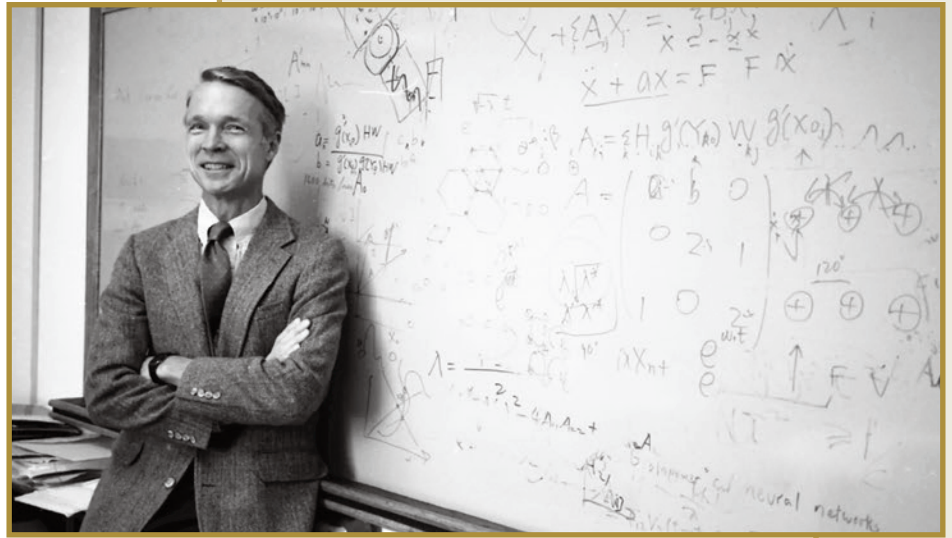
"I watched the first moon landing and felt privileged, and now I get to see a helicopter scanning the Mars landscape. Thank you, Ingenuity and team."

"Ingenuity, you danced in Martian skies, a testament to human brilliance. Your legacy inspires us all. Farewell, dear friend."

"So very proud of you and the team that built you. We must never forget that exploration is a wondrous endeavor."

"Congratulations on being the first 'flying machine' on Mars. Jules Verne would be so amazed!"

AI Pioneer John Hopfield Wins Nobel Prize



Caltech professor emeritus John Hopfield won the 2024 Nobel Prize in Physics along with Geoffrey Hinton of the University of Toronto "for foundational discoveries and inventions that enable machine learning with artificial neural networks." Hopfield, now a professor of molecular biology at Princeton University, served as a professor of chemistry and biology at Caltech from 1980 to 1996 and is currently the Roscoe G. Dickinson Professor of Chemistry and Biology, Emeritus, at Caltech. He co-founded Caltech's Department of Computation and Neural Systems (CNS) in 1986.

Today's machine learning, or artificial intelligence (AI), tools—such as ChatGPT and other programs that can assemble information and seemingly converse with humans—have roots in Hopfield's pioneering work on artificial neural networks. In the early 1980s, Hopfield merged his background in physics with neurobiology to create a simple computer model that behaved less like the computers of that time and more like the human brain.

Referred to as the Hopfield network, his computer model mimics the architecture of the human brain to store information. The Hopfield network consists of nodes that are connected to each other like neurons in the human brain; the connections between nodes can be made stronger or weaker, such that the strong connections form memories.

Shortly after joining the Caltech faculty, Hopfield teamed up with the late physicist Richard Feynman and with Carver Mead (BS '56, PhD '60), the Gordon and Betty Moore Professor of Engineering and Applied Science, Emeritus, to co-teach a yearlong course called The Physics of Computation. The course was intended to unite their respective fields to explore the relationship between nanoscale physics, computation, and brain function. Three years later, the class evolved into CNS, a new interdivisional program at Caltech that is now a vibrant community of scholars that includes dozens of faculty and has produced more than 100 PhDs.

"We never even thought about it being a department," Mead recalls. "We had lunch at the Athenaeum together. I was in engineering, John was in chemistry, and Dick [Feynman] was in physics, and we had such good arguments that we thought we should have this discussion with the students. It was the best of all worlds, and that happens at Caltech."

Hopfield's Nobel Prize is the 48th awarded to Caltech faculty, alumni, and postdoctoral scholars.

Intergalactic *Verse*

Emily Silich, a Caltech graduate student in astronomy, wrote a poem inspired by her studies of collisions between two massive clusters of galaxies in which vast clouds of dark matter have decoupled from so-called normal matter. Here is an excerpt:

t = zero:
particles initialized,
gas defined as air.

Opposing dipoles
traversing as livid breath
sans its collisions.

Magma-colorized,
decoupling from itself in
tumultuous twists

from tessellations.
An issue of memory
nonessential for

epochs defined by
some time within another;
Parallel elapse.

The full poem was published as part of a collection in the *Altadena Poetry Review Anthology.*

Adoniya Paul (first-year undergraduate 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.***

Adoniya Paul, a first-year undergraduate from Long Beach, is passionate about engineering, rocketry, and art. She came to Caltech through the QuestBridge National College Match program, which connects high-achieving students from low-income backgrounds to top colleges. Through an early-decision process, students rank their college choices among 50 partner institutions and receive a full scholarship. Paul is a member of Caltech's undergrad class of 2028, which is the first incoming class comprised of 50 percent women since the Institute began admitting female undergraduates in 1970.

"I pretty much put all my eggs in one basket. With QuestBridge, you can rank up to 15 schools, and every school is binding except MIT. I only ranked two—my top choice was Caltech, and the second was MIT. The only reason I ranked MIT was because it wasn't binding, so I thought if I do get into MIT, at least I still have another chance to get into Caltech.

I feel proud and inspired to be part of this historic incoming class. The 50 percent represents a lot more than having an equal number of men and women. It represents the fact that women are now confident to go into the areas they are interested in and don't feel limited by their surroundings or a lack of support."

In the Community

Making a Chemistry Connection

Caltech Connection participants and organizers during a poster session in May 2024.

“I wanted to create a program for LA-area people who have that scientific knack but have no way or no confidence to make their first step into the scientific realm.”

Growing up in West Virginia, Scott Cushing knew little about scientific laboratories or careers, but he loved to tinker with mechanical things, and he repaired cars for money and for fun.

Lasers first captivated him as an undergraduate at West Virginia University, inspiring his career trajectory and ultimately leading him to Caltech. As an assistant professor of chemistry, Cushing builds laser-based scientific instruments. He has also started a mentoring program called Caltech Connection to give students from community colleges and other schools without broad research programs an opportunity to discover if there is something in science that sparks their interest. “I wanted to create a program for LA-area people who have that scientific knack but have no way or no confidence to make their first step into the scientific realm,” Cushing says.

Now in its fourth year, Caltech Connection pairs graduate students and postdocs at the Institute with undergraduates from Pasadena City College (PCC), Compton College, Santa Monica College, East LA College, Cal State Los Angeles, Cal State Dominguez Hills, and Charles Drew University, the latter a historically Black graduate institution in South Los Angeles. More than 60 percent of the program’s mentees come from low-income households and some 70 percent work at least part-time to pay for their education.

During the 2023–24 academic year, the program’s 50 students performed research using state-of-the-art scientific equipment and with mentors who engage in that work daily. Most mentor–mentee pairs meet once a week or once every other week. In the first half of the program, mentors often try to teach soft skills such as time management and how to read a scientific paper. In the second half, many mentors identify a specific research project for their mentees to dig into—maybe completing a calculation, coding a problem, or learning how to operate an instrument. “By the end, we hope the mentees are making independent or joint contributions to their mentor’s project,” Cushing says.

PCC student Kevin Aday applied to the program in fall 2022. He was paired with Greg Lavrentiadis, a postdoctoral scholar research associate in mechanical and civil engineering at Caltech who studies fault displacement and ground motion models of earthquakes. By early 2023, Aday was working with Lavrentiadis to correct seismic records affected by instrument response during the magnitude 6.5 and 6.8 earthquakes in Taiwan the previous year.

Next, he worked with Lavrentiadis to create a model to characterize ground motions in Groningen, Netherlands, an area that has experienced human-made earthquakes caused by the removal of natural gases. “Getting the opportunity to not only observe but take part in the work being done in the lab was the most valuable experience that I’ve had in college thus far,” says Aday, who recently began studying engineering as an undergraduate at UC Berkeley.

About 80–90 percent of students from PCC who participate in Caltech Connection and similar programs transfer to research-intensive universities compared to only 10–20 percent of their PCC peers. “The mentees are incredible,” says Tiffany Kimoto, executive director of the Kavli Nanoscience Institute at Caltech, who serves as an administrator for the program. “I’ve watched some folks start off as shy students ... and develop into stellar graduate researchers at top-rate institutions and leaders among their peers.”

—Kimm Fesenmaier

Origins

A Feline Predator in Arms Lab

In an unassuming corner of the Charles Arms Laboratory of the Geological Sciences, a fanged feline snarls behind a glass cage. But this predator can no longer hurt you. The skeleton of a *Smilodon fatalis,* or saber-toothed cat, has been on display since 1997, when it was loaned to the Division of Geological and Planetary Sciences (GPS) by the Natural History Museum of Los Angeles County (NHM).

The blackened *Smilodon* bones excavated from LA’s La Brea Tar Pits between 1913–15 come from multiple saber-toothed cats between 12,000 and 33,000 years old; the composite skeleton was assembled in the mid-20th century. Caltech paleontologist Chester Stock measured the skull for his 1932 publication, *The Felidae of Rancho La Brea*, and, in many ways, the *Smilodon* on display in Arms tells his story.

Stock, who went on to shape GPS, NHM, and public engagement with paleontology for generations to come, became enamored with the La Brea asphalt pools after excavating there as a geology student at UC Berkeley, and he continued to study the site’s large vertebrate fossils for the rest of his career.

Stock joined the Caltech faculty in 1926, helping to found the GPS division and establish its paleontology program. In the classroom, Stock wove vivid lectures about the Pleistocene-era creatures that once roamed the region. He also took students into the field on fossil-digging expeditions across the American West and Mexico. When the Arms building opened in 1938, most of its ground floor served as a museum to display Stock’s specimens, including a towering dinosaur skeleton.

Meanwhile, Stock also served as a curator at NHM, where he ignited imaginations with fossils and laid the groundwork for the development of the La Brea site into a museum that invited guests to descend into an excavation area. Stock did not live to see the results, passing away in 1950. But the Observation Pit, now part of NHM’s La Brea Tar Pits Museum, opened in 1952 and was dedicated in his honor.

After his death, NHM acquired Stock’s fossil collection at Caltech for $100,000, and the museum in Arms was converted to office space. GPS used the funds to invest in a new research frontier: geochemistry (see story on page 14). “I find it interesting that the money from the collections helped to start the geochemistry program,” says Julia Tejada, an assistant professor of geobiology at Caltech and a William H. Hurt Scholar. “It’s very full circle, because my research combines both paleontology and geochemistry.”

Tejada also has an academic connection to her paleontological predecessor at the Institute. Her master’s advisor at the University of Florida and her PhD advisor at Columbia University both were advised by Stock’s student Malcolm McKenna.

Now working just a few doors down from the *Smilodon*, Tejada finds that the skeleton connects Caltech’s history with that of the region. “Having such a magnificent specimen here is incredible. It shows you how LA was only 15,000 years ago: populated by mammoths, giant ground sloths, saber-toothed cats, and camels. It just humbles you and evokes your imagination.”

—Julia Ehlert

Signatures from the Past

How isotope research digs deep to solve mysteries from ancient Earth and beyond.

By Lori Dajose (BS '15) • Illustrations by Charis Tsevis

John Eiler used isotope studies to measure the body temperature of dinosaurs.

It was Thanksgiving Day 2015, and geochemist John Eiler was sitting alone in an airport in Bremen, Germany, eating goose—the closest thing he could find to the turkey he would have been having back home with his family in Sierra Madre. He had ventured to Bremen, an ancient port city of industrial infrastructure, on a quest to realize his dream of creating a powerful machine that could see tiny variations in the abundances of rare isotopes and map their positions within a single molecule.

All matter is made up of chemical elements. The individual atoms of a particular element can vary in the number of neutrons in their nuclei; these variants are called isotopes. For decades, existing instruments called mass spectrometers had been effective at measuring the ratios of different isotopes—each of which have a different atomic mass but the same elemental properties—of atoms and of the atoms within a few simple molecules. These ratio measurements had enabled major discoveries about the solar system and Earth's ancient history, but they had also missed the vastly more comprehensive and potentially useful information encoded in the isotopic structures of more complex molecules. Eiler knew that with a more powerful and specialized machine that could interrogate these isotope structures, isotopes could be used to answer an even broader set of questions about Earth, the wider universe, and the human body.

Isotopes act as chemical fingerprints, enabling a forensic-like analysis of materials that can answer an array of surprisingly diverse questions, like what extinct giant sloths liked to eat and where asteroids formed in the cold expanse of outer space. The technology Eiler spent years designing and developing would go on to break new ground, allowing researchers to unlock even more valuable data. "I felt like it was going to happen, but I don't think anybody else thought that it would happen," he says of the arduous process.

Eiler's work builds upon a long history of Caltech researchers who have pushed the frontier of isotope geochemistry since the 1950s, using isotopic signatures to discover Earth's age, analyze lunar samples obtained by the Apollo missions, and understand ancient climate records preserved in natural environments. Now, a new generation of Institute faculty, including geobiologist-paleontologist Julia Tejada and geochemist François Tissot, is adding to that legacy by pioneering new technical advances and practical applications that have led to a wide variety of breakthroughs, including better ways to detect osteoporosis in humans, a more detailed understanding of the evolution of life on Earth, and how the chemical building blocks of all living things got here.

A Paleontologist's New Tool Kit

On her annual expeditions to the hot, humid Amazon rainforest, Julia Tejada wields the traditional tools of a paleontologist—pickaxes, brushes, hand lenses, the ability to ignore swarms of mosquitos—with ease while unearthing ancient animal fossils. But she is not a traditional paleontologist. Tejada's tools back in the lab enable her team to peer at the atomic-level isotopic variations in fragments of fossil samples. "You don't need isotopes to look at a saber-toothed tiger skull and know that it ate meat; just look at the morphology of its teeth," she says. "But to answer deeper, subtler questions about how ancient life evolved on Earth, you need to look at the molecular level."

Isotope geochemistry allows Tejada to study ancient environments like lush forests and oceans even though they are long gone. This is because their chemical record can still be found in the fossils of creatures that roamed Earth millions of years ago, such as bear-sized sloths and giant penguins. These early environments contained water, air, and nutrients with isotopic ratios that differ from those of today and which left distinctive signatures in ancient fossils. Tejada studies isotopes in these fossils to uncover stories about the past; in particular, she examines extinct sloths (see cover) that could grow to be almost 10 feet tall and were a major component of ancient ecosystems.

"More than 90 percent of organisms that have ever lived on our planet are now extinct," says Tejada, who joined the Caltech faculty in 2023. "To understand how the evolution of life led us to where we are today, we have to look deep back in time. In the absence of fossil plants, biomarkers preserved in soil or incorporated into bones, teeth, or hair can tell you something about the environment in which an organism lived millions of years ago."

Most elements on the periodic table exist in multiple isotopic variations. For example, the majority of carbon atoms have six neutrons and six protons in their nuclei, earning the name carbon-12 or C-12. But slightly more than 1 percent of all carbon atoms have seven neutrons (and six protons) and are thus dubbed carbon-13. Extra neutrons make atoms heavier, which causes them to behave slightly differently in chemical reactions. These variations in weight and behavior can be detected in the lab. Using mass spectrometers, researchers can measure isotopic ratios to draw conclusions about an object's history.

While Tejada's laboratory contains the modern tools to make measurements at the atomic level, it also seems to double as an animal-skeleton emporium. During a hot morning this past July, she pulled large bones out of cardboard boxes to show students, deftly explaining the differences between a pelvis and a femur. These particular bones, she noted, were not fossils; they came from a modern cow. Tejada will use them to teach the students how to properly cut and treat bone samples before they move on to handling more precious fossil samples.

Tejada's lab can analyze these older specimens and make startling discoveries with a mere whisper of material. Her work has revealed surprising insights that may not be evident from morphology alone. For example, a particular ancient sloth was presumed to be a herbivore due to the shape of its preserved teeth. By studying the isotopes present in specific amino acids within the sloth fossil, Tejada proved that the animal also ate meat, overturning the original hypothesis.

In this way, isotope geochemistry helps underscore the old maxim, "You are what you eat." For example, elements you consume become embedded within your bones, teeth, and hair. But the power of isotopes is not limited to analyzing nutrition in living beings; many chemical processes impact isotopic ratios. Certain isotopes of lead are only produced as part of the decay of uranium atoms over millions of years. The more of this "radiogenic" lead in an object, the longer the object has been around. The late Caltech geochemist Clair Patterson used this logic, along with measurements of the lead isotope ratios in ancient rocks, to measure the age of our planet: 4.6 billion years, certainly enough time to evolve myriad sloths.

Did You Know?

Julia Tejada is only the second paleontologist to join the Caltech faculty. Learn more about the first, Chester Stock, and a feline fossil from his collection still on display at the Institute, on page 13.

Julia Tejada uses isotope geochemistry to study the fossils of ancient animals and learn more about their lives.

Digging Deeper

Rainwater in the Rocky Mountains is isotopically lighter than in California because as clouds travel across land from the ocean, heavier isotopes are rained out, leaving a higher abundance of light water by the time the clouds reach the interior land. In this way, the water you drink carries a signature of where it came from.

A History of Discovery

Before the 1950s, isotope research in the United States focused primarily on isotopes of a certain subset of radioactive elements, like plutonium and uranium, that could power nuclear weapons. After World War II, scientists who honed their skills on the Manhattan Project found themselves looking for less destructive ways to apply their knowledge. In the '50s, several young scientists who had studied how to translate isotope science into the study of ancient Earth came to Caltech.

These geochemists turned Caltech into a powerhouse in the geological and planetary sciences. After Patterson created one of the nation's first clean room laboratories in the process of measuring Earth's age, he used his expertise to campaign for the removal of lead from gasoline, reducing air pollution. Samuel Epstein, who was invited to Caltech by Harrison Brown, founder of the Institute's geochemistry program, used isotopes to study the Antarctic and Greenland ice sheets and learn about the origin of meteorites, tektites, and lunar rocks and minerals. In a laboratory fondly nicknamed the "Lunatic Asylum," lunar expert Gerald Wasserburg built the first-ever digital mass spectrometer and used isotopes from lunar samples to study cataclysmic collisions between asteroids and the Moon. Due to these scientists and other luminaries in the field, the Institute's technology and laboratories became top of the line, with researchers accessing the latest mass spectrometers for their discoveries.

When Eiler arrived at Caltech in 1994, he found himself in awe of these famed geochemists and others. "They had really big personalities, and they trained virtually everybody who was influential in the field at that period," he says. "My first impression was, 'I'm not ready for this. These people are on a completely different level!'"

Still, Eiler soaked up their insights like a sponge. After a few years of attending daily seminars and developing what he calls "good taste in problems," he proposed a new direction for isotope research that would ultimately define his career. It was driven by a simple question: What if, instead of simply measuring how much of a given isotope was in a sample, you could also measure where an individual isotope was located in the structure of each molecule?

Eiler knew that if you could understand isotopic positions within molecular structures, the questions you could answer would be extremely wide ranging. It amounts to the difference between having aggregate data about a large group of people versus knowledge of each individual's specific qualities. Suddenly, otherwise identical molecules become unique, like a fingerprint.

Consider an everyday molecule of sucrose, the main component of white sugar: One molecule of sucrose contains 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms arranged in two connected hexagonal loops with protruding spiky branches. Each of these atoms could be a different isotope—perhaps a heavy oxygen atom sits on the outside edge of the molecule, or perhaps close to its center. Maybe there are two, or more, heavy isotopes of hydrogen, carbon, or oxygen—or all three. When all these possible combinations are considered, sucrose must exist in quadrillions of isotopic variations, each pointing to the unique conditions under which they formed.

"The isotopic structures of molecules—that is, the numbers and spatial organizations of the rare isotopes they contain—can be measured on literally any compound known to science, and they record a vast amount of detailed information about how and where that molecule formed and what it has experienced since its formation," Eiler explains. "The ability to probe these data brings the complexity of something like genomics to the study of even simple, mundane-seeming molecules. This is something that can be used to understand the formation of molecules in interstellar space, the evolution of life on Earth, the detection of life on Mars or other planets, or metabolism and disease in the human body."

Eiler knew he would need a machine more sensitive than existing mass spectrometers to accurately examine a large variety of molecules and differentiate their isotopic signatures. Unfortunately, such a tool did not exist—yet.

Star Stuff

While Tejada and Eiler use isotopic geochemistry to examine Earth's past environments, their next-door colleague in Caltech's North Mudd Laboratory, geochemist François Tissot, started his career by using isotopes to peer even further into the past—to the beginning of the solar system itself.

Tissot keeps pieces of ancient meteorites safely locked in his office and will readily pull them out to show to any visitors who may be interested. Shiny white geometric chunks within the rocks are compounds of calcium and aluminum, the oldest remaining objects in the 4.6-billion-year-old solar system.

Looking at these rocks, it is hard to imagine that the elements in our own bodies also have the same far-off origins—but it is true. The calcium atoms in our bones, along with all other elements on Earth, were originally forged in the heat of stars—indicating we are not only what we eat, but we are also "made of star stuff," in the words of the late astronomer Carl Sagan. While we share common origins with all matter on Earth, isotopes are able to tell tales of the journeys that atoms and molecules have taken to reach their present-day forms.

Take Hadean zircons, for example—tiny crystals from the early formation of Earth, preserved over 4 billion years, and the only remaining solids from the earliest crust of the planet. Tissot wanted to use zircons to understand Earth's primordial environment. In the absence of any rock from this time period, finding hard evidence of what Earth looked like is a true challenge, and many varying theories about its earliest days have been proposed. For instance, it had previously been hypothesized that our planet was so hot and radioactive at this time that nuclear fission spontaneously occurred on the surface. The isotopic composition of uranium in zircons could confirm or refute this, but the samples of zircon available were far too minuscule to use traditional techniques. So, in 2018, Tissot invented a way to probe the isotopic ratio of uranium inside a single crystal of zircon, and he used that to show there is no evidence supporting the hellish vision of an early Earth covered in natural nuclear fission reactors.

Tissot had always wanted to find a way to apply the knowledge and expertise he gained from studying meteorites and terrestrial samples to help humankind, and he got that opportunity after joining the Institute faculty in 2018. He was named one of Caltech's Heritage Medical Research Institute Investigators in 2021, becoming part of a program that supports translational sciences and health technology work. Tissot proposed a project to use his isotope geochemistry skills in the study of calcium isotopes in human urine to detect osteoporosis, a disease affecting millions of people over the age of 50.

Osteoporosis occurs when bones become weaker and less dense. It has no outward symptoms and is usually only detected after an elderly person suddenly breaks a bone. Currently, osteoporosis is measured with costly reconstructions of bone density using X-ray techniques. Nearly a quarter century ago, a team of geochemists from Berkeley had proposed that bone health could be determined by monitoring the calcium isotopes in blood or even urine samples. "In meteorites, calcium isotopes can provide clues about the early solar system, but in bones, they can serve as a useful marker of health," Tissot notes. "In particular, calcium isotopes in bone tend to be slightly less heavy than those found in blood, tissue, and muscle. In osteoporosis, this light calcium leaks out of the bone and into the bloodstream, altering the blood's isotopic ratios and ultimately becoming detectable in urine."

While the rationale is simple to understand, the potential of the approach had seldom been put to the test.

To demonstrate the medical applications of this research, Tissot and his team first solicited participants from the Caltech community to provide urine samples so the technique could be refined. "The techniques used in isotope geochemistry are very good at making precise measurements of tiny purified samples," he says. "But it's very different to transfer to a medical application where you need to measure samples from hundreds, if not thousands, of people in a reasonable time frame."

François Tissot studies isotopes in meteorite fragments to learn more about the origins of our solar system.

Next, his lab scaled up the project with a nearly 300-person population survey to see whether or not calcium isotope levels vary demographically or over short periods of time in healthy people. As a result of their findings, the Tissot lab has developed procedures for handling more than 100 samples in a single week, indicating that their techniques could one day be scaled up and implemented in clinical settings that manage larger volumes. "We can now do measurements that are unparalleled in precision and at such a rate that large-scale clinical studies are possible. We're starting to design them now," Tissot says.

In addition to the osteoporosis project, Tissot remains connected to his planetary science roots. Recently, Tissot gave a lecture discussing how samples returned from Venus could tell us at what point in their evolution Earth and its twin diverged so dramatically. "Whether it's in the human body or outer space, isotopes respond to the same general rules no matter the system," he says. "If the question is interesting, the isotopes allow you to study it."

Learn more about how sample return work continues to play an important role in Caltech's Division of Geological and Planetary Sciences.

Eiler's Machine

In 2003, Eiler began working with LA-based Thermo Fisher Scientific to achieve his goal of nailing down the exact locations of isotopes within atoms in order to unlock vast amounts of molecular information. The trick was convincing the manufacturer that new types of machines designed for this purpose would not only function, but that they would be used by other researchers. "I think they thought I was crazy," Eiler recalls.

Although the first generation of this new mass spectrometer was capable of studying only a small fraction of the chemical compounds he hoped was ultimately possible, Eiler produced some preliminary findings and began to give talks around the world about the machine's potential for breakthroughs. As knowledge of the instrument and its use grew, and with as many as 50 other labs signaling their interest in the technology, Thermo Fisher became convinced of the utility in developing the product, which would eventually become known as the Orbitrap mass spectrometer.

Eiler filed a patent and continued to work through generations of increasingly more capable designs of the Orbitrap with Thermo Fisher engineers, visiting the company's factory in Germany multiple times. The Orbitrap's capabilities expanded, enabling researchers to examine the isotopes in more complex molecules. And Eiler continued to demonstrate its value through his own research. In 2011, his team showed that isotopes in fossilized dinosaur eggshells could be used to directly measure, for the first time, the body temperatures of ancient dinosaurs. In the years since, Eiler's lab has made similar breakthroughs in the understanding of the ancient climate on Mars and the origins and fates of methane and other organic molecules in the natural environment.

In the last decade, Eiler's dream of creating an atom-by-atom view of a wide range of molecules has been realized. Thanks to the Orbitrap, more precise measurements of isotope ratios have been made possible—even in small samples. This ability could prove crucial in planning future missions to study samples returned from other bodies in the solar system like asteroids and Mars.

Orbitrap mass spectrometers are now up and running in labs around the world, and multiple versions of the machine are now available. They are making a difference on campus as well. In addition to the work Tejada and Tissot are doing, collaborators across Caltech are using the Orbitrap in a wide variety of studies: to look at the degradation of plant litter in soil, the "prebiotic" chemistry that enabled the emergence of life, and more. Eiler's team even uses it to help detect steroidal doping in elite athletes, funded by the research collaborative Partnership for Clean Competition. "Molecules of synthetic testosterone look identical in shape to the testosterone naturally produced by your body, but not when you really scrutinize down to the isotopic level," Eiler explains. "We can take blood samples and see if the testosterone all looks the same, or if there are two different kinds—which would indicate that someone was doping."

The Orbitrap's diverse applications are the reason Eiler dedicated so much time to building the technology. "You don't ask the first person to invent a telescope what star they're looking for," Eiler says. "This is to look at absolutely everything. If there's a molecule, and you have a question about it, we can do something to answer it."

Eiler's successful journey to expand the realms of possibility builds on a legacy of geochemistry excellence at Caltech that helped draw both Tejada and Tissot to Pasadena. "John is the man," Tissot says. "It's inspiring to be surrounded by people who are legends in their fields." C

John Eiler is the Robert P. Sharp Professor of Geology and Geochemistry and the Ted and Ginger Jenkins Leadership Chair of the Division of Geological and Planetary Sciences. His work is funded by the National Science Foundation, among others.

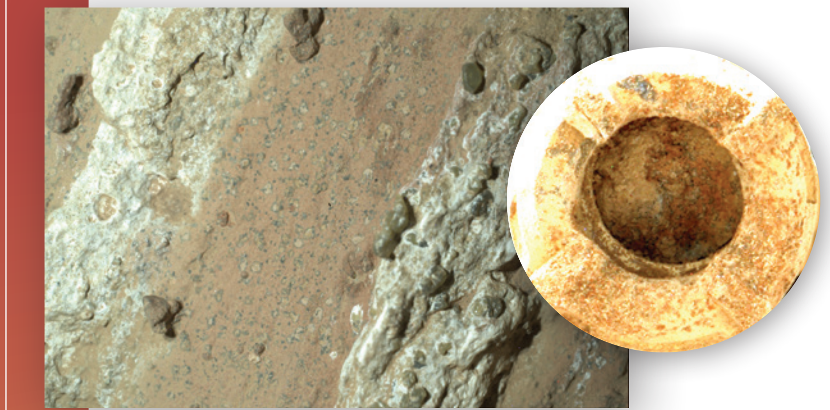
Julia Tejada is an assistant professor of geobiology and a William H. Hurt Scholar. Her work is funded by the Shurl and Kay Curci Foundation, among others.

François Tissot is a professor of geochemistry and a Heritage Medical Research Institute Investigator. His work is funded by the Heritage Medical Research Institute, a Packard Fellowship, and the National Science Foundation.

An Intriguing Red Planet Rock

A sample discovered by the Perseverance rover offers hints that Mars may have hosted microbial life billions of years ago.

By DC Agle



NASA's Perseverance Mars rover used its Mastcam-Z instrument to capture this view of the Cheyava Falls rock sample within the rover's drill bit.

A vein-filled rock nicknamed "Cheyava Falls" discovered by the Mars Perseverance rover on the northern edge of Jezero Crater in July 2024 contains fascinating traits that may indicate possible signs of ancient microbial life.

The rock, which measures 3.2 feet by 2 feet, exhibits chemical signatures and structures that could have been formed by life billions of years ago when the area being explored by the rover contained running water. The rock was collected on July 21, 2024, as the rover explored an ancient river valley called Neretva Vallis that measures a quarter-mile wide and was carved by water rushing into Jezero Crater long ago. Multiple scans of Cheyava Falls by the rover reveal it contains organic compounds. While such carbon-based molecules are considered the building blocks of life, they also can be formed by nonbiological processes.

"Cheyava Falls is the most puzzling, complex, and potentially important rock yet investigated by Perseverance," says Ken Farley, Caltech's W. M. Keck Foundation Professor of Geochemistry and Perseverance project scientist at JPL, which Caltech manages for NASA. JPL manages the Mars 2020 mission. "On the one hand, we have our first compelling detection of organic material, distinctive colorful spots indicative of chemical reactions that microbial life could use as an energy source, and clear evidence that water—necessary for life—once passed through the rock. On the other hand, we have been unable to determine exactly how the rock formed and to what extent nearby rocks may have heated Cheyava Falls and contributed to these features."

> "To fully understand what happened … we'd want to bring the Cheyava Falls sample back to Earth, so it can be studied with the powerful instruments available in laboratories."

Running the rock's length are large white calcium sulfate veins, between which lie bands of material whose reddish color suggests the presence of hematite, one of the minerals that gives Mars its distinctive rusty hue. When Perseverance took a closer look at these red regions, it found dozens of irregularly shaped, millimeter-sized off-white splotches, each ringed with black material akin to leopard spots that contain both iron and phosphate.

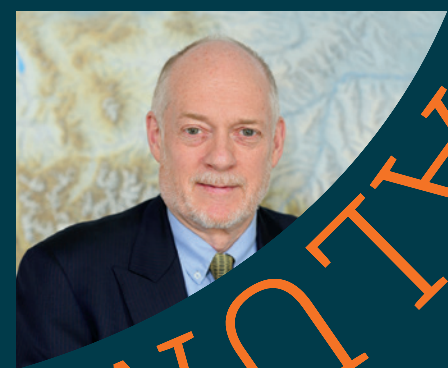
"These spots are a big surprise," says David Flannery, an astrobiologist and member of the Perseverance science team from the Queensland University of Technology in Australia. "On Earth, these types of features in rocks are often associated with the fossilized record of microbes living in the subsurface."

Spotting of this type on sedimentary terrestrial rocks can occur when chemical reactions involving hematite turn the rock from red to white. These reactions, which may serve as an energy source for microbes, can also release iron and phosphate, which cause black halos to form. In one scenario posed by the Perseverance science team, Cheyava Falls was initially deposited as mud with organic compounds mixed in that eventually cemented into rock. Later, a second episode of fluid flow penetrated fissures in the rock, enabling mineral deposits that created the large white calcium sulfate veins seen today and resulting in the spots.

"To fully understand what happened … we'd want to bring the Cheyava Falls sample back to Earth, so it can be studied with the powerful instruments available in laboratories," Farley says. C

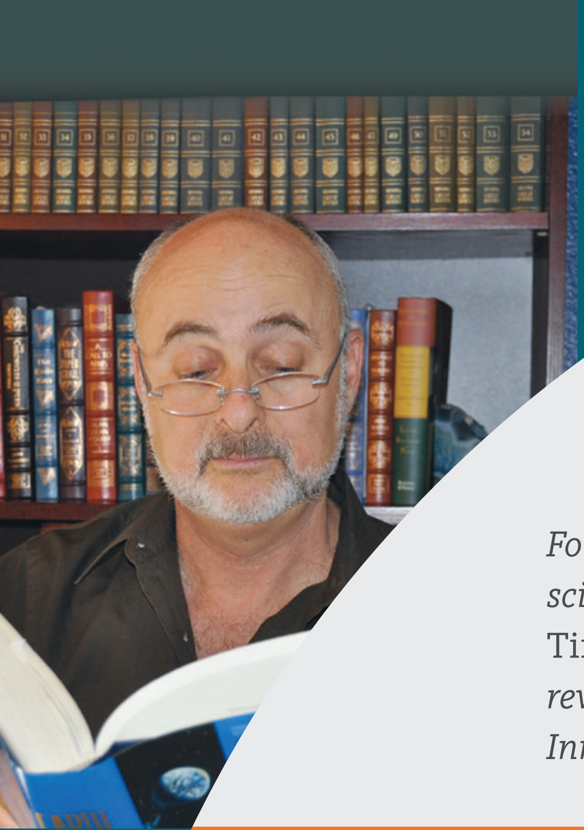
Meet the 2024 DISTINGUISHED ALUMNI

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 2024 luminaries include a lauded best-selling science-fiction author and futurist; a chemist whose electron microscopy analysis revolutionized our understanding of genes and messenger RNA; a leading tech industry executive, venture capitalist, and mentor; and a chemical-sensing innovator whose research has led to life-saving discoveries.



By Chris Quirk

Awardee interviews were conducted by the Caltech Heritage Project.



David Brin (BS ’73)

Astronomy; Science Fiction Author and NASA and Corporate ‘Futures’ Consultant

For his enduring excellence in storytelling, examining how change, science, and technology affect the human condition in his New York Times *best-selling science fiction novels, and for his support of revolutionary ideas in space science and engineering through NASA’s Innovative and Advanced Concepts Program.*

When David Brin began his studies at Caltech, he found it curious that many of his scientific heroes at the Institute had creative or literary pastimes—including Nobel laureates Murray Gell-Mann (an enthusiast of James Joyce, obscure English literature, and Greco-Roman history) and Richard Feynman (a bongo player and painter). “I was told by my father that he took me to see Einstein play the violin—at Caltech—when I was 3,” Brin says. “It always struck me how many top researchers also nurture an arty side.”

Brin came to Caltech to pursue his love of astronomy and went on to earn a doctorate in astrophysics at UC San Diego. But he, too, harbored an artistic passion: writing. During his student days in Pasadena, he crafted stories and novels on evenings and weekends.

He intended to continue in academics, but lightning struck. His second novel, *Startide Rising,* won both the Hugo and Nebula prizes in 1984 for best novel, cementing his place as a bright new talent. “It became clear that civilization valued my art a bit more than it valued my science,” he recalls. “Who am I to argue with civilization?”

Brin has since written more than 20 books, including both novels and short fiction, which have been translated into 20-plus languages; those books have earned him two additional Hugo awards, as well as other honors. *The Postman,* Brin’s postapocalyptic tale of human redemption, was adapted into a 1997 feature film starring Kevin Costner.

A sought-after public commentator on science and technology, Brin has appeared on CBS, PBS, the BBC, and other media outlets, and has served as a keynote speaker at more than 200 meetings and conferences.

In 2013, Brin assisted in the creation of the Arthur C. Clarke Center for Human Imagination at UC San Diego, where imagination is studied and cultivated through research that focuses on neuroscience, technology, speculative futurism, and the cosmos. As a “future-tech” consultant, he has worked with Google, Microsoft, the U.S. Air Force, the CIA, and NASA, among others, advising on topics as diverse as space exploration, national defense, nanotechnology, and the future of science and society. He is also a member of the External Advisory Council of NASA’s Innovative and Advanced Concepts Program. “It’s NASA’s agency for looking—very successfully—into projects that are just this side of science fiction,” he explains.

Brin’s books are regularly lauded for their level of scientific precision and detail, as well as their plausible extrapolation of the possible. But the story always comes first and, when circumstances dictate, Brin does not let fidelity to known scientific laws cramp his creativity. “I like to keep my work credible, but I don’t allow that to exclude a rip-snorting yarn!” he says.

In 2023, Brin collaborated with the Institute’s literary society TechLit to mentor “awesome-good writers” for its anthology *Inner Space & Outer Thoughts: Speculative Fiction From Caltech and JPL Authors*. “Of course, I already knew top science types can do excellent art,” Brin says. That same year, Caltech Playreaders premiered Brin’s stage play *The Escape* at the Athenaeum.

Brin credits his time at Caltech as having a profound impact on his life and his writing. “I came away from Caltech with probably the best education I could possibly have had,” he says. “The exposure to ideas was fantastic, and the after-class discussions and arguments with the both classmates and teachers? Unparalleled.”

Louise T. Chow (PhD ’73)

Chemistry; Biochemist and Molecular Geneticist

For her pioneering research using electron microscopy to determine genome organization and RNA transcription, which led to the Nobel Prize-winning discovery of split genes and RNA splicing, one of the most important breakthroughs in molecular biology, as well as for research that has opened doors to improved diagnosis and treatment of human papillomaviruses.

Louise Chow, a world-renowned expert in human papillomavirus (HPV) biology, played a crucial role in the discovery of split genes and mRNA splicing.

After receiving a bachelor’s degree from National Taiwan University in 1965, Chow came to Caltech as a chemistry graduate student in the lab of Norman Davidson, the Norman Chandler Professor of Chemical Biology, where she investigated relationships between bacterial genes and integrated bacteriophages using electron microscopic analyses. “Norman was brilliant and provided excellent training; I am grateful for his mentorship and kindness,” says Chow. She would go on to meet her future husband and lifelong collaborator, Thomas Broker, when he joined the lab as a postdoc in 1972.

Chow discovered her strong aptitude for electron microscopy (EM) characterization of nucleic acids while at Caltech. “With the scope, you find structures of interest and assess what they are right on the spot,” she says. “I was good at and loved interpreting complex DNA pairing interactions.” This skillset initiated her 50-year career investigating the basic science of DNA tumor viruses.

Chow and Broker joined Cold Spring Harbor Laboratory in New York in 1975 and started mapping human adenovirus mRNAs by EM visualization the next year. In 1977, she and collaborators discovered split genes and mRNA splicing, which would garner the 1993 Nobel Prize in Physiology and Medicine for her Cold Spring colleague Richard Roberts, along with MIT’s Phillip Sharp. Chow and Broker additionally demonstrated that adenovirus mRNA genesis used alternative polyadenylation sites and alternative splicing of primary transcripts; a year later, they found it used alternative promoters as well. These processes produce families of messages, greatly expanding the coding capacities of genomes and enabling sophisticated regulation of gene expression.

Many scientists felt Chow should have been awarded the Nobel Prize as well, noting that the EM experiments unambiguously demonstrated split genes and mRNA splicing, and provided a logical interpretation of puzzling biochemical results from her colleagues. “The evidence she discovered was a critical part of the total creative insight that splicing was taking place. Only she could have interpreted those data,” Davidson told *The Boston Globe* at the time.

In 1982, Chow and Broker began investigating prevalent human papillomaviruses that can cause anogenital and oropharyngeal cancers. Their research continued at the University of Rochester from 1984–93, and then at the University of Alabama at Birmingham from 1993 onward, where Chow was a professor and Distinguished Professor of Biochemistry and Molecular Genetics, now Emerita. Their lab has characterized HPV RNA transcription, gene regulation, and viral DNA replication and amplification, and deciphered virus-host cell interactions and 3D tissue culture systems to recapitulate the productive infection program or to simulate HPV cancers. They exploit these systems to identify potential inhibitors of HPV-caused diseases that include benign lesions, dysplasia, and cancers.

Chow was awarded the American College of Physicians Medal in 1996; she was elected to the National Academy of Sciences in 2012 and Taiwan’s Academia Sinica in 2013. She became a fellow of the American Academy of Microbiology in 2013.

Because HPV prophylactic vaccines have no effect on preexisting infections, Chow and Broker still work five days a week during retirement in the hope that their research will lead to effective, inexpensive drugs to treat HPV diseases. “It may not be in my lifetime, but at least we have a better knowledge of what could work,” she says.

Bill Coughran (BS, MS ’75)

Mathematics; Technology Investor, Executive, and Mentor

For his influential role as a Silicon Valley executive, mentor, and investor, helping ambitious start-ups grow into transformative companies, and for overseeing the development and continual improvement of iconic products at Google, including Chrome, Maps, and Google Search.

Bill Coughran first saw a computer as a middle-school student in Fresno in the 1960s. The local high school had just acquired a desktop Digital Equipment Corporation PDP-8 machine that used paper tape punches and readers. “It was an ancient system,” he recalls.

But the experience of trying out the machine propelled his early interest in math and science, a passion that brought him to Caltech and, later, to Silicon Valley, where his combination of technical know-how and business acumen has made him a lodestar in the tech industry. Coughran has served as a founder’s coach and partner at venture capital firm Sequoia Capital for more than a decade, mentoring numerous innovators and executives, and helping them navigate the tricky channels on the journey from great idea to successful company.

Coughran took so many math courses at Caltech that he earned both a bachelor’s and a master’s degree in four years. “Caltech was very challenging from an intellectual standpoint,” he says. “When I was an undergraduate, I enjoyed the smallness of the place because we got to know each other.” He then decided to pursue computer science at Stanford, earning a second master’s and a PhD.

In 1980, Coughran accepted a job at Bell Labs, then one of the most innovative research and development companies in the world. He had the freedom to work on open-ended projects, such as semiconductor simulations, and he reveled in the collaborative, multidisciplinary environment. “There were world-class physics people there, chemists, mathematicians, people working on acoustics, and they had some remarkably strong research work in computer science,” he recalls.

Eventually, he was tapped to lead Bell’s scientific computing and numerical analysis group before heading up the renowned computer science research center.

Coughran returned to the West Coast in 2000 and co-founded fiber-optic broadband company Entrisphere, which was eventually bought by telecommunications company Ericsson. Then, in 2003, Google recruited Coughran to run the internet search firm’s infrastructure group. “Google had a few hundred employees when I joined, so it was a start-up, but it was a start-up with some heft already,” he says. Toward the end of his Google tenure, Coughran managed an engineering department of more than 7,000 employees on four continents. He had also overseen much of the development of Google Maps and helped create the Chrome browser team.

In 2011, Sequoia presented Coughran with a challenge that appealed to his spirit of innovation: working with entrepreneurs to develop small companies. “One of the things that is very hard to simulate inside a large company is the life-or-death experience in a start-up,” he says. “Tension and that existential risk adds a dynamic to a small company that’s stressful, but it also is a crucible that creates new ideas.”

Coughran now mentors a select group of promising start-ups and sits on the boards of several tech companies, as well as that of the San Francisco Opera.

“Caltech made me much better as a problem solver,” he says. “It heightened my ability to take ambiguous problems and constraints, analyze them, and deconstruct them into solvable components. The experience was transformative for me and made me intellectually stronger.”

Timothy M. Swager (PhD ’88)

Chemistry; Chemist

For his groundbreaking advancements in molecular electronics and chemical sensing, which created a new generation of devices with unparalleled levels of chemical sensitivity, and for translating these discoveries to benefit humanity, such as keeping troops safe from explosives.

As a child in rural Sheridan, Montana, Timothy Swager felt more comfortable tending livestock than stepping into a classroom. As a teenager, he spent his summers working on the farm owned by his future wife’s grandfather and uncle. “I wanted to be a rancher,” Swager says. “I don’t think anybody back then would’ve expected me to be an MIT professor.”

Despite some early struggles with reading comprehension, Swager excelled at chemistry in high school, and when he began his studies at Montana State University, the department gave him the keys to the building. “I started doing research in that lab, and I didn’t look back,” he says.

Now the John D. MacArthur Professor of Chemistry at MIT, Swager has delved into some of the most complex regions of chemistry, and his discoveries have led to the creation of lifesaving tools and inventions. Most notably, Swager’s work has transformed the field of chemical sensing through the development of technologies that can detect vanishingly small traces of dangerous compounds.

Swager’s Fido explosive detection system, for instance, is a handheld device that can be used to sniff out explosives and land mines; it can detect as little as a femtogram of TNT in seconds. As a way to keep food supplies safe, he created a sensor to detect pathogenic bacteria. Recently, Swager developed a method of finding minute quantities of toxic PFAS (per- and polyfluoroalkyl substances), which are found in a variety of consumer products. “We can detect these forever chemicals in under an hour, at levels below the EPA limits, which are in the low part-per-trillion range,” Swager explains. “This is all really exciting and important. There are big health risks from PFAS in the environment, and I feel good about the fact that we can help prevent exposure.”

As a Caltech student, Swager did research in the lab of the late Nobel laureate Bob Grubbs, who recruited Swager to his research program to start an effort in polymer chemistry. “Bob’s group was teeming for decades with spectacular postdocs and graduate students. Being part of the Grubbs clan also gave me a little cachet, and helped make good things happen for me,” Swager says. “Caltech is particularly good for people who really want to grow and find themselves because they encourage you to take courses outside your area and not just be monolithic in your coursework.”

In recognition of his groundbreaking research, Swager has received the Carl S. Marvel Award for Creative Polymer Chemistry from the American Chemical Society, the Christopher Columbus Fellowship Foundation Homeland Security Award, and the Lemelson–MIT Award for Invention and Innovation. Swager is also a fellow of the American Chemical Society, and is a member of the American Academy of Arts and Sciences and the National Academy of Sciences.

Swager notes that his teaching philosophy at MIT is informed by what he learned from his Caltech professors as a student. “From day one at Caltech, I felt that the culture was to be a virtuous scientist, and the Caltech philosophy prepared me to be the best scientist possible,” he says. “I tell my students that you can’t bury a piece of data because it doesn’t fit. In fact, that piece of data is usually telling you something profound.” [C]

The EVOLUTION of TROLLING

Understanding the scientific underpinnings of toxic online behavior.

By CYNTHIA ELLER

What causes people to display more toxic behavior when interacting with others online rather than in person? Caltech's Dean Mobbs, professor of cognitive neuroscience, along with postdocs Swati Oandity and Ketika Garg, and former research assistant Jianjin Zhang, have constructed a theoretical model to answer that question.

Mobbs, who is also the director and Allen V. C. Davis and Lenabelle Davis Leadership Chair of the Caltech Brain Imaging Center, and an affiliated faculty member of the Tianqiao and Chrissy Chen Institute for Neuroscience at Caltech, calls the model he and his team created the DAD framework (Disembodiment, lack of Accountability, and Disinhibition). The factors that comprise the framework's name make it more likely that social media interactions skew toward a level of nastiness and misinformation not seen in face-to-face communication.

First, disembodiment: In most social media exchanges, people have no direct sensory experience of one another. "When I'm speaking to somebody online, the conversation I'm having is all in my head; it's completely disembodied," Mobbs explains. Without cues from another's facial expressions or body position, these interactions, though they may feel external, are transacted entirely within one's internal world. It is here, Mobbs says, where the problem lies. "Your internal world is your playground not just for ideas or for what you want to say, but sometimes for things you shouldn't say. When you are communicating in this disembodied state, having a conversation in your mind, you begin to forget that you're having a conversation with a real person."

Lack of accountability occurs when social and cultural norms that operate in person to provide checks on interpersonal communication are absent and, with anonymity, even the fear of criminal punishment is gone. "I can say something via text on social media, and, often, I don't have to pay the consequences of saying it," Mobbs says. "I don't get social disapproval at the same level I would as if I were with someone in person, and, frequently, I either am or believe myself to be completely anonymous."

The first two factors lead to the third: disinhibition. "It is disinhibition that allows you to say whatever you think, whatever you want," Mobbs says. "All of those nasty thoughts that you have in your head can just come out of your fingertips without interference."

The DAD framework is grounded in an evolutionary perspective on emotion that is at the core of Mobbs's research. "Other animals have different strategies, such as camouflage or enhanced senses that detect threats, but we typically rely on avoiding predators before actually encountering them. We have not evolved for a social media environment," Mobbs says. "The sensory systems and theory of mind systems we have evolved in previous millennia do not translate well into an online domain," which leads to the "impaired interactions" that create online toxicity.

Mobbs and his co-authors suggest accountability can be strengthened by forcing users to register their social media accounts under their legal names, by slowing down the rate of interactions, or by introducing AI content moderators to provide more time for users to think about the consequences of their actions. Even the simple use of emoticons and avatars can help to mitigate the effects of disembodiment on our online behavior as they help to make others appear more real and their feelings more apparent.

The paper, "Three roots of online toxicity: disembodiment, accountability, and disinhibition," appears in the September 2024 issue of *Trends in Cognitive Sciences*. The work was funded by a gift from Sonja and William Davidow.

Inside Look

Joe Parker

Beetles are on the brain and the desk of this evolutionary biologist

By Omar Shamout

Joe Parker calls California "frontier territory" for undiscovered insects. The Caltech entomologist and evolutionary biologist estimates he has found dozens of new species since arriving at the Institute in 2017 and possibly thousands during his lifetime. "I would need several more lifetimes to actually put names on everything," he says.

While Parker unearthed many of these specimens doing field work in the nearby San Gabriel Mountains, he did not even have to leave home to make one recent find. "We wanted to study the chemical defense gland of a beetle species attracted to flesh flies, which gather on rotting mammal carcasses," says Parker, an assistant professor of biology and biological engineering, director of the Center for Evolutionary Science (CES), and a Chen Scholar. "So, my kids and I put dead rats behind our fence in South Pasadena. As soon as the rats started getting munched by flesh-fly larvae, some beetles showed up. It turns out, there's a species that had never been found that was living, literally, in our backyard, and we now have a whole genome sequence for it."

Parker, who was recently named a MacArthur Fellow, has loved bug hunting since he was a kid growing up in Swansea, Wales. A childhood hobby turned into a lifelong passion at age 7, when Parker visited the National Museum of Wales with his father and toured a zoology exhibit. "There was an insect display with a giant southeast Asian cicada," he recalls. "It was completely mesmerizing with its bulbous eyes, almost mechanical body segments, and huge wings. I just thought, 'There's a parallel world on planet Earth, and it's the world of insects.'"

Today, Parker's lab focuses on the symbiotic relationship between insect species, particularly rove beetles and ants. Rove beetles (*Staphylinidae*), which live in soils and dead leaves around the world, represent a sprawling radiation of over 66,000 species, making them not only the largest known beetle family but the largest known family in the entire animal kingdom. Parker's team studied one group of rove beetles that has evolved to mimic ant pheromones or produce chemicals that pacify aggressive worker ants, enabling the beetles to live symbiotically with the ants and even prey upon them.

> "There's a parallel world on planet Earth, and it's the world of insects."

Recently, Parker and colleagues, including Caltech Professor of Biology Mitchell Guttman, assembled whole genomes from species spanning the rove beetle's evolutionary tree. They analyzed the genes expressed in two cell types found in a gland on the abdomen of rove beetles; this enabled the researchers to uncover a genetic toolkit that evolved over 100 million years ago to equip these insects with their powerful chemical defenses. "What you have in these beetles is a virtuoso example of organisms evolving new ways to interact with other species," Parker says.

Through his role as director of the CES, Parker is able to offer seed funding to a wide variety of research projects across the Institute. "The center has managed to start nascent projects in labs that may not previously have had the opportunity to do something with an evolutionary dimension to it," he says.

The design of Parker's office in Caltech's Mabel and Arnold Beckman Laboratories of Behavioral Biology is appropriately insect themed: The hexagonal shelving and floor tiles are inspired by insects' compound eyes, and the carpet pattern is reminiscent of an insect's wings. Framed insect specimens sit around his desk, which also contains thousands of tiny nonliving specimens housed in custom glass-encased drawers. Glass walls in his office and lab are adorned with enlarged versions of his own insect line drawings.

Despite working in such a buggy sanctum, Parker enjoys going outside to hunt for new colonies to study. "I love being in the field," he says. "I worked in sterile biomedical campuses as a PhD student and postdoc, but I grew up rooting around in the dirt. Bringing those two ways of looking at insects together was always something I wanted to do."

Here are some of the objects adorning Parker's office.

Beetles encased in amber

Parker keeps this 99-million-year-old amber deposit on the shelf above his desk. Inside are some of the first species of rove beetles to evolve on Earth, found in the same amber that encases the earliest-known ants. "This encapsulates a very important time in insect evolution, just as ants and other social insects were starting to appear," Parker points out. "It embodies an ecosystem before ants rose to ecological dominance."

Beetle treadmill

Parker's lab uses this tiny sphere, affectionately known as a beetle treadmill, to study how the insects behave and interact with ants and other stimuli in real time. It was given to Parker by his colleague Michael Dickinson, the Esther M. and Abe M. Zarem Professor of Bioengineering and Aeronautics, who wrote the names of Parker; Parker's wife, Heidi; and their oldest two children, Jonah and Eden, on the tiny white ball, which is about 1 centimeter in diameter. "The beetle walks along on this air-supported spherical treadmill," Parker says. "You can prod it with an ant or another stimulus to see if it deploys its chemical defenses. The names on the ball serve as landmarks so we can calculate its path and trajectory. This ball is older than my youngest son Oscar; he has his own."

The Guests of Japanese Ants (2013)

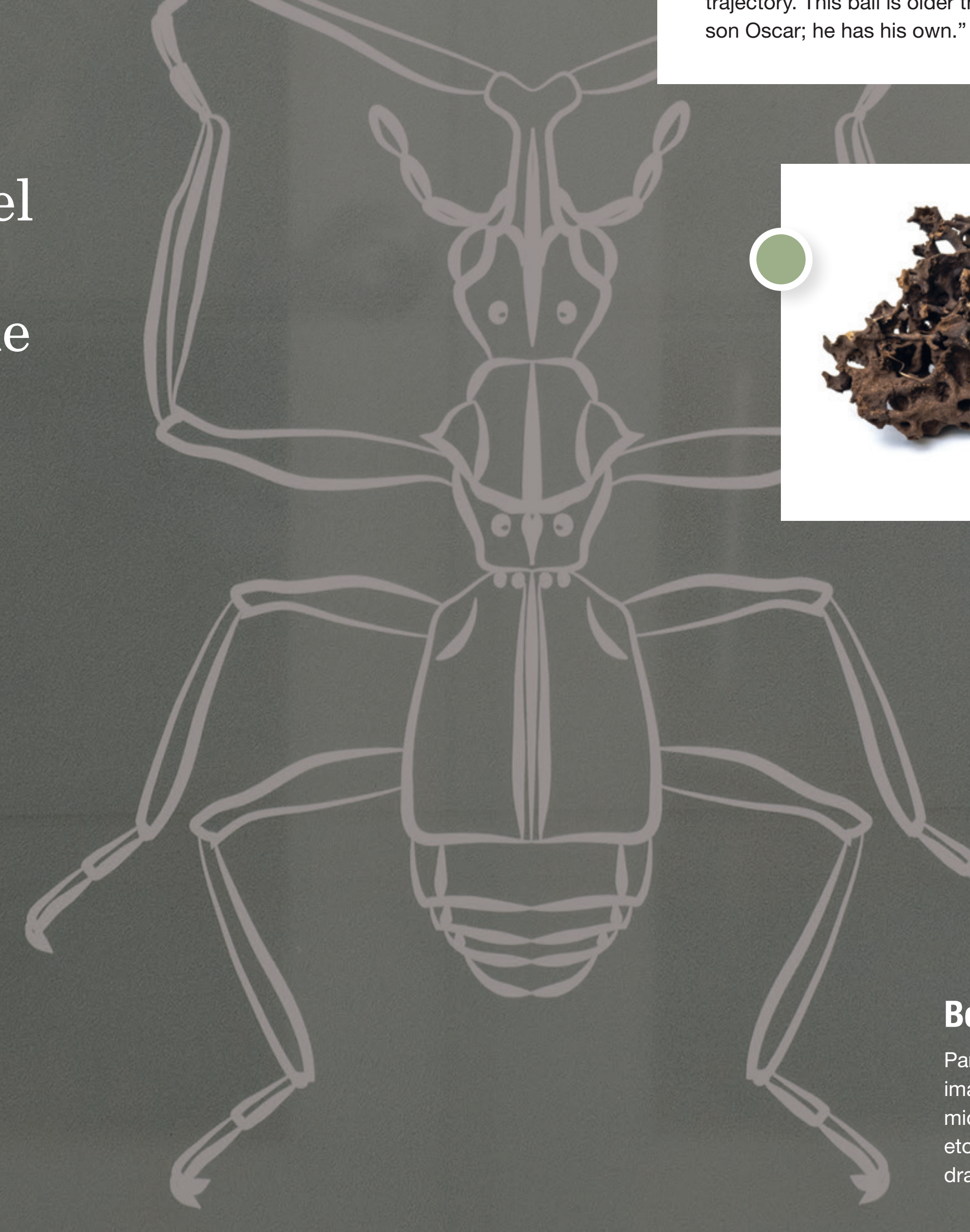
This book, which documents every species of organism in Japan that lives inside a colony, was co-written by entomologist Munetoshi Maruyama, a friend of Parker's. Japan, Parker says, is fertile ground for studying insects due, in part, to the humid climate and mountainous terrain. The field of entomology has also attained an uncommon level of mainstream attention in the country. "The best entomology in the world happens in Japan, and they have an appreciation for insects that is unique," he says. "This book would never have any market over here, but this is a popular book in Japan. Each one of the authors frequently appears on TV shows. They're almost like celebrities."

Velvety tree ant nest chambers

Colonies of the velvety tree ant build these intricate nest structures inside oak trees. Each colony contains perhaps a million ants, which together transform the insides of a trunk into a labyrinth of microchambers. "We call it the crunchy magic material," Parker says, noting the rove beetles studied by his lab, which pose as ants, also live in these nests. "Inside the tree is this incredibly complex microenvironment with probably thousands of these tiny chambers." Velvety tree ants bite, however, so collecting specimens can be dicey. "If you find a hole in a tree and reach inside to pull out the nest, you will get annihilated by the ants," he says.

Surrealist painting

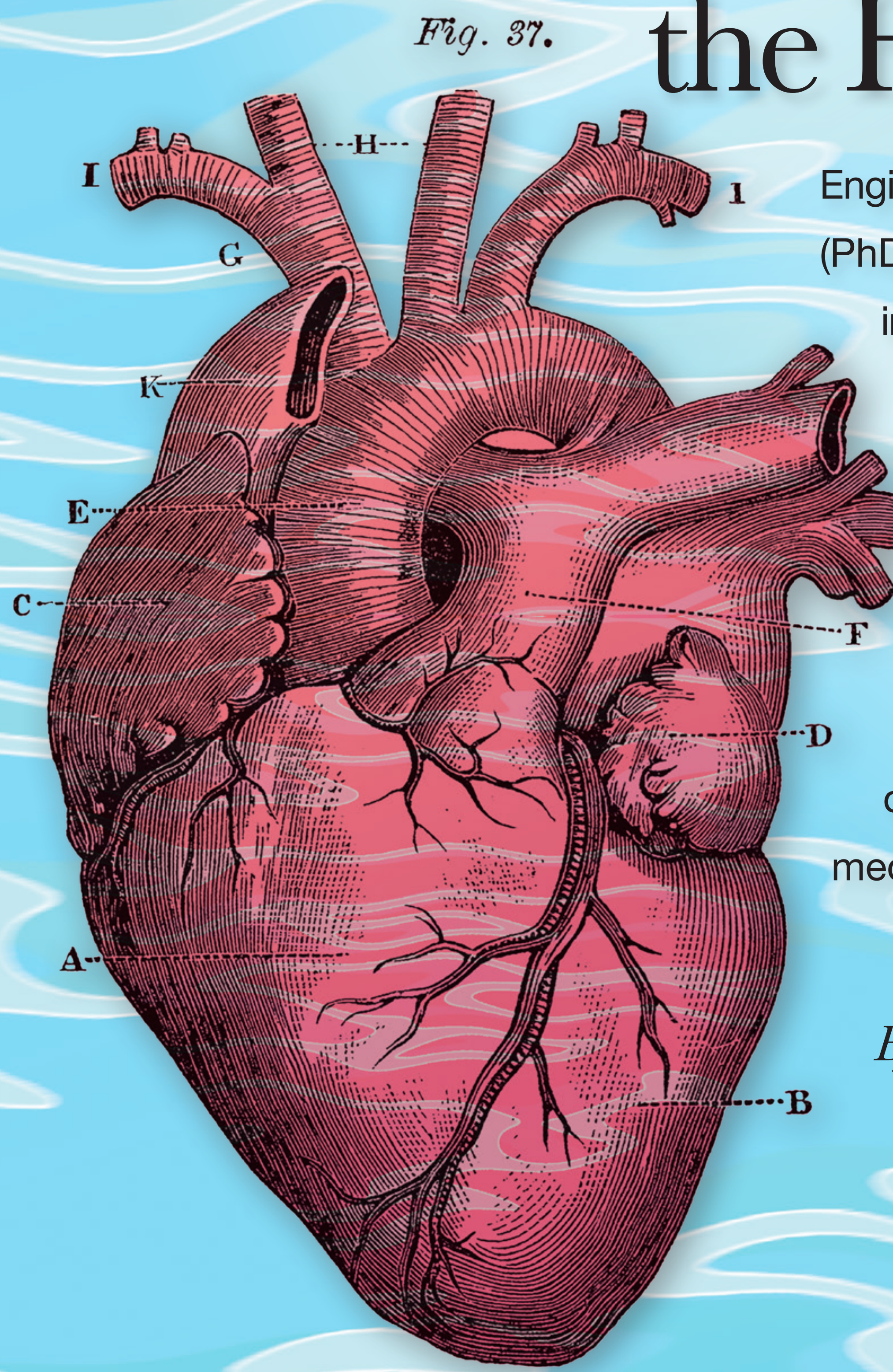
Parker's father, John, a sociology professor, made this small painting, along with several others of a similar style, for his son. John has always enjoyed making art, though wood sculpture is his usual medium. A few years ago, John began to experiment with painting on thick blocks of wood. "Each one of them is kind of surrealist," Parker says, noting this piece contains shapes and figures that could be construed as insects. "Sometimes they converge into things that you recognize."



Beetle line drawing

Parker himself sketched this line drawing (at left) of a rove beetle based on a confocal image of the insect. The image was made by placing a specimen sample under a microscope and shining a laser on it, thereby illuminating its autofluorescent exoskeleton. Autofluorescence is naturally emitted light from cells and tissues. Many similar drawings of beetles and ants made by Parker decorate his lab and office.

Ripples from the Heart



Engineer **Mory Gharib** (PhD '83) delves into the mechanics of the body's most critical biological pump to reveal its secrets and develop lifesaving medical devices.

By Katie Neith

The heart is an enigma that has mesmerized philosophers, physicians, and scientists for centuries. At its most basic level, it is a muscle that pumps blood throughout the body and delivers oxygen and nutrients to cells while removing waste. But if you look closer, the heart is much more than that, says engineer Mory Gharib (PhD '83), who has not only been intrigued by the organ's mechanics but has spent decades trying to understand how it functions at its most fundamental levels.

"It's a fascinating physiological machine," Gharib said in his 2023 Watson Lecture, "Enigma of the Heart," noting the organ's remarkably intricate structure of four chambers and four valves represents a wonder of evolutionary engineering. "It is also a sensory organ that can detect changes in environment and respond to them in complex ways. It beats up to 2 billion times over our lifetime. We can't find any mechanical machine that lasts that long. It is one of the most impressive autonomous systems in nature—as long as it is taken care of."

The pursuit of enhanced cardiological care has been bolstered in recent years thanks to Gharib's expertise in fluid dynamics and aerodynamics. While the study of how aircraft fly and how the heart pumps blood may seem like unrelated fields, phenomena such as vortex dynamics and turbulence affect planes and the human body alike. "All it requires is somebody to be curious and try to connect the two," Gharib says. He and his team apply their knowledge to the development of more sustainable and efficient medical devices and technologies that can both harness information hidden within pulse waves emitted by the heart and lengthen the organ's lifespan.

Over his career, much of which has been spent at Caltech, Gharib has welcomed the challenge of finding creative solutions to a wide range of problems, especially those involving the fluid dynamics of biological machines. He traces this trait back to his childhood in Tehran, where his brother, a pediatric surgeon, came to him with an intriguing idea. "I was in high school, and he challenged me to design a shunt for hydrocephalus, which occurs when the pressure in the brain goes up due to a buildup of cerebrospinal fluid," Gharib says.

Gharib finally completed the design 30 years later after investigating how liquid flows and pulses in and around the brain. He and his brother now hold a patent for a pump that is small enough to be implanted without interfering with the brain's functions.

Listening to His Heart

Gharib remembers the day his cardiac curiosity was first sparked. After receiving a PhD from Caltech in 1983, he worked for two years as a senior scientist at JPL, which Caltech manages for NASA, before joining UC San Diego as a professor. "We were working on an experiment trying to see the drag reduction around submerged bodies, like underwater vehicles," Gharib says. "The room is dark, the laser is going, and the head of pediatric cardiology just walks in and says, 'Can you tell me why your engineers aren't working to design a better heart valve?'"

Current mechanical replacements for valves—the parts of the heart that open and close to regulate the flow of blood through the organ—are rigid and damage blood cells. Plus, they are loud; the metal "doors" make an audible noise when they click back and forth. The alternative—biological valves from pig hearts—typically last 10 to 15 years. And they are expensive, both in the cost to prepare them for transplantation and in the lives of the pigs themselves. Gharib knew there had to be a better solution.

He returned to the Institute as a faculty member in 1992, and with the help of lab members and other Caltech faculty, Gharib spent years exploring the mechanics of animals. Jellyfish propulsion, the vascular systems of embryonic zebrafish, and the respiratory systems of dragonfly larvae taught him more about how nature builds valves, which proved valuable to his concurrent research in how blood flows, pulses, and pushes through the human heart. After analyzing how the fluid dynamics they observed might be affected by different materials used to create artificial valves, Gharib and some of his students teamed up with the late Caltech chemist and Nobel laureate Bob Grubbs, who lent his polymer synthesis and characterization expertise to help Gharib's team design a biocompatible, polymer-based mitral valve. The device has no pig or other animal parts and can be manufactured by programmable robots, reducing the cost of each valve by thousands of dollars.

The mitral valve, one of the heart's four valves, regulates the flow of blood from the upper left chamber (the left atrium) to the lower left (the left ventricle), which is the heart's main pumping chamber. When the mitral valve weakens or is damaged, the amount of blood being pumped from the ventricle and into the body is reduced; this can lead to fatigue, dizziness, irregular heartbeats, and even heart failure if left untreated.

Gharib co-founded Foldax, a Caltech-funded company committed to delivering polymer heart valves to patients in urgent need. In 2019, doctors implanted the valve, called TRIA, into a patient for the first time as part of an FDA clinical trial. The Foldax team, together with the patient, recently celebrated the fifth anniversary of the successful procedure.

The TRIA polymer heart valve.

Foldax is currently sponsoring clinical trials of the TRIA mitral valve in India for young female patients who have had rheumatic fever, an inflammatory disease more common in developing countries that can cause severe mitral valve damage. Currently, women of childbearing age have only two options if their mitral valve begins to disintegrate: a mechanical valve that requires the patient to take blood-thinning medication for the rest of their life and can lead to pregnancy risks, or an animal-tissue valve that might degenerate and thus require multiple replacements through open heart surgery.

"The TRIA polymeric mitral valve represents an opportunity for these patients to obtain a better quality of life with a valve that can last their lifetime," says Ken Charhut, executive chair of Foldax and a co-founder, adding that Caltech's backing played a crucial role in the device's development. "It's not only Mory who's unbelievable. Caltech is unique in the way it supports technology and is committed to supporting the road to success over immediate financial gain." Charhut worked as a biotech executive for more than 40 years and has teamed up with Gharib on numerous projects over the past 30 years.

The trials in India represent the largest clinical evaluation to date of a polymer heart valve in humans. The data will be submitted for commercial approval of the valve upon the trial's completion; early results have been positive. "We're saving lives and at a low cost," Gharib says. "Millions can potentially benefit from this device in a way that I hope helps to make it more affordable."

A Wave of Discoveries

One of the heart's mysteries that has piqued Gharib's curiosity is the idea that our pulse might encode information about our health beyond simple heart-rate readings. So, Gharib challenged the students and staff in his lab to help him figure it out. Through that collaborative process, he and his students were the first to calculate that for every heartbeat that generates a pulse, an ensuing wave returns to the heart, bringing with it information in much the same way that sonar bounces back to a submarine.

Right: The Vivio device, which noninvasively measures pressure buildup in the left ventricle, enabling clinical diagnosis of heart failure.

"When the heart contracts, it generates a pressure wave," explains Alessio Tamborini (PhD '23), who studied with Gharib as a graduate student and is now a postdoctoral research associate in Caltech's Andrew and Peggy Cherng Department of Medical Engineering. "As this pressure wave propagates through the vascular system and eventually returns to the heart, its morphology changes in a patient-specific way. By capturing and analyzing this waveform, we can gather information noninvasively about an individual's cardiovascular health."

But Gharib's team first needed to figure out how to extract that information for use in diagnostics. They decided to combine two common devices—a blood pressure cuff and an electrocardiogram patch—with a machine-learning algorithm to detect pulse characteristics associated with heart failure. More specifically, they developed a noninvasive way to measure the pressure that builds in the left ventricle immediately before the aortic valve opens to let blood flow out into the body's arteries. Left ventricular end-diastolic pressure (LVEDP) is greatly elevated in patients with heart failure.

"We collected pulse data from patients with various stages of heart failure," Gharib explains. "This information allowed us to then develop software to detect high LVEDP, a sign of heart failure, which affects millions of people worldwide and is hard to catch in the early stages."

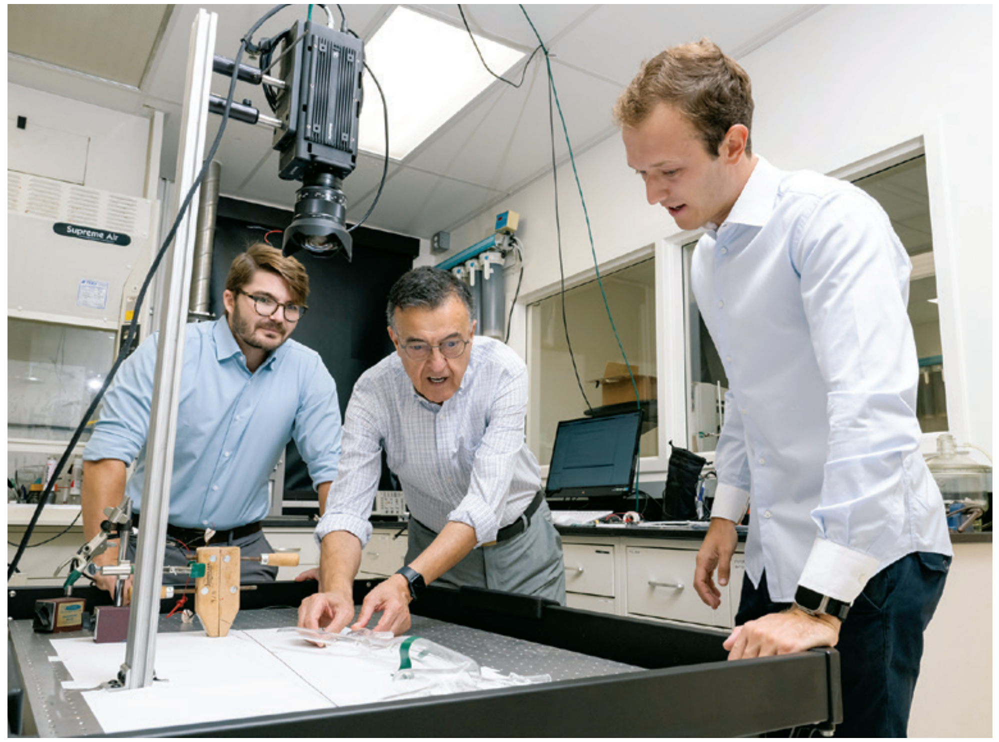
This work led to Vivio, the first and only device to enable noninvasive clinical diagnosis of heart failure. Current diagnostics often require cardiac catheterization—a process in which a tube is inserted into a major artery and maneuvered through the body to the heart—to accurately diagnose, and sometimes treat, the condition.

Vivio, on the other hand, does not require a trained specialist to operate it. A health care provider simply needs to place a cuff on a patient's arm and push a button. The information is then collected on a tablet computer that connects to the cloud, where the data can be reviewed by physicians. This means it can be used in patients' homes, in nursing homes, and in rural communities that might not have easy access to a range of diagnostic tests. "Four or five years ago, this work began as just a box of wires, but now, after multiple iterations, it is being used in clinics by physicians as a cardiovascular diagnostic tool," Tamborini says. "I love being able to develop medical device prototypes in the lab and seeing them evolve to potentially impact human health."

Using the noninvasive Vivio for diagnostic tests also lowers exposure to radiation for both patients and their cardiologists during catheterization because the new device does not require using X-ray technology, while a fluoroscope uses live X-rays to guide the catheter as it moves through an artery to the heart. "We hope to shift the way in which heart failure and other cardiovascular diseases are diagnosed," says Sean Brady, CEO of Ventric Health, a company he co-founded with Gharib and Caltech alumni Niema Pahlevan (PhD '13) and Derek Rinderknecht (PhD '08) to bring Vivio to market. "Earlier diagnosis allows for earlier intervention, improved outcomes, and an overall better quality of life for patients," Brady says.

Ventric Health received FDA clearance for Vivio in 2023 and launched commercially in 2024. The device has been used on more than 2,000 patients since its launch as the rollout continues, Brady says.

Tamborini and Gharib are also working to expand Vivio's capabilities. They believe the device could be used not only to diagnose heart failure but to predict onset of the condition by monitoring pressure measurements both in high-risk situations and over time. Combined with advanced data analysis and machine learning, the product could be used, for example, during surgery or in an emergency room to get real-time readings of a patient's heart health. "Often, the cardiac pulse signal is used in combination with other clinical measurements to give detailed diagnostics of the heart," Tamborini says. "Our objective is to build a comprehensive device to assess pressure throughout the cardiovascular system, enabling physicians to noninvasively understand how the heart is functioning and where it might be failing. This could provide physicians with more accessible information to support more informed clinical decisions."



Alexandros Rosakis (PhD '23), left, **Mory Gharib** (PhD '83), center, and **Alessio Tamborini** (PhD '23) working on their new heart catheter system in the lab.

The Shape of Catheters to Come

Although Vivio could reduce the need for catheters in some diagnostic tests, those catheters are still needed to perform heart biopsies, repair heart defects, and implant stents and replacement valves. That is why Gharib is also working with Alexandros Rosakis (PhD '23), an aerospace research scientist at Caltech who performed heart valve research in Gharib's lab as part of his graduate and postdoctoral work, to design a new shape-sensing cardiac catheter.

To eliminate the radiation risks that come with visualizing the steering of a catheter through blood vessels to the heart for these intricate procedures, Rosakis and Gharib, along with aerospace graduate student Ioannis Mandralis (MS '22) and others at Caltech's Center for Autonomous Systems and Technologies (CAST) have developed an inexpensive catheter guide wire equipped with sensors that can be located using ultrasound instead of X-ray technology. "For our catheter, information from the sensors is combined with a preexisting MRI scan of the patient, which allows surgeons to 'see' the catheter as it travels through the body without the need for direct imaging of the body," says Rosakis, who also works at Foldax. "The data is then fed into an algorithm so that AI can help inform the catheter how to move based on the shape of the artery it is traveling through."

The team soon plans to test the new catheter system in a tabletop model of the vascular system, which will gauge how accurately the device can be navigated from outside the body using a combination of human and AI input. "It's very exciting," Gharib says.

Even after decades of success and multiple spin-off companies that are advancing health care, Gharib is not done delving into the enigmas of the heart. There are, after all, still questions to ask about this complex organ and its individual components, and Gharib sees the Institute as the place where he and his colleagues will be able to find their answers.

"At Caltech, we don't educate technicians, we educate visionaries," Gharib says. "I'm proud that, together with my students, I've been able to come up with unique solutions that not only improve health but do so inexpensively, ensuring that large populations can access them in a more democratized system of care." [C]

Mory Gharib is the Hans W. Liepmann Professor of Aeronautics and Medical Engineering, director and Booth-Kresa Leadership Chair of Caltech's Center for Autonomous Systems and Technologies (CAST), and director of the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT).

Watch Mory Gharib's Watson Lecture

The Lab in the Sky Says Goodbye

A NASA DC-8 aircraft used to train many Caltech student-scientists has taken its final flight.

By Andrew Moseman

When the vintage DC-8 airliner made one of its harrowing low passes over California's Central Valley, things got a little bumpy for the undergraduates packed inside.

It was often hot and stuffy inside the flying atmospheric chemistry laboratory, which NASA had rebuilt in the 1980s and which gave students the chance to perform research, says Emily Schaller (PhD '08), who ran the NASA internship program from 2011 to 2021. On any given research flight, the jet full of budding chemists and climate scientists, some of whom came from Caltech, might plow through the turbulent air at low altitudes to measure methane emissions from a large cattle ranch or study the health of kelp in the Santa Barbara Channel.

"A fair number of the students would end up losing their lunch," Schaller says. "But that bonded them in a new way. We used the hashtag #IPukedforScience on social media and, one summer, they made a T-shirt to that effect. But they were all very proud of the data they collected."

The trusty aircraft gave countless undergraduates a turbulent baptism as airborne scientists. Because it was based at the NASA Armstrong Flight Research Center in the nearby California desert, the DC-8 also helped a generation of Caltech scientists conduct research on Earth's atmosphere. Now its day is done: The DC-8 made its final science flight in April 2024.

Paul Wennberg, the R. Stanton Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering, tweeted a photo of the DC-8 after it landed at Armstrong, which is near Palmdale, following its swan song. "This was the last science flight of the aircraft," he wrote. "It is headed to a well-deserved retirement."

Kat Ball, a graduate student in Wennberg's lab, was aboard that flight and many others, as the DC-8's airborne lab powered her graduate research in atmospheric chemistry. Ball uses mass spectrometry to study and quantify pollutants that come not only from vehicle emissions but also from volcanoes, wildfires, agriculture, and manufacturing. While satellites can analyze the atmosphere below them, Ball says they measure the whole column of air and cannot determine the composition of gases at discrete elevations. For that, you still need a plane.

"We could look at different altitudes in a pretty quick time span as the plane went up and down," Ball says. "The composition can change as you go up and down. That is important for understanding chemistry and how things are transported in the atmosphere."

Graduate student Kat Ball fills a cryogenic pump with liquid nitrogen. The pump keeps her instruments clean during the downtime between flights.

History in the Air

The Douglas DC-8 line was among the planes that powered the jet age. It debuted in the 1950s as one of the first narrow-body airliners, allowing for six seats in each row. Douglas (later McDonnell Douglas) made hundreds of DC-8s for clients such as Pan American World Airways up until the early 1970s, when bigger and better jets came on the market. Kirsten Boogaard, deputy project manager for NASA's DC-8 program, says the specific plane bought by the agency in the 1980s had flown for Alitalia in its previous life. Refitted as a platform for aerial science, the DC-8 would fly for nearly four more decades.

NASA's plane retained some of the first-class seats from its passenger days, and the retro blue carpeting remained too. Apart from that, the DC-8's redesigned interior bore little resemblance to an airliner. The fuselage was packed full of metal racks where researchers could mount the computers and tools they would monitor during the flight. These machines were connected to instruments mounted on the outside of the plane that sampled the air and were changed to meet the needs of each mission. "We stripped the entire inside to be able to do specific configurations of the scientists and their instruments for each flight," Boogaard says.

Cushy seats aside, the DC-8 trips were not an exercise in aerial luxury. Flight days, Ball explains, included three hours of prep to work out preflight procedures and instrument calibrations. Then came eight hours in the air, followed by one more after landing to shut down the tools and retrieve data. Some researchers worked these 12-hour shifts for days on end.

John Crounse (PhD '11), lead staff scientist at Caltech's Ronald and Maxine Linde Center for Global Environmental Science, flew on the DC-8 for nearly 20 years to map the composition of the atmosphere throughout each year. The proximity of the plane's home base to Caltech gave Institute researchers a terrific opportunity to study the atmosphere firsthand, he says. "We could take our instrument in a rental truck up to Palmdale in half a day, unload it, put it on the plane, and go back home."

He also remembers the heat. Much of the plane's air-conditioning equipment was stripped to make room for laboratory gear. Ducts to blow cool air remained in the front and back of the plane. "By the time you got to the middle, there's not a lot of airflow that comes out," he says. "The heat concentrates there, and that's where we sat for 20 years."

Around the World

The rewards were worth the discomfort, Ball says, and not just because of the unique atmospheric chemistry dataset and scientific opportunities. Flying in the DC-8 allowed her to see the world. Ball's missions included the Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas campaign in summer 2023, which sampled air above big cities; this meant Ball rode in the plane as it made low passes by the Statue of Liberty. A similar campaign called ASIA-AQ early in 2024 took Ball across the Pacific Ocean to study the atmosphere above East Asian nations such as South Korea, Thailand, and the Philippines. "I've been able to see cities all over the world that I would not have gotten to see otherwise," she says. "And I got to see them from pretty low altitudes."

continued on page 38

continued from page 37

Similarly, flights for NASA's Operation IceBridge mission throughout the 2010s carried Schaller to the far ends of the planet, with close passes over glaciers in Antarctica and Greenland. "One of my fondest memories is flying over the North Pole at about 1,500 feet while the Icebridge team was making measurements of the thickness of the sea," she says. "I was leading a live chat with a classroom back in the United States, and they were asking if we saw Santa."

Crounse has flown on nearly a dozen DC-8 research campaigns over the past two decades. One of the most memorable projects, he says, was the Atmospheric Tomography Mission from 2016 to 2018, during which the DC-8 circumnavigated the globe during each of the four seasons of the year. The missions took him to sites including Alaska, Hawaii, the Azores, Chile, and New Zealand. He also traveled over the western United States in 2019 to quantify the atmospheric impacts of major wildfires. "The airplane would go from its maximum altitude, which is somewhere around 12 kilometers, down to about 500 meters above the ocean," he says. "And it would do that repeatedly throughout the whole flight. That dataset has proven invaluable for understanding the global atmosphere."

The DC-8's rugged nature—this was a tough, overbuilt machine, the scientists agree—helped it to withstand its many shaky trips through the atmospheric boundary layer, the lowest portion of the atmosphere affected by Earth's surface. But even a durable plane does not last forever, especially when decades have passed since the last one was built. "Every time something breaks it's just a big effort to find that part," Boogaard says. "You can compare it to an old car."

But, Wennberg notes, "this old car was an enormous asset for airborne investigations. With its ability to host a large payload and operate from only a few hundred feet above the ground to more than 40,000 feet, the DC-8 was a workhorse for Caltech earth scientists studying global change in atmospheric composition, the glaciers, the oceans, and the terrestrial biosphere."

NASA recently acquired a Boeing 777 to serve as its next-generation airborne lab, and Boogaard will be moving to the East Coast to oversee its various missions. The DC-8, meanwhile, is not going to the boneyard. NASA has donated the plane to Idaho State University. "They are using it to train the next generation of aircraft technicians," Boogaard says. "They're going to get hands-on real-time experience with a beautiful aircraft."

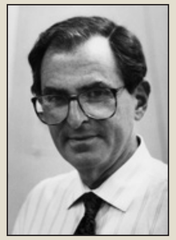
In Memoriam

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

Camilla Chandler Frost (1925–2024)

Frost, a life member of the Caltech community, passed away on February 7, 2024, at age 98. Frost was appointed to the Caltech Board of Trustees in 1977 and became a life member in 2007. She served as co-chair of Caltech's Biological Sciences Initiative. The Chandler family's philanthropy has supported endowed professorships as well as the Norman Chandler Scholarship Fund, the Norman Chandler Memorial Laboratory, and the Camilla Chandler Frost Laboratories.

David Goodstein (1939–2024)



Goodstein, the Frank J. Gilloon Distinguished Teaching and Service Professor, Emeritus, and professor of physics and applied physics, emeritus, passed away on April 10, 2024, at age 85. He served as a professor at Caltech for 40-plus years and as the Institute's vice provost from 1987 to 2007. In the 1980s, Goodstein was the director and host of *The Mechanical Universe,* an educational TV series. He authored several books, including *Feynman's Lost Lecture,* which was written with his wife, Judy Goodstein, Caltech university archivist, emeritus.

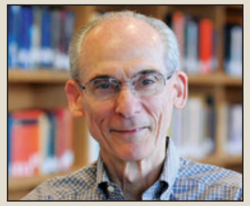
Fred C. Anson (BS '54, 1933–2024)

Anson (BS '54), the Elizabeth W. Gilloon Professor of Chemistry, Emeritus, passed away on May 22, 2024, at age 91. Anson spent his entire career at Caltech. He was appointed assistant professor in 1958, associate professor in 1962, full professor in 1968, and the Gilloon Professor in 1995. His research focused on the kinetics, mechanisms, and catalysis of electrode reactions. Anson was chair of Caltech's Division of Chemistry and Chemical Engineering from 1984–1994.

Virginia V. Weldon (1935–2024)

Weldon, a life member of the Caltech community, passed away on May 23, 2024, at age 88. Weldon was first named to the Caltech Board of Trustees in 1996 and became a life member in 2010. She served on the pediatrics faculty at the Washington University School of Medicine and as co-director of the division of pediatric endocrinology and metabolism. Later, she became deputy vice chancellor for medical affairs and vice president of Washington University Medical Center. She was Monsanto's senior vice president, public policy, from 1989–1998.

Edward C. Stone (1936–2024)



Stone, the David Morrisroe Professor of Physics, Emeritus, passed away on June 9, 2024, at age 88. Stone spent six decades at Caltech, leading numerous space missions, overseeing the construction of the W. M. Keck Observatory, establishing the Institute's Space Radiation Lab, and more. He served as project scientist for NASA's twin Voyager spacecraft for 50 years. He was chair of Caltech's Division of Physics, Mathematics and Astronomy from 1983–88, and director of JPL from 1991–2001.

Jeff Kimble (1949–2024)

Kimble, the William L. Valentine Professor of Physics, Emeritus, passed away on September 2, 2024, at age 75. Kimble became a professor at Caltech in 1989, the William L. Valentine Professor in 1997, and professor emeritus in 2021. He helped found and served as the inaugural director of the Institute for Quantum Information (now the Institute for Quantum Information and Matter). A giant in the field of quantum optics and quantum information science, Kimble's cavity quantum electrodynamics experiments formed the basis of many current quantum technologies. Kimble and colleagues conceived and demonstrated the methods for generating squeezed light that are now employed at LIGO (the Laser Interferometer Gravitational-wave Observatory).

Endnotes

What does the Caltech Honor Code mean to you?

The Honor Code embodies the Institute's commitment to trusting and empowering students to reach their full academic and leadership potential. It gives faculty the freedom to push the intellectual limits of their classes, unrestrained by time limits or whether an exam can be proctored, and it holds the administration to a higher standard in how it treats the student body. Caltech is united by everyone's shared responsibility in upholding the Honor Code in letter and spirit.

Mason Smith (BS '09)
IRVINE, CA

It was one of the things that made the environment manageable. It is also a point of pride. I use it as a teaching point that, as scientists and engineers, honesty and integrity are important.

Albert Nichols (BS '80)
SAN RAMON, CA

One of the main factors in my choice for undergraduate education—and a source of pride since.

Stan Shepherd (BS '71)
MORGAN HILL, CA

I loved the latitude the Honor Code gave students to take exams when and where we felt comfortable. I have "fond" memories of taking exams late at night in the second-floor library in Kerckhoff, or while blasting Dave Matthews Band at my off-campus apartment.

Anandi Raman Creath (BS '96)
PHOENIX, AZ

I recall being in the middle of a one-hour take-home closed-book exam at 4 a.m. in my apartment when a 4.0 earthquake began. I continued with the exam and did not leave the building, sticking with the Honor Code.

George Pashel (MS '75)
PITTSBURGH, PA

The Honor Code alone was a nice philosophy, but it became the core of my Caltech experience once I recognized that other students believed in it. Being trusted felt good, but the responsibility that came with it turned the Honor Code into action.

John Andelin (BS '55, PhD '67)
ARLINGTON, VA

The truth is you are no longer the smartest person in every room. Come to grips with that and enjoy the freedom.

Tim Cotter (BS '88)
SUNNYVALE, CA

It meant I'd reached a point where my genuine goal was learning—grades were a tool for self-awareness, so cheating would be self-defeating. It's an ethic that helped motivate me then and continues to do so now in life and career.

Ron Goodman (BS '89)
SANTA CRUZ, CA

For more Endnotes responses, go to:

The Honor Code—A quintessential expression of how an individual should behave when interacting (in any way) with any member of society.

Rene Gandolfi (BS '74)
CASTRO VALLEY, CA

It is quite simple: Not lying to yourself comes first, then not lying to others. I taught the code to my granddaughter when she was 6, and she continues to apply it. No need to steal cookies.

Paul Wegener (BS '71)
SAN DIEGO, CA

Everything.

Peter Schupp (MS '90)
BREMEN, GERMANY

Connect with us

Join the conversation

Email us at **magazine@caltech.edu**

And remember to get social:

Caltech
magazine

1200 East California Blvd., Pasadena, CA 91125

A Portrait for Posterity
In May, Caltech unveiled a new portrait of Grant D. Venerable (BS ’32) by artist June Edmonds. The painting stands in the front lobby of Venerable House, named in 2021 in his honor, and embodies the enduring legacy of the Institute’s first Black undergraduate.