

Spring 2026

Caltech

magazine

The Beauty of Convergence

When theorists and
experimentalists
merge their skills,
breakthroughs
begin to bloom.

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Spring 2026

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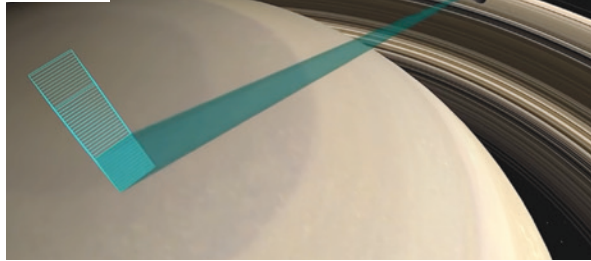
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Above: A photo of the Braun pools at sunrise taken by women's volleyball head coach Thomas Gardner.



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

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Letters



Hopping for Joy

Note: Caltech partnered with Disney and Pixar to host an advance screening of the animated film Hoppers on March 6 for undergraduate students. Caltech's mascot Bernoulli was also in attendance. In the movie, an animal-loving college student uses new technology to transfer her consciousness into a robotic beaver.

“We love beaver representation on the big screen 🐹🐹

Huge thanks to Disney for making this unforgettable experience happen!”

– Caltech's Office of Student and Family Engagement posting on Instagram on March 2

For the Record

As pointed out by reader John R. Torczynski (PhD '83), the Inside Look feature published in the Fall 2025 issue incorrectly stated that the Trinity nuclear test took place in Los Alamos, New Mexico. The test site is actually located approximately 200 miles to the south of Los Alamos in the White Sands Missile Range.



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Caltech



- Ask the athletic director
- The Techers prepping PRIMA
- Turtle wrangling season; and more

Desert Travelers

Field trips, even those not centered solely on research, are a core element of instruction in Caltech's Division of Geological and Planetary Sciences (GPS). The division offers all graduate and undergraduate GPS students the opportunity to attend one enrichment trip during their time at the Institute. These excursions, which are funded by philanthropic donations, typically occur annually and are designed for students to bond while exploring a country's geography and taking part in cultural experiences.

"Enrichment trips are truly a special part of the division," says Claire Bucholz, professor of geology, who led the August 2025 trip to Mongolia, which included a visit to the country's Flaming Cliffs to look at dinosaur fossils, as well as a tour of the Oyu Tolgoi porphyry copper-gold mine, among other activities. Typically, graduate students come up with a plan for which country or countries to visit and sketch out the itinerary. Then, they recruit two faculty or staff members to go along. Past trips have ventured to Alaska and Canada, Iceland, and New Zealand. "We have atmospheric chemists, sedimentologists, planetary scientists all getting together and going on this big adventure," Bucholz says. "The insights from different parts of the division and the connections and the relationships you build are really important. On this trip, we were fortunate to have five graduate students from Mongolia with us with whom the Caltech students quickly became friends and learned so much from."

The photo at left was taken just after sunrise at the Khongoryn Els dune field, the largest in the Gobi Desert, where the Caltech group stayed in *gers*, or traditional Mongolian circular dwellings. "I got up early and wanted to get to the sand dunes for the sunrise," Bucholz says. "I was looking out at these really impressive macroscopic features, but you could also see the little ripples on the surface, which show you the direction of more recent wind transport. Then there was this little beetle walking across, so it caught my eye as an interesting juxtaposition of biology and geology."





Four Questions for :

◀ Caltech Athletic Director Terry Tumey

Terry Tumey, who joined Caltech in October 2025, brings with him professional experience as a college football player and coach, and as a college athletics administrator at NCAA Division I, II, and III schools, including UC Davis, Claremont-Mudd-Scripps, and, most recently, Fresno State. Here, we speak with Tumey about his first few months at the Institute and his vision for the Department of Athletics, Recreation, and Instruction (ARI).

1. Given your professional background, what made a return to Division III athletics, and at Caltech in particular, appealing for you?

The main reason I got into higher education was the investment in the experiences of students, which to me is extremely valuable and is an opportunity that I don't take lightly. Where else can you do that at the purest form, which is at Division III and at Caltech? You can't find a better place to really feel that sense of investment and that sense of worth, where I'm doing good work to really enhance the experience of people.

2. What have you learned about Caltech student-athletes?

They may be the most efficient people I've ever met in my life. I don't know how they accomplish all that they do and perform at such a high level. They are excelling, of course, in research, in their classrooms, in their personal lives. Then to top it all off, they have the ability to achieve growth through competition. I have such an admiration and respect for our student-athletes because they are truly some of the best of the best as it relates to what you would expect of a student in a collegiate space.

3. Is there a particular encounter with a student-athlete that stands out?

I spoke to one of our swimmers, who was in the midst of applying to law school. She shared how she's been able to

navigate and feel completely supported within this community and by the array of individuals who have participated in her experience—not just coaches, though they're a large part of it. She also has faculty members and administrators who are part of her team. Candidly, I'm hoping that I can be a part of her team as we move forward.

4. What do you envision for Caltech athletics and recreation in the next five years?

The biggest opportunity is to re-engage our community. I would begin right here with our Caltech population by creating open channels, such as surveys or a portal for commentary. Communication and response are key for a healthy relationship with our community. We also need to have a real understanding and appreciation from our surrounding community of what Caltech means to the city of Pasadena, to California, to those who come and engage with us. If that can be reflected in what we do here at ARI, that would be a great way to encapsulate the power of Caltech.

Passing the Torch of Knowledge

Fourth-year graduate student Muntasir Hassan often read a book per day in high school. In 2025, however, deep into his PhD candidacy at Caltech, he read only two books during the entire year.

That shift led him to ponder how to keep reading present in not only his life but those of his peers and community. At a campus event in September 2025, Hassan approached Joseph Greenwell, then newly appointed as associate vice president of student life, with an idea: to create an open library and book exchange hub on campus.

On March 1, 2026, his vision officially opened to the public. Located in the Hameetman Center, between the Caltech Store and the Red Door Marketplace, the Moshaal book exchange hub—named for a Bengali word meaning “torch”—operates like a Little Free Library. Any member of the Caltech community is welcome to take a book and/or leave one for others to enjoy.

The term *moshaal* alludes to the official Caltech seal, in which two hands hold up a torch. Hassan says he hopes Moshaal will represent the light of knowledge passed through the books Caltech community members will share with each other.

Moshaal was developed with support from the Graduate Student Council (GSC), Student Affairs, and the Caltech Library. The GSC will serve as a steward for Moshaal; its members will regularly maintain the hub and check on the books to make sure they are in good condition and align with Caltech's community standards.



Turtle Wrangling

Every spring, Caltech gardeners like Thanh Vanh Du (right) take on an additional responsibility: turtle wrangling. As Throop Pond's famous red-eared slider turtles come out of hibernation, some traverse campus to find a place to lay their eggs. "There are two that love to go into the Caltech Hall fountains," says Delmy Emerson, director of Buildings and Grounds. "We get a lot of calls about their wandering." Facilities staff members are trained to bring the turtles back home safely. They also provide the aquatic animals with a balanced diet and monitor and clean the pond's water filters twice a week.



Celebration Selfie

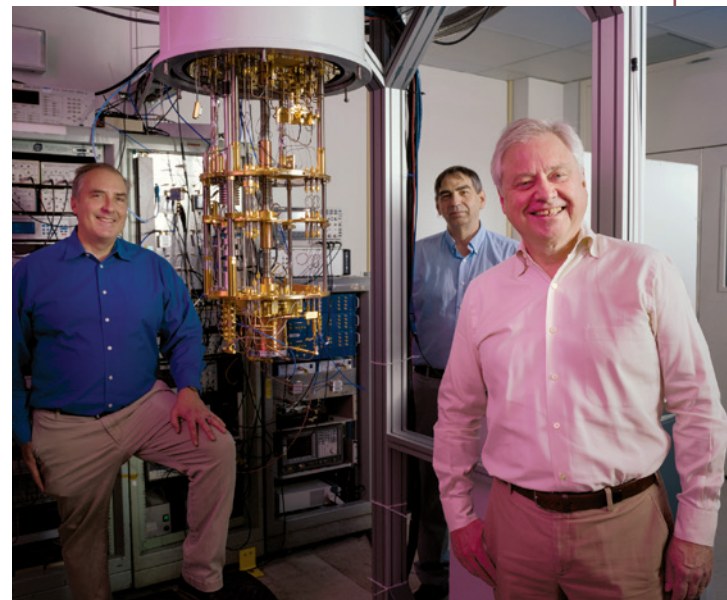


President Thomas F. Rosenbaum poses with well-wishers on the Olive Walk after a February celebration in which he thanked the Caltech community for their energy, insight, ingenuity, and commitment during his tenure of more than a decade, which ends in June 2026.

PRIMA's Caltech Connections

NASA's PRIMA (PRobe far-Infrared Mission for Astrophysics), aims to be the most advanced mission to date for studying far-infrared light emanating from planets, galaxies, and other cosmic objects. To do that, it would rely on strong connections to Caltech, including an invention by 2026 Watson Medal winner Jonas Zmuidzinas (BS '81), Caltech's Merle Kingsley Professor of Physics, and his JPL colleague Rick LeDuc. In 1999, the pair came up with the idea for superconducting microwave kinetic inductance detectors (MKIDs or KIDs), which are ultrasensitive photon sensors that can be built into large arrays. Because PRIMA requires superior detectors that can observe faint far-infrared light from deep space, the mission's concept and science goals rely on their invention. Meanwhile, JPL's Matt Bradford, who is also a visiting associate in physics on campus, serves as PRIMA's project scientist. Should NASA give PRIMA the green light in 2026, Caltech's IPAC would handle observation planning and scheduling as well as scientific data processing, archiving, and dissemination.

Caltech manages JPL for NASA. The Watson Medal is a National Academy of Sciences honor presented every two years for "outstanding contributions to the science of astronomy."



From left: Matt Bradford and Rick LeDuc with Jonas Zmuidzinas in JPL's Microdevices Laboratory.

Amber Liu (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.

Liu, who grew up in Atlanta, has played table tennis since age 7. She has competed in dozens of tournaments, and, at age 15, earned a spot on the US team that competed in the 2024 World Team Table Tennis Championships in South Korea, where she won the only match she played in. As a member of the Caltech Table Tennis Club, Liu helped the team win the 2025 National Collegiate Table Tennis Association tournament. She is exploring applied and computational mathematics as a possible major.

"My hardest competition was the US National Table Tennis Championships in 2023 when I was 15. I needed to reach the semifinals to make the national team for the world championships the next year. After a long fight, I placed first in the under-15 girls' singles event. It was a lot of pressure because it's what I had been working for the whole year. It's also single elimination, so if you lose, you're out. Winning required a lot of mental and emotional strength. I doubted myself a lot, but my coach would tell me, 'Just go and do it whether or not you think you can.' In the world championships, we were the underdogs, so I felt less pressure. I was the youngest on our team, and the entire team was much younger than the others. For many of us, it was our first time playing in an adult championship, so we didn't have anything to lose.

Table tennis has taught me a lot about discipline and how to adjust my mindset and control how I feel and perform. It gives me a lot of courage to try things that may seem out of my comfort zone or like I have to put in a lot of effort, because I've already done something harder. For example, I wasn't scared at all to come to Caltech, and it's been great. Meeting people I didn't know through the club has been really exciting. Even though the other members are all graduate students, it's nice to play with people, and we also get to play as a team in collegiate tournaments. I really hope that more undergrads, even people who just play for fun, decide to join the club."



In the Community

The Pasadena Math Pipeline

Thanks to a recent partnership between the Pasadena Unified School District (PUSD) and Caltech, as many as five high school juniors and seniors in the district's Math Academy now have the opportunity to join the Institute's first-year math core courses (Math 1 a, b, and c) each year.

Omer Tamuz, professor of economics and mathematics, directs the dual-enrollment program for Caltech and says the program aligns with the Institute's recruitment efforts. "I think there's a general wish to expand Caltech's relationship with local schools," he explains. "We don't want to miss out on exceptional local talent."

Math Academy students, who can join the accelerated program as early as sixth grade, finish the high school Advanced Placement math curriculum in middle school and turn to proof-based college mathematics in ninth grade. "They are about four years ahead," Tamuz says.

Lucas Kittle and Jacob Monson, a junior and senior at PHS, respectively, were the first students to simultaneously enroll at Caltech and PUSD under the new program, which launched in fall 2025. "Having this solid Caltech credit is going to be a big help when I apply to colleges, and I value the opportunity to learn what college classes are like," Kittle says.

However, going from intimate Math Academy sessions to the Math 1 series at Caltech, which enrolls more than 100 students, was a major transition for the high schoolers. Monson values how teaching assistants personalize learning during recitation sections, and says he appreciates the depth of exploration. "Compared to Math Academy classes, Math 1 helps you dive deeper into each

topic and see the root of how it's built and how it connects to other topics."

PUSD teacher Chris Anderson helped formulate the Caltech-PUSD program. "A lot of these students want to go to Caltech; it's one of the schools on their list," he says. "So, Caltech gets



to see them, they get to see Caltech, and you can have a beautiful marriage of high-achieving student with high-achieving institution."

The Math Academy, which was formally adopted into the PUSD curriculum in the 2016–17 school year, has seen two participants go on to

become Caltech students before the launch of the dual-enrollment program: Justin Hong, now a second-year undergraduate studying computer science, and first-year graduate mathematics student Luisa Boateng. In addition, Math Academy alumnus

Matteo Paz, now a research support technician at IPAC, a science and data center for astronomy at Caltech, won the 2025 Regeneron Talent Search for writing an AI algorithm that helped reveal 1.5 million celestial objects, research he conducted at the Institute.

Laureen-Nadirah Nayo, PUSD's director for the joint program, selects dual-enrollment candidates from among the pool of students who have completed all the prerequisites. Students are recommended on the basis of their grades, focus, maturity, and work ethic.

Caltech reviews the candidates proposed by Nayo. Selected participants provide their own transportation and fit the Caltech classes into their broader high school schedules. Though their enrollment is limited to the three first-year math classes,

they have the same requirements and responsibilities as the Caltech students in those courses, and they receive a transcript upon completion for use in college applications. The high school students do not pay tuition fees.

"We are very excited about this collaboration with Caltech for our students," Nayo says. "This opportunity directly addresses a need that they have expressed."

—Ann Motrunich

Above: Pasadena High School students Jacob Monson (left) and Lucas Kittle at Caltech.

Origins

A Dash of Caltech's Culinary History

Nestled deep in the shelves of Caltech's Archives and Special Collections, amid volumes dedicated to particle physics and molecular biology, sits a recipe collection. The culinary trove, belonging to the Tolman and Bacher families, is an heirloom that serves up a plate of Caltech history and recalls a slice of time when entertaining was a science of its own. The collection also provides insight into the lives of these two families that helped shape the Institute and American history.

The recipes span from 1925 to the 1950s and represent a snapshot of American 20th-century flavors, ingredients, and cooking methods. Richard and Ruth Tolman and Jean and Robert Bacher were avid hosts, and the home on Caltech's campus first occupied by the Tolmans and later by the Bachers was the site of decades of gatherings and dinner parties attended by many of the Institute's (and the world's) preeminent scientists. Parties hosted by the Bachers were reminiscent of potluck gatherings at the home of J. Robert and Kitty Oppenheimer in Los Alamos, New Mexico, during the Manhattan Project, said Shirley Gray, wife of Harry Gray, Caltech's Arnold O. Beckman Professor of Chemistry and founding director of the Beckman Institute, in a 1991 introduction to the recipe collection in the Archives.

Notable guests at the house included Albert Einstein, who had a Thanksgiving meal with the Tolmans. Robert Oppenheimer often stayed in the guest house during the 1930s, a decade in which he split his time between Caltech and UC Berkeley.

The house, which sits at 345 S. Michigan Ave., was built in 1925 for the Tolmans. Richard Tolman, a physicist and chemist, served as dean



of the graduate school and was the scientific host to Einstein during the famed physicist's visits to Caltech in the early 1930s. Richard also served as scientific advisor to US Army Gen. Leslie Groves, director of the Manhattan Project. One of the first graduate students Richard recruited to Caltech was Arnold O. Beckman (PhD '28), a former Caltech chemistry professor, Board chair, and an Institute benefactor.

Robert Bacher, a former Caltech physics professor who also served as the Institute's vice president and as its first provost, came to Caltech in 1949 after working with Robert Oppenheimer on the Manhattan Project as head of the experimental physics division and then the bomb physics department.

During construction of the Beckman Institute in the 1980s, Caltech purchased the house from Robert Bacher. Shirley Gray had been friends with Beckman's wife, Mabel Beckman, until Mabel's death in 1989. Shirley knew about the recipes and collected them in 1991. "I thought visitors to the Tolman House would like to try the recipes, so I put them together to make them accessible to all and revive a bit of Caltech's history," Shirley says. "After all, the house had a kitchen, so why not use it!" One Caltech guest who stayed in the house and tried some of the recipes was Nobel Laureate Pierre-Gilles de Gennes.



There are around 150 recipes from Tolman and Bacher in the collection, including many from Jean Bacher's mother, Byrd Fox Bacher. The handwritten instructions are organized in binders, folders, composition notebooks, and even envelopes from the WWII-era National Defense Research Committee. Other recipes are clipped from newspapers, magazines, and catalogs. Among them are dishes such as white layer cake, oyster salad, lemon souffle, and "yum-yum pudding."

Above is a handwritten recipe for spaghetti sauce—one that was used and loved, if the drips, splatters, and smudges on the worn page are any indication.

—Sharon Kaplan

To see the written recipes online, visit



The Beauty of Condensed Matter



How Caltech researchers blend fields and scientific approaches to achieve results.

By Ker Than

Theoretical physicist Kathryn Zurek has dedicated much of her professional life to trying to solve the riddle of the universe's missing mass, also known as dark matter. In her view, dark matter could be far richer than many theorize—not a single particle but an entire “shadow world” with its own variety of particles and forces.

Her proposal fits within the standard model of particle physics, but condensed matter theorists she conferred with initially struggled to see how it connected to the problems they were interested in. “Even among theorists, people have very different ideas about what’s worth pursuing, and they build tools around the questions they care about,” she explains. “If you’re asking a question that’s just slightly off that well-trodden path, it can be difficult to extract the answer.”

While theorists can disagree on lines of questioning among themselves, the difficulties are often amplified during collaborations between experts from different disciplines, or between theorists and experimentalists. But Omer Tamuz, a Caltech professor of economics and mathematics, says this heavy lifting breeds strong interdisciplinary research at a place like Caltech. “Our job is to explain why our work is interesting” to experts trained to care about different things and who have their own language, norms, and expectations about how assertions should be framed and considered, he explains.

It takes great effort to push insights across scientific boundaries, but when those who think about or see the world differently figure out how to work together effectively, the breakthroughs can be beautiful. Recognizing that the Institute can play a role in sparking these budding partnerships, Caltech has built its culture, teaching philosophy, and even parts of its campus, to facilitate these interactions. “We have to build these cross-disciplinary bridges and collaborations,” says Sergei Gukov, the John D. MacArthur Professor of Theoretical Physics and Mathematics.

THE “LANGUAGE BARRIER”

In conversations with condensed matter theorists—physicists who study the properties of materials like crystals and superconductors—Zurek, the Louis E. Nohel Professor of Theoretical Physics, kept posing questions that fell just outside of what their field’s tools were designed to tackle.

The turning point came when she stripped dark matter out of the conversation almost entirely. Instead, she described the problem in terms of quantum mechanics—a language shared by all physicists. When Zurek and her theorist colleagues began discussing dark matter not as

a specific particle but rather as a generic probe that deposits energy and momentum into a system, the problem narrowed to calculations and other mathematical tools commonly used in condensed matter physics. “Once you’re able to ask the right question in the right way of the right people, you’ve already won a significant part of the battle,” Zurek says. “At that point, you can unlock and take advantage of all the resources in a field.”

The disciplinary divide becomes particularly evident when it is time to turn ideas into papers, Tamuz says. That is because no matter how interdisciplinary the work, the paper itself has to pick a side. “When you write a paper, it’s either a math paper or an econ paper,” he says. This is notable because each field evaluates research findings differently. “You have to understand the culture to get your papers published or risk dismissal due to ‘too much math’ or ‘not enough economics.’”

So, Tamuz learned to code switch, reframing abstract ideas so economists not as concerned with math can see why those concepts and calculations matter. It is a beneficial skill, he says, because it forces him to explain what a theory actually predicts about the world rather than just what it proves mathematically.

Gukov says some of the challenges to finding connections between his mathematics and physics research, as well as between subfields within mathematics, are more about translation than synthesis. “It’s a language barrier,” he says. “It’s no different from French and English.”

Early in his career, Gukov helped develop what became known as the Gukov–Vafa–Witten superpotential, a type of mathematical function used in quantum physics. This work became an important tool in string theory, one that drew on different branches of mathematics to address a technical problem concerning the shape and structure of hidden extra dimensions. Later, physicists realized the tool could help explain why string theory allows so many possible universes—and why one like ours, with properties seemingly fine-tuned for life, might number among them.

Gukov says the ability to bridge fields, as he has done with math and physics, and more recently with math and computer science, cannot be done through intuition alone. It can take years to learn another discipline well enough to understand which problems it already considers solved, which questions it deems trivial, and where the knowledge gaps lie. “Graduate students accept being beginners and put in the sustained work to master new fields,” Gukov says. “So, we really have no excuse not to master a new field as professionals.”

This process has required slow and unglamorous work: reading unfamiliar literature, absorbing seemingly arbitrary conventions, and most importantly, learning not

to label yourself as only a certain type of scientist, Gukov says. During a visit years ago with mathematician and Fields Medalist Michael Atiyah, Gukov began outlining how he planned to approach a problem “as a geometer.” Atiyah cut him off. “Consider it from all perspectives, from the point of view of geometry, algebra, physics, etc.,” Atiyah told him.

Gukov took it to heart. Now, when people ask him what he does, he answers, “I love building bridges.”

A FOOT IN BOTH WORLDS

In the late 1950s, Rudy Marcus proposed an idea that seemed to break a basic rule of chemistry. According to his theory of electron transfer, pushing a reaction harder would not always make it go faster. Indeed, after a certain point, it should actually slow down—a breakthrough that came to be known as the inverted region and helped earn Marcus the 1992 Nobel Prize in Chemistry.

Confirming this theory took nearly 25 years because the experiments were extraordinarily difficult to build. The effort required chemists to combine their talents “to construct systems where some of the things that were preventing one from seeing the inverted region were absent,” says Marcus, the John G. Kirkwood and Arthur A. Noyes Professor of Chemistry, who came to Caltech in 1978.

Theoretical research, he argues, requires discipline and detachment. “It’s desirable not to get stuck on an idea simply because you thought of it,” he says. “If it doesn’t look good, forget it. Try something else.” But you also have to know when to hold firm. Marcus is matter of fact about why he never wavered on his inverted-region prediction. “As long as the conditions on which it was based were met,” he says, “I felt the prediction was right.”

Marcus, who celebrated his 102nd birthday in July 2025, began his career as an experimental chemist. But during his time as a postdoc at the National Research Council of Canada, he and a friend started a two-person seminar, reading theoretical papers to each other weekly to teach themselves what no one around them could. In chemistry, theory helps researchers understand patterns, explain observations, and predict future results. “I thought, this is more interesting than the experiments I’m doing,” Marcus recalls.

Even after becoming known as a theorist, Marcus continued to use what he calls “physical intuition”—thinking in physical rather than abstract terms. “I really had no problem interacting with experimentalists, and a number of times their experiments were the basis of my working on a particular problem,” he says. “The important thing is to keep an open mind and not remain focused on one thing.”

That perspective helped shape his openness to computational chemistry, which was still relatively new when

Marcus began engaging with it in the 1960s. The approach offers a new way to think of experimentation: The computer simulations used in this field are, essentially, mathematical and physics-based models that can predict the results of lab experiments before they have taken place, offering insights into molecular structure and behavior.

Caltech’s Rudolph A. Marcus Center for Theoretical Chemistry, which launched in 2024, institutionalizes this computational approach to the field. Thanks to a gift from Drs. Jack Yongfeng Zhang and Mary Zi-ping Luo, both former Caltech postdocs, the center offers fellowships as well as research funding, and it hosts meetings and workshops for researchers from across the country to exchange ideas and foster new collaborations in theoretical chemistry.

For Garnet Chan, the center’s director, computation goes hand in hand with theory, so the center’s goal is to bring these efforts together. “In chemistry, what people call theory and what people call computation are often just different pieces of the same process,” says Chan, a Bren Professor of Chemistry. “You write down equations, and then you have to find ways to solve them—and those ways involve computation. It’s all kind of the same thing.”

WHEN CHALK MEETS BENCH

The decades it took to confirm Marcus’s theory of electron transfer highlight an asymmetry between theory and experiment. While a theorist can abandon an idea by wiping a chalkboard clean, an experimentalist often commits years of labor, specialized equipment, and grant funding before learning whether an idea holds. This often makes experimentalists more cautious before investing in an idea.

For experimental physicist Rana Adhikari, deciding whether to pursue a theoretical idea begins with trying to break it. “I always ask: What would disprove your theory?” says Adhikari, a longtime member of the LIGO (Laser Interferometer Gravitational-wave Observatory) team. He presses theorists to name specific observable outcomes that would rule out their ideas. “If there’s nothing that could disprove it, then it’s not science.”

When a theory survives that first cut, Adhikari and his collaborators often review decades of prior experiments to determine whether the idea has already failed without their knowledge. “Half the time, you find someone did the experiment in 1975,” he says. “Then you write it down and move on.”

It took Adhikari plenty of time and effort to recognize the importance of this dialogue. When he first arrived at Caltech as a postdoc in 2004, the divide between theory and experiment felt like a source of constant friction for him. “I thought, why doesn’t everyone just handle everything themselves?” he says. “Figure out the engineering, figure out the math, and we’ll all be the same!”



Kathryn Zurek, left, and Rana Adhikari at a blackboard near the Moore Lab of Engineering.

He would often get hung up on details that made it hard for him to find common ground with theorists. He recalls a particular conversation about a proposed experiment to build a continental-scale quantum network. “I’d ask, ‘Why does t stand for frequency and f stand for time?’” he recalls. “Everyone uses t for time.”

Adhikari’s stance eventually softened in part due to a friendship. When Adhikari and Yanbei Chen (PhD ’03), a Caltech professor of physics, met at the Institute in the mid-2000s, they formed a partnership that shaped both their careers. The two worked closely and traveled together, spending long stretches talking through problems and gradually absorbing one another’s way of thinking. “I believe he’s way more interested in experimental physics because of me,” Adhikari says. “And I know so much more theoretical physics because of him.”

Adhikari says he now realizes that nascent ideas are fragile and should not yet be subject to real-world stress tests. “It’s like a little bird in a nest,” he says. “At the beginning, you have to work in that ideal world where everything is mathematical and simple. I now like to avoid anything negative at that point that could break it.”

Today, the two sometimes work together at the LIGO control room in Livingston, Louisiana, where Adhikari sits at the console making minute adjustments to an instrument designed to measure ripples in space-time smaller than a proton. Alongside him, Chen watches the

readouts, talking through the physics as the experiment responds in real time.

Adhikari jokes that it can feel like having a backseat driver, but it works. Chen understands the experiment's constraints without becoming overwhelmed by day-to-day details. "They don't have screwdrivers in their world," Adhikari says of theorists. "They throw away a lot of these engineering constraints that we have, and they'll come up with ideas we would never get to because we're always thinking, 'I can't fit a wrench in there.'"

During a recent discussion about a gravitational-wave detector design, Chen corrected how Adhikari was describing the motion of a mirror by adding a mathematical term to properly account for relativity, replacing Adhikari's more simplified description. "I was like, 'Why are you nitpicking right now?'" Adhikari recalls. Only later did Adhikari realize that the correction forced a fundamental rethinking of the mirror system. "Most of us, when we think about Einstein and gravity, we ignore these tiny corrections," Adhikari says. "It's really just the theorists who think about it." But that 0.1 percent correction opened a new possibility: measuring space-time itself without worrying about the actual motions of objects on Earth. The insight led to the publication of a series of papers in *Physical Review Letters*.

Adhikari and Chen's collaboration stems from a practice that LIGO co-founder and Nobel Prize winner Kip Thorne, the Richard P. Feynman Professor of Theoretical Physics, Emeritus, established in the 1960s, requiring his most mathematically inclined students to spend a full year working alongside experimentalists. "Apparently, there was a lot of kicking and screaming among the students," Adhikari says. "They'd say, 'I came here to study Einstein, not rubber gaskets.'" But some of those same students went on to make consequential contributions to materials and mechanics—gritty details that can make or break an experiment.

Chen, one of Thorne's last students, absorbed that ethos. Adhikari now mirrors it from the other direction, sending his own experimental students to spend weeks embedded in Chen's group. "The issue is too sophisticated to be able to do it in a lunchtime conversation," he says. "They have to sit over there and live in it for a while, then come back and translate it into our world."

Sometimes the exchange of thoughts and ideas runs even deeper. When Haixing Miao, then a visiting student in one of Adhikari's classes, designed a magnetic levitation system that looked elegant from a theoretical point of view, Adhikari was not convinced it would work in practice and challenged him to prove it. "People told me I was nuts for doing that," Adhikari says. Then, when Miao later returned to Caltech as a postdoc, he took Adhikari up on it.

What surprised Miao most was the lead time involved in experimental work. "In theory, you can move very quickly, and most things are under your own control. In experiments, that is not true," he says. "You depend on other people, on equipment, on parts, on machining, on delivery times, so planning becomes extremely important. A bad plan can easily cost you a lot of time and slow the whole project down. Rana was the steering wheel that pushed me back on track."

Two years later, Miao had what he called a "successful proof of principle," a working levitation system that could suspend a test plate with multiple degrees of freedom. He came away with a recalibrated sense of the distance between theory and reality. "A lot of the simplifications you make in theoretical analysis are not always justified in practice," says Miao, who is now an associate professor at Tsinghua University in China. He splits his time evenly between theory and experiment, and continues to refine the magnetic levitation system with his students. "That experience changed the way I think about physical systems."

People like Miao are rare, Adhikari says. "They're like switch hitters in baseball."

Theorist **Sara Mahdavi**, left, and experimentalist **Tom Roeschinger** are graduate students in the lab of Rob Phillips.



ONE LAB, TWO METHODS

One of Caltech's own "switch hitters" is Rob Phillips, the Fred and Nancy Morris Professor of Biophysics, Biology, and Physics, who has built a lab in which theory and experiment are integrated from the start. His group aims to "mathematize" biology by combining mathematical models with empirical work to turn biological observations into precise testable claims rather than after-the-fact explanations.

For Phillips, separating theory and experiment has never made much sense. "Science cannot progress with either experiment or theory alone," he says. "In my lab, it's expected that there's a dialogue between them, and we never ever forget that or pretend that there's not." He compares developing fluency between the two to learning to surf. To a novice, waves appear chaotic. To an experienced surfer, they are legible: a secret language inscribed on water by wind, tide, reef, and current. "An observer who has never surfed has zero concept of all the things that are going on," he says. Good science, in his view, works the same way: Theory teaches you how to read the system; experiment reveals which intuitions hold up and which ones do not.

This worldview shapes how Phillips trains students. His experimentalists learn theory by deriving equations with him on the white board. His theorists, meanwhile, are expected to build instruments—and not just once, Phillips says. "You need to solve that differential equation 30 times. You need to build a microscope 20 times. It needs to be second nature no matter who you are."

After meetings with Phillips, experimental students sometimes follow up with a two-page walk-through of a mathematical argument. Phillips typically sends these back covered in notes and new equations. The idea is that designing good experiments requires theoretical insight, and making serious theoretical claims demands an understanding of what instruments can and cannot measure. This leads to models with as few unknown parameters as possible, which form the basis for what Phillips calls "dangerous predictions," meaning ideas that are precise enough to either fail or succeed in experiments. "You don't get to come back later and say, 'Oh, I forgot this parameter,' or 'We can tune this knob to make it work.'"

CONVERGING BY DESIGN

None of this openness to switch hitting is new at Caltech; the Institute has a history of researchers who refused to treat theory and experiment as separate domains. Physicist and Nobel Laureate Richard Feynman moved freely between abstraction and hands-on work, from quantum electrodynamics to wet-lab studies of viruses. Physicist George Zweig (PhD '64), best known for the quark model,

also ran his own biological experiments as a professor, studying auditory processing in cats. Chemist and Nobel Laureate Linus Pauling (PhD 1925) pioneered quantum mechanical theories of chemical bonding as a professor at Caltech, where he also directed research at the Gates (now Gates–Thomas) and Crellin laboratories.

And these sorts of intellectual mergers are not limited to the natural sciences. The philosophy behind them can also be found in the Division of the Humanities and Social Sciences' Center for Theoretical Experimental Social Science (CTESS), where theorists and experimentalists work together from the outset, and students move between theory- and behavior-based seminars.

"A lot of the theories that economists write can be tested in a very controlled setting," says Marina Agranov, the Rea A. and Lela G. Axline Professor of Economics, who directs the center. "If this theory fails in this very controlled environment in my experiment, we don't have any hope that it's going to hold in reality, which is much, much more complicated."

Interaction can also be promoted by conscientious physical design. For example, a pedestrian bridge under construction as of April 2026 will connect the forthcoming Ginsburg Center for Quantum Precision Measurement to the Downs-Lauritsen Laboratory of Physics, thereby linking quantum information and condensed matter theorists with high energy physicists. The bridge exists because the faculty pushed for its inclusion, says Zurek, whose office sits in Downs-Lauritsen.

"Physical access matters," she explains. "If you have to go from the fourth floor down to the ground floor, walk across, and then take an elevator back up to the third floor of the next building, you're much less likely to interact than if you can walk down the hall through the bridge."

For Zurek, the bridge acknowledges how science actually happens. Reducing friction changes behavior and leads to conversations. "That's a fact of physical embodiment," Zurek says.

Phillips agrees with Gukov that Caltech's small size plays a role by fostering playful, productive dialogue. "There's a sense that you're allowed to try things, to engage across boundaries, and to take ideas seriously without deciding in advance where they belong," he says.

Chan, meanwhile, relishes that Institute faculty members encounter one another constantly, students move freely between groups, and disciplinary labels matter less than the problems people want to solve. "In some sense," Chan says, "we're all just working with friends, people to whom you don't feel ashamed to say, 'I didn't understand the first line,' and who then help you understand what you didn't get. That matters." 🍌



Catching Up With Caltech's Incoming President

Ray Jayawardhana has spent his career exploring other worlds. Now, he is ready to begin a new adventure in Pasadena.

Ray Jayawardhana, a renowned astrophysicist, award-winning communicator, and transformative academic leader who has held senior roles at two of the country's preeminent research universities, will become Caltech's 10th president on July 1, 2026.

Jayawardhana's ties to Caltech and JPL trace back decades. As a teenager in Sri Lanka, he wrote to JPL asking for photographs from the Voyager missions to the outer planets. He recounted that formative memory at community gatherings in January, where he was welcomed by Board of Trustees Chair David W. Thompson (MS '78), presidential search committee chair and Merle Kingsley Professor of Physics Jonas Zmuidzinas (BS '81), and student leaders.

"Ray is a visionary leader who embodies the qualities and attributes that distinguish Caltech's community," Thompson said. "He has deep and broad curiosity for exploring our world and the universe around us. He possesses a daring yet thoughtful disposition for tackling complex problems in new and innovative ways. And he has an unwavering commitment to cultivating the research and educational environment in which shared ambition and collaboration thrive."

Thompson added: "He believes deeply that the knowledge we create should be shared widely, ensuring that discovery ignites public imagination and serves as a catalyst for broader progress. He will be a forceful ambassador for Caltech and for the critical and essential role that this community plays in advancing fundamental science, in training the next generation of leaders, and in further extending and accelerating humanity's reach across the solar system and beyond."

Zmuidzinas noted that while scientific distinction is a prerequisite for any Caltech president, Jayawardhana represents considerably more. "Ray brings to Caltech a stellar record of academic leadership, defined by close, collaborative partnership with faculty and other institutional leaders; productive engagement with external partners; and a proven ability to harness collective ambition to deliver results with lasting impact. ... All members of the Search and Selection committees are united in our enthusiasm that Ray has agreed to come to Caltech to serve as our next President," he said.

Prior to joining Caltech, Jayawardhana served as a professor of physics and astronomy and as provost of Johns Hopkins University, overseeing its 10 schools and an expansive portfolio of interdisciplinary

programs, centers, and core administrative and operational units. He was previously the Harold Tanner Dean of the College of Arts and Sciences and Hans A. Bethe Professor at Cornell University. Earlier, he spent a decade on the faculty at the University of Toronto, where he held a Canada Research Chair and served as senior advisor on science engagement to the university's president. He re-

"The opportunity to be part of this community, and to steward and champion it, is the honor of a lifetime."

ceived a bachelor's degree in astronomy and physics from Yale University and a PhD in astronomy from Harvard University.

At the gathering in January, Jayawardhana told the Caltech community he aimed to "steward curiosity at scale and harness the power of bold ideas and support the people who pursue them."

Caltech magazine spoke with Jayawardhana to learn more about his personal and professional journey.

Dr. Jayawardhana, welcome to Caltech. What made Caltech and this opportunity appealing to you?

The word "unique" gets overused, but Caltech truly is a singular place with a close-knit community whose commitment to excellence is relentless. That ethos runs deep and wide, and it imbues everything we do. It's simply how people here approach their work, from the rigor of the core curriculum to the discernment exercised in faculty recruitment, from the daring spirit fueling interplanetary exploration to the creativity sparking technological breakthroughs.

What I also find remarkable—and this is something that becomes clearer the closer you look—is the sheer scale of impact that a relatively small, highly engaged community has had on science and on humanity. There are institutions many times Caltech's size that haven't come close to matching its contributions. That's not an accident. It results from

the intensity of focus, the caliber of the people, and the culture that takes seriously the idea that the questions you choose to pursue matter as much as how vigorously you pursue them.

I'm also clear-eyed about the moment we're in. The funding and policy landscape for science is shifting, and Caltech and JPL have felt those pressures too. I intend to be a fierce advocate for the Institute's mission, for the people who advance it, and for the case that fundamental discovery and applied innovation are not in tension, that they reinforce each other. Making that case with passion and conviction is a challenge I welcome.

The opportunity to be part of this community, and to steward and champion it, is the honor of a lifetime.

What first drew you to astronomy?

My interest goes back to about age 4 when we lived in southern Sri Lanka. I was in our garden with my father when he pointed to the moon and said, "People have walked on that."

As a kid, it blew my mind. I didn't quite know what to make of it, but the thought that occurred to me was that if humans could do that, what couldn't we do?

It wasn't the science that captivated me initially; it was the sense of adventure, the sheer audacity of traveling to the Moon. That was the first spark. Over the years, it developed into a passion for astronomy rooted in wonder, curiosity, and a drive to explore. Beyond pursuing my research, I've been privileged to take part in adventures that I could only dream of as a child, such as searching for meteorites in Antarctica, watching a total solar eclipse on the Mongolian steppe, and experiencing the thrill of weightlessness on a parabolic flight.

Clockwise from top right: **Ray Jayawardhana** at the W. M. Keck Observatory in Hawai'i, which is jointly run by Caltech and the University of California; Jayawardhana has authored four popular science books, including a book for children; Jayawardhana during a European Space Agency parabolic flight.



At your introduction in January, you spoke about your childhood connection with JPL. Could you tell us more about that?

Alongside reading books and popular science magazines and being active in amateur astronomy groups, I was an avid listener of BBC Radio and Voice of America. Through everything I consumed, JPL kept emerging as a center of action, particularly in the exploration of our solar system through missions like Viking and Voyager.

So, I remember typing up a letter and sending it to 4800 Oak Grove Drive, asking for information and images from those missions. Weeks later, I came home from school to an envelope with the JPL logo waiting for me. Inside was a viewbook filled with photographs of Jupiter and Saturn, their moons and ring systems, as captured by Voyager a few years earlier. It was spectacular.

I finally had the chance to visit Caltech for the first Sagan Summer Workshop—then called the Michelson Summer School—as a graduate student. And now, years later, I find myself here not as a visitor but as an incoming member of this community. It still feels a bit surreal!

What excites you the most about the research you are doing now?

We're living through an incredible revolution in our understanding of the universe and our place within it, a moment comparable to Galileo's in some ways. When I started graduate school, we knew of one planetary system: our solar system. Since 1995, astronomers have identified more than 6,000 planets orbiting other stars. We've moved from speculating about other worlds to actually finding them, tracking them, and now, most excitingly, getting to know them as physical objects.

My research group explores exoplanets, brown dwarfs, and star formation using the largest telescopes in space and on the ground, including the Keck Observatory. One of my postdocs recently led a paper about an ultra-hot gas giant exoplanet for which we've begun characterizing the atmosphere through remote sensing with spectroscopy. We can tell you the temperature difference between the night and day sides, that winds reach 10,000 miles per hour, and how clouds fill the sky at dawn but dissipate by the evening. Even though I do this kind of work for a living, I still find it mind-blowing that we can make such measurements for a world hundreds of light-years away!

Staying active in research during my years as a dean and provost has been important to me. It keeps me intellectually engaged and

personally inspired. I also retain some sense of the highs and lows of being a faculty member, from the excitement of a long-awaited result to the frustration of a rejected proposal to the joy of mentorship. That lived experience shapes how I think about supporting faculty and what an institution owes its researchers.

I'm looking forward to continuing our group's work here as a professor of astronomy. The presidency is a privilege and so is the opportunity to remain a working scientist.

As a widely recognized writer and science communicator, you have also authored popular science books and a children's book; you have contributed to outlets like *The Economist*, *The New York Times*, and *The Wall Street Journal*, and you have been the inspiration behind a television documentary. How did that interest take shape, and what public engagement efforts have you been especially proud to be part of?

I inherited a love of writing and language from my late father. My first published piece appeared on the children's submissions page of a local paper when I was in sixth grade, and I still remember the thrill of seeing my name in print for the first time. At Yale, I wrote for the student newspaper and a campus science magazine. The summer after my first year, I had an internship at *The Economist* in London. That experience showed me that the





Ray Jayawardhana in Antarctica during an expedition in search of meteorites.

best writing demands the same intellectual vigor and clarity of thought as the science itself.

But public engagement takes many forms beyond books and bylines, and I've always been drawn to approaches that meet people where they are. One initiative I'm particularly proud of is the "Cool Cosmos" campaign that was carried out while I was on the faculty at the University of Toronto. We deployed 3,000 ads with catchy phrases and designs inside Toronto's subway cars, streetcars, and buses. The goal was to pique people's curiosity about the universe and remind them of our intimate connections with the cosmos.

Beyond your own work, you have also built structures within universities that support public engagement. How have you approached that?

Public engagement flourishes when institutions offer opportunities and encouragement.

At Cornell, we launched a Distinguished Visiting Journalist program that embedded working journalists on campus for extended periods, deepening the relationship between the media and the academy in ways that a single lecture or panel never could.

And at Hopkins, we created the Provost's Fellows for Public Engagement, selecting a cohort of outstanding faculty for tailored communications training and engagement opportunities. The demand from faculty was high from the start and the outcomes were tangible. It was gratifying to receive enthusiastic feedback from the participants, many of whom found the experience a highlight of their career.

What are some of your priorities as you prepare to begin your term?

First, let me say that I'm following in the footsteps of great leaders who have served Caltech well. Second, I begin with a deeply held commitment to safeguard, build upon, and amplify what sets Caltech apart.

The president can play a useful role in bringing people together and helping to identify where the Institute can have truly transformational impact. We should develop dynamic frameworks to understand our strengths, identify compelling opportunities, and focus resources, then recalibrate as the opportunities and the landscape evolve. I'm starting with listening and learning, and I've already enjoyed many inspiring conversations this spring.

One aspect I'm particularly excited about is expanding the kinds of investments that allow faculty and students to pursue blue-sky, high-risk ideas that wouldn't otherwise take flight. Caltech is already doing that in a number of areas, and we should cover more of the waterfront.

At Cornell, thanks to philanthropic support, we launched a seed-funding program at a meaningful scale, \$200,000 grants for up to two years, and the returns on investment were remarkable in terms of research outcomes and external funding that followed. You have to take risks and trust that a handful of these bets will take off in ways that are incredibly impactful. With the caliber of faculty at Caltech, and the collective ambition of this community, the potential for such ventures here is truly exceptional.

Lightning Round

Favorite dish to make or bake?

Tiramisu.

What's something you're trying to learn?

Tennis.

Best advice you have ever received?

The biggest room in the world is room for improvement.
—Cyril Ponnampereuma [Sri Lankan-American scientist]

Where do you want to travel next?

Into orbit and to the bottom of the deep ocean.

Olympic event you most want to attend in 2028?

Track and field.

If you weren't an astronomer, what would you have done with your life?

I'd probably have become a writer or journalist. 📖

Hear more from Caltech's incoming president



Inside Look **Bil Clemons**



Music and mentorship can be found in the office of this biochemist • • •

By Omar Shamout

If you were to walk into Bil Clemons’s office in Braun Laboratories, it is likely that his 6-year-old Aussie doodle, Mila, would be the first to greet you. “The students love interacting with Mila,” says Clemons, a Caltech biochemist. “You can tell she’s friendly when she first meets you.”

Meeting with students is important to Clemons, who, in 2024, received the Institute’s Shirley M. Malcom Prize for Excellence in Mentoring. “In terms of being empathetic, relating to students, and helping them see where their potential is, I like to think that those are things that I do well,” he says.

The students in Clemons’s lab help him investigate life on the molecular scale using structural biology tools such as X-ray crystallography to study viruses called phages that specifically infect bacteria. Some phages produce peptide inhibitors that kill bacteria by breaking the cell-wall machinery in a way similar to penicillin. “We put a lot of energy toward understanding how certain phages have evolved to have the ability to kill bacterial cells with proteins that act as inhibitors,” says Clemons, Caltech’s Arthur and Marian Hanisch Memorial Professor of Biochemistry, who joined the Institute in 2005. “I believe future discoveries about this evolutionary process will be transformative in our ability to combat bacteria.” He explored this topic in an October 2024 Watson Lecture titled “Combating Future Pandemics with Viruses.”

Clemons received his bachelor’s degree from Virginia Tech and a PhD in biochemistry from the University of Utah, where he worked under Venki Ramakrishnan, who shared the 2009 Nobel Prize in Chemistry for research on the structure and function of ribosomes. Clemons contributed to this work as a graduate student, and the findings led to a greater understanding of genetic code translation. “I was his first PhD student at a time when we both were new to Salt Lake City,” Clemons says of Ramakrishnan. “Venki had just moved with his wife, and their kids were already out of the house, so I became a sort of an extended family member.”

Clemons believes that helping students find a sense of belonging on campus is crucial to their success. In an effort to fortify the Caltech community, he helped organize Caltech’s Black Lives Matter program in June 2020, facilitated the work of Black Scientists and Engineers of Caltech, and helped found Black@Caltech. “Chosen or not, a large part of my career is trying to make science more equitable for everybody and bringing as many people into the fold as I can,” he says.

Clemons’s sense of self is also evident in his workspace. “Being one of the few Black professors at Caltech, I think it’s meaningful to people that I have representation of that in my office,” Clemons says.

A piece of Clemons’s identity was forged at age 15, when he decided to drop the second “L” in his first name. “As a kid, I went by Billy, and I didn’t want to be Billy anymore. But I also didn’t want to be Bill, which was my dad’s name,” he recalls. “The beauty of it was, whenever my friends would call the house, they’d just ask for ‘Bil with one L.’”

Visitors to Clemons’s office are often greeted by music—artists such as De La Soul, John Coltrane, and Jimmy Cliff are in regular rotation. Musician Nina Simone also gazes out from above the couch in the form of a print by artist Jeffrey Pierson. “She was somebody who attracted very large, diverse audiences but never shied away from being overtly proud of her identity,” Clemons says.

Music is central to the Clemons family story: Clemons’s father, Bill Sr., played in and served as a band director in the Marine Corps. His uncle Clarence was the saxophonist for Bruce Springsteen and The E Street Band from 1972 until his death in 2011, at which point Bil’s younger brother Jake took over.

As for his interest in discovery, Clemons says that came in part from encyclopedias. When he was young, a door-to-door salesman sold his family a set, and he would spend hours poring over the wonders inside. Clemons even took a summer job selling encyclopedias while in college. “Growing up in that era without internet, having those encyclopedias was really a window into the world,” he says. “I would just hang out, pick a different letter, and comb through it. I was a curious kid, and learning about new things always gave me a lot of satisfaction.”



Bruce Springsteen and the E Street Band, *The River*, gold record

Columbia Records presented this honorary gold record—commemorating the success of the 1980 album—to Clemons’s uncle Clarence, the band’s saxophonist. “I don’t remember him not being famous,” Clemons says. “I never thought anything about it, but there were moments where you’d be backstage at a concert, and there are 50,000 people shouting for your uncle, and it’s like, ‘Oh, that’s cool.’ He always had a distinct sound. You’d hear the sax and say, ‘OK, that’s Clarence Clemons.’”



Jake Clemons, “Democracy”

Clemons showcases this single, a reinterpretation of a 1992 Leonard Cohen song, from his brother Jake’s 2019 solo album, *Eyes on the Horizon*. Jake took over for Clarence Clemons as saxophonist for the E Street Band in 2012. “My brother is a natural entertainer. He always brightens a room when he comes in because his energy is super positive,” Clemons says. “When he joined the band, it really changed the tours. My dad could play any instrument, and my brother is similar. On his own albums, he plays everything.”

“A large part of my career is trying to make science more equitable for everybody.”

X-ray crystallography image of alpha helix

Structural biologists like Clemons create three-dimensional molecular models based on experimental data, often obtained by shooting protein crystals with X-rays and measuring how those X-rays scatter. In the frame are slides made by Robert Corey, a former professor of structural chemistry at Caltech. In the 1950s, Corey, together with Caltech professor of chemistry Linus Pauling (PhD 1925) and visiting researcher Herman Branson, discovered the basic units of protein structure. The framed slides highlight the planar nature of the peptide bond, the alpha helix, and a beta sheet. “These images represent the birth of protein structure, which happened here at Caltech,” Clemons says. “Branson was a Black man on sabbatical here under Pauling. The three published the paper that described the alpha helix for the first time, and subsequent work from Corey and Pauling described the beta sheet.”

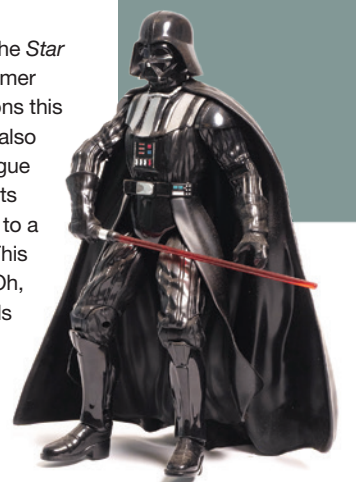


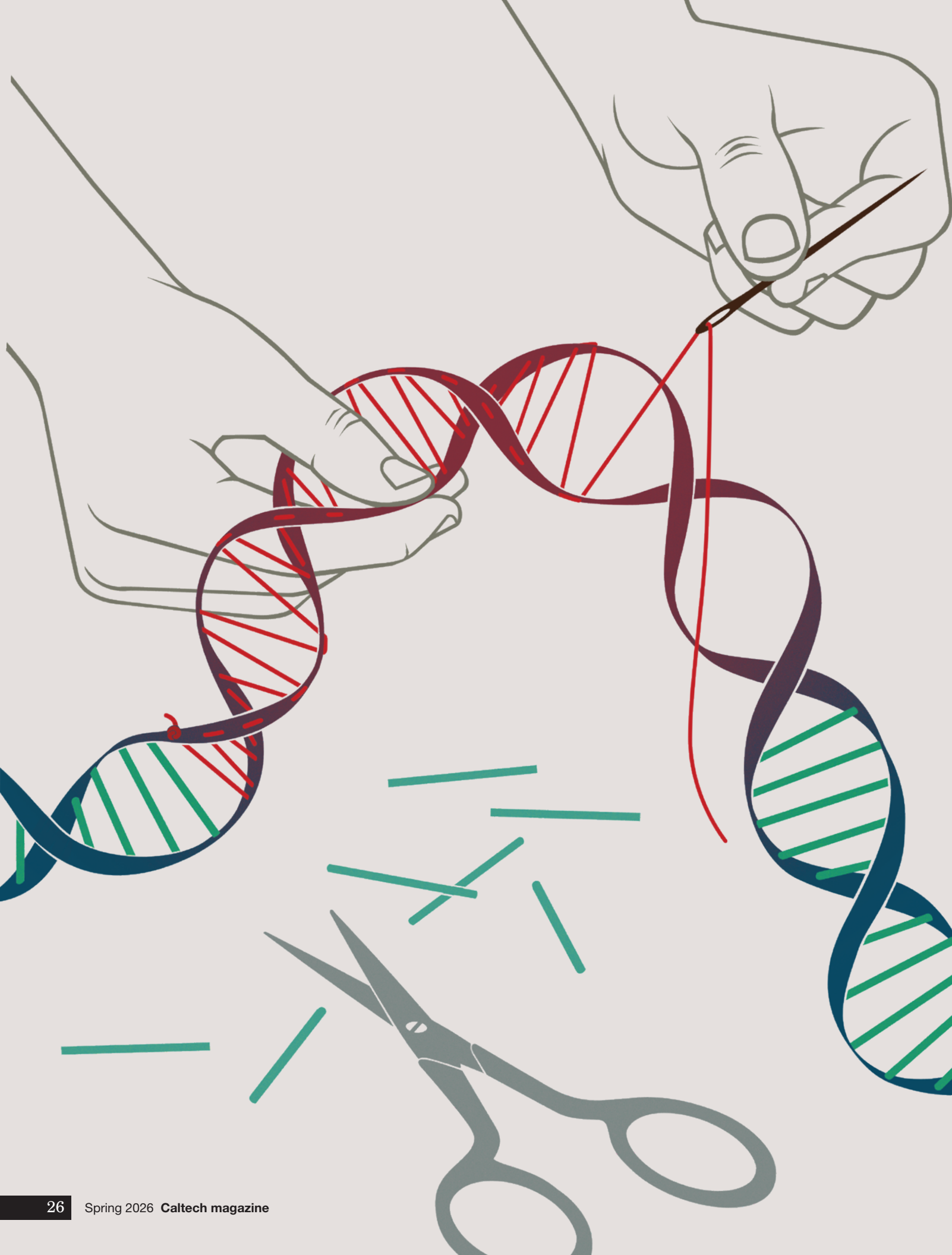
Quincy Clemons artwork

Clemons has on display several pieces of art by his brother Quincy, an LA-based artist who goes by the moniker Unyenz. The works include a drawing of their uncle Clarence; a box painted with Rastafarian imagery; and a portrait of their father, Bill Sr., who was a band director in the Marine Corps. “My dad enlisted, but he was a music major in college. He played saxophone, which is kind of the family instrument, but he could also play the flute and piccolo, which they needed for the marching band. Eventually, he became the officer that oversaw the band, and he was the conductor.”

Darth Vader action figure

Clemons is a fan of the *Star Wars* franchise. A former student gifted Clemons this large figurine, which also speaks lines of dialogue from the movies. It sits beside his desk next to a replica light saber. “This student asked me, ‘Oh, do you think your kids will like this?’ My kids didn’t care, but I was like, ‘I’m going to keep that!’”





Stitching the Synthetic Biology Revolution

Caltech is building tools for and shaping approaches to the discipline, which could change the way we live.

By Lori Dajose (BS '15)

Billions of years of evolution have slowly, iteratively, produced a vast library of genomes through DNA mutations, encompassing the genetic information for everything that has ever lived. Mother Nature has had a monopoly on writing in the language of life. Until now.

Earlier this year, Caltech bioengineer Kaihang Wang unveiled a new technique that can stitch together short pieces of DNA—the building blocks of living organisms—to create long unbroken strands of millions of individual genes. His invention, called Sidewinder, is the functional equivalent of “page numbers” for DNA. Think of it like assembling a book: Sidewinder enables small pieces of synthesized DNA to be labeled sequentially, like page numbers, so the strands can organize themselves in the correct order.

Wang’s DNA-weaving tool represents a major advance in synthetic biology, the practice of engineering not with electrical components or steel but with the biological components of life. Synthetic biology allows scientists to study the complex workings of living organisms by breaking apart, redesigning, and constructing new molecular parts, systems, and devices. In turn, these processes lead to the development of useful applications for treating disease, improving agriculture, and much more.

Since the field coalesced at the turn of the 21st century, Caltech researchers have led the development of tools that are integral to the practice of synthetic biology. These efforts are giving rise to a new biological frontier in which

synthetic biologists at the Institute wield cellular machinery to develop and deliver effective cancer treatments, control populations of invasive mosquitos, and manipulate plants to improve resiliency in the face of a changing climate—turning imagination, Wang says, into reality.

Origins of the Field: “A Magic Time”

Many of synthetic biology’s nascent components were developed at Caltech.

In 2003, a physicist-turned-biologist named Michael Elowitz arrived on campus as an assistant professor. As a graduate student at Princeton, Elowitz had invented a biological circuit called the repressilator: a circuit of three genes engineered into a cell where the genes interact with one another in an oscillating cycle akin to the game rock-paper-scissors. Each gene produces its own protein—think of them as rock, paper, or scissors—that physically represses the expression of one of the other genes: Rock represses scissors, scissors repress paper, and paper represses rock. Proteins degrade over time, so as concentrations of “rock” decrease, production of “scissors” shoots up, which blocks the gene for “paper.” After “scissors” eventually degrades, the “paper” proteins increase, which silences “rock,” and so on, in a perpetual cycle. This achievement marked the first time anyone managed to program a living cell to execute complex dynamic behaviors like a computer does.

When Elowitz came to Caltech, electrical engineer Richard Murray (BS '85) had not taken a biology class for two decades. However, the repressilator piqued his interest. Murray’s research focused on control and dynamical systems—systems that sense inputs in real time

and modulate themselves accordingly, like thermostats. The repressilator was an example of a dynamical system made out of biological rather than electrical parts.

“I started to get interested in the idea of engineering biological systems in the same way you would engineer electrical systems,” Murray says. “Take all the discrete components of the cell: How can we not only tweak them by adding in or repressing a gene but also engineer the entire system of biomolecular components to behave in ways that we direct?”

In the early 2000s, interdisciplinary collaborations emerged around these questions and involved researchers such as Murray, Elowitz, biophysicist Rob Phillips, chemical engineer and Nobel Laureate Frances Arnold, computer scientist Erik Winfree (PhD ’98), applied mathematician Niles Pierce, and more. “It was just a magic time in terms of crystallizing that there was an idea here that could take off,” Murray recalls.

Engineering with the components of life also helps answer open questions about life itself—a process that many researchers call “building to understand.”

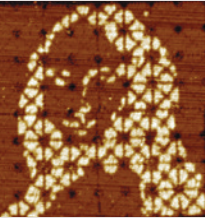
“Biology seeks to explain how complex organisms work through a kind of reverse engineering process—by discovering what genes and other molecular components are necessary for a given process and then working out how they interact with one another to provide a natural function,” Elowitz says. “Synthetic biology works in the opposite way: We take molecular components such as proteins, alter them, and redesign their interactions in order to program a new cellular behavior. What makes this interesting and challenging is that this whole engineering process unfolds inside a living cell—an environment that we did not create and do not fully understand.”

Other researchers, like Winfree, take a “bottom-up” approach to synthetic biology, removing biomolecules like DNA from their normal context in cellular systems in order to engineer dynamic systems at the nanoscale, such as a test tube of molecules that behave like a neural network. “For me, the next frontier is the study of information-based chemistry—the ‘magic sauce’ of biology, independent of biological cells,” Winfree says.

No matter the approach, says biophysicist Rob Phillips, at its core, synthetic biology is about “the imagination to create that which has never existed before.”

Nanoscale Engineering with DNA

DNA’s unique chemical properties, or the “magic sauce” Winfree describes, enable the work of synthetic biology researchers. The four kinds of nucleotides that make up a DNA strand—adenine (A), cytosine (C), guanine (G), and thymine (T)—pair together precisely (A with T and G with C). In biology, these base pairs form within the familiar DNA double helix of an organism’s genome.



Traditionally, genes within the genome are transcribed into RNA and then translated into proteins that function within the cell. However, researchers can take advantage of the programmability of nucleic acids like DNA and RNA to design sequences that assemble themselves into complex structures or function as dynamic devices. Researchers refer to this new discipline as molecular programming—one of the foundational tools for biological engineering.

Molecular programming occurs on the nanoscale. Designing DNA and RNA molecules to independently carry out tasks on the nanoscale within living cells and organisms exploits the very programmability that living organisms use in order to function. Programming is invaluable because researchers cannot simply take tweezers and move molecules around like you might with the wires and switches in an electrical circuit.

“Molecular-programming researchers seek to develop the principles and tools to program molecules with the ease and rigor that computers are programmed today,” says Pierce, who in 2004 developed a key technology in the field of molecular programming known as hybridization chain reaction (HCR). HCR was the first experimental demonstration of conditional nucleic acid self-assembly, opening up the possibilities for molecules to autonomously self-assemble via prescribed kinetic pathways without human intervention. Now used in thousands of labs around the world, HCR is a way to visualize and quantify biological molecules in a sample using short sequences of DNA that, in the presence of a target sequence, perform a chain reaction to produce a detectable signal, enabling imaging of individual target molecules within intact tissues. This process is central both to biological research (such as studying the development of a single cell into an adult organism) and to the creation of new therapeutics (such as measuring the effect of a candidate drug on a set of molecular targets in a cancer cell).

To enable molecular programming, Pierce and colleagues developed and support NUPACK (short for nucleic acid package), a software suite for the analysis and design of nucleic acid structures, devices, and systems used by thousands of labs worldwide. NUPACK algorithms are crucial tools to analyze and design molecular interactions that are a hallmark of the emerging fields of molecular programming, nucleic acid nanotechnology, and synthetic biology.

Such molecular interactions were on vivid display in 2016, when bioengineer Lulu Qian crafted the world’s smallest *Mona Lisa*, among other nanosized illustrations, using a technique called DNA origami developed by then Caltech research professor Paul Rothemund (BS ’94). Images captured by atomic force microscopy show the iconic smiling face of the Mona Lisa, rendered not in paint and

brushstrokes but in DNA molecules half a micrometer wide—the size of a small bacterium. These images were more than just minuscule artwork—they were proof of the accuracy and precision Qian had developed through the hierarchical self-assembly of DNA origami.

The technique involves designing DNA molecules with specific sequences so that, when tossed in a test tube, the individual sequences interact and thus assemble themselves into a desired shape. Many small shapes then assemble into a larger one like puzzle pieces forming a puzzle. The assembly process is also dynamic: The DNA sequences can process information and make decisions about whether one strand should replace another in response to signals in a molecular environment. In this way, Qian can create nanoscale computing systems such as neural networks made out of DNA instead of electrical pieces, taking advantage of the unique chemical properties of biomolecules.

Building the Bioengineer’s Toolkit

When synthetic biology is used for specific types of applications, the process follows a general pipeline. First, researchers design what they want to make in the same way an architect would create a blueprint for a building. The desired product could be a circuit of molecules to destroy cancer cells or an enzyme to make plants more drought resilient. Then, they turn their design into biological reality using synthesized DNA, proteins, and other biological building blocks. Next is lab testing, which includes delivering the synthesized material into cells. Researchers then make adjustments to improve their results.

Wang’s Sidewinder is a revolutionary new tool for synthesizing biological designs. To help people understand Sidewinder, Wang likes to point to the invention of the printing press in the 1440s, which enabled the creation of thousands of pages each day from a single printer. But assembling these individual pages into books was an arduous process, requiring book binders to scrutinize each page for contextual clues and place them in the correct order. Pagination was not invented until decades later and did not become commonplace for centuries.

The practice of DNA synthesis encountered a similar bottleneck. Until Wang’s Sidewinder invention, it was challenging to synthesize long pieces of DNA, though it was possible to synthesize short pieces that are a few hundred base pairs long, called oligonucleotides (or oligos), as used in the HCR and DNA origami processes.



Kaihang Wang, center, together with grad students Noah Robinson, left, and Weilin Zhang, right, developed the Sidewinder technology.

► The Qian group has shown that these DNA neural networks can use heat as an energy source and can learn to perform pattern classification tasks on their own.

But to create entire genes, and ultimately genomes, and thereby enable the realization of biotechnologies from personalized cancer vaccines to synthetic crops, longer DNA sequences up to billions of bases in length would need to be stitched together with perfect accuracy from an ever-increasing number of oligos.

Sidewinder enables the synthesis of new genes and even entire genomes within just a few days, if not hours. “We can now make long DNA, regardless of complexity and sequence, and do this faster, more easily, and more cheaply than has been possible,” Wang says.

The final stage of the synthetic biology pipeline, delivery, focuses on how molecular components get where they need to go. One method for delivery draws inspiration from naturally occurring viruses. Viruses, much like a Trojan horse, are adept at sneaking past cellular barriers to get their genetic material into cells. While real viruses can make you sick, scientists such as biologist Viviana Gradinaru (BS ’05) are testing whether viral packaging could instead be filled with therapeutic molecules or genes and designed to make its way into the intended cells.

Gradinaru uses a class of virus known as adeno-associated viruses (AAVs) and alters their capsids, or shells, based on their ability to penetrate specific cells. For example, some AAVs can be designed to target specific brain cells called neurons. These would be useful when developing treatments for brain disorders such as Huntington’s disease, which is caused by a mutation in a single gene. Gradinaru’s team modifies the AAV to custom applications whether the cargo is intended for a neuron or another kind of cell.

As with AAVs, delivery tools often need to be customized for specific applications. In particular, many of the tools developed to work with human cells do not translate to plant cells. To address this, chemical engineer Gözde Demirer is developing tailored tools for plant engineering, a major frontier in agricultural sustainability.

A World of Applications

As the synthetic biology toolkit expands, so does its potential applications. Twenty-five years after unveiling the repressilator, Elowitz is now applying synthetic circuit design to cancer therapeutics. The two leading forms of cancer treatment, chemotherapy and drug-based targeted therapies, each have their own drawbacks. Chemotherapy is great at killing cells but lacks specificity, leading to debilitating side effects like liver toxicity. Targeted therapies, on the other hand, can be very specific for diseased cells but often lead to resistance.

Projects in Elowitz's lab, led by graduate students Andrew Lu and Lukas Moeller, provide foundations for an alternative paradigm. Their therapeutic circuits are sets of engineered proteins that detect whether a cell is expressing the mutant *RAS* oncogene, the most prevalent cancer-related gene in human cancers. If mutant *RAS* is detected in the cell, the circuit initiates a cell-death program that destroys it. But the same circuit has no effect on healthy cells. Along with collaborators, the team has analyzed the livers of mice with cancer that had received the treatment through an injection and some, the control group, that had not. The control group mice had livers riddled with tumors while the livers of the mice treated with the circuits were cleared. An exciting aspect of the system is that it is programmable. By swapping out sensor modules in the proteins, it should be possible to adapt the system to other cancers or diseases.

In addition to treating individual organisms, synthetic biology research can be applied to entire populations. Biologist Bruce Hay spends his time focused on swarms of pesky insects. Mosquitoes, for example, carry infectious diseases like malaria. However, they are also a major food source for birds, so wiping them out entirely would be damaging to the ecosystem. Hay's team is engineering ways to deliver genes into mosquito populations that would only kill the insect if it were carrying malaria.

Importantly, rather than catching and injecting every mosquito with the therapy—an impossible and absurd task—Hay is engineering the gene therapy to be passed along in the population. These so-called “selfish” gene systems take advantage of the Darwinian concept of survival of the fittest to ensure the inheritance and spread of the desired anti-malaria gene among the offspring. Hay designs these systems to be reversible, so that the effects of synthetic elements can be counteracted if need be.

▶ One tool uses self-assembled protein nanoparticle platforms to deliver useful small molecules and proteins into plant cells, leading to more productive crops.

Synthetic biology can also provide alternatives to working with real organisms. For example, researchers have limited access to donated embryos for research, and the embryos may only be grown for a set period of time (up to 14 days, according to international policies, or 12 days in California). However, there are many unanswered scientific questions about this important stage of development, one at which most pregnancies fail.

Developmental biologist Magdalena Zernicka-Goetz is a pioneer in creating synthetic human embryos for research. Her lab uses mouse stem cells to make embryo-like structures that look and behave identically to a mouse embryo, complete with a primitive heart and brain cells. These structures do not come from a sperm and egg; they are the result of chemically coaxing mouse stem cells to interact and self-organize into structures that develop like an embryo, enabling the study of the earliest stage of life without using real embryos. Zernicka-Goetz has used these models to discover how defects in certain genes impact brain development, among other discoveries.

Phillips notes there is still much to learn about biological systems. “For 60 percent of genes in the *E. coli* bacteria family—not to mention 99 percent of genes in mammals—we don't know how they are turned on or off at all,” Phillips says. “We can build a genome, but we don't know how it works or how to control it. It's like sailors navigating on flawed maps from 400 years ago: We will find land, but it may take time. Synthetic biology is a major field of opportunity that could improve the human condition. There's so much to be done.”

Much of the research mentioned in this story was made possible by federal funding from the National Science Foundation and the National Institutes of Health, among others. For a full list of funding sources, scan the QR code at right.



Gözde Demirer is the Clare Boothe Luce Assistant Professor of Chemical Engineering.

Michael Elowitz is the Roscoe Gilkey Dickinson Professor of Biology and Bioengineering and a Howard Hughes Medical Institute Investigator.

Viviana Gradinaru is the Lois and Victor Troendle Professor of Neuroscience and Biological Engineering and a Howard Hughes Medical Institute Investigator. She is also the Allen V. C. Davis and Lenabelle Davis Leadership Chair and director of the Richard N. Merkin Institute for Translational Research.

Bruce Hay is a professor of biology.

Richard Murray is the Thomas E. and Doris Everhart Professor of Control and Dynamical Systems and Bioengineering.

Rob Phillips is the Fred and Nancy Morris Professor of Biophysics, Biology, and Physics.

Niles Pierce is the John D. and Catherine T. MacArthur Professor of Applied and Computational Mathematics and Bioengineering, and the executive officer for biology and biological engineering.

Lulu Qian is a professor of bioengineering.

Kaihang Wang is an assistant professor of biology and biological engineering.

Erik Winfree is a professor of computer science, computation and neural systems, and bioengineering.

Magdalena Zernicka-Goetz is a Bren Professor of Biology and Biological Engineering.

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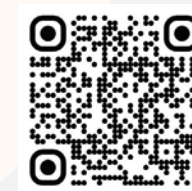
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In Our Backyard

Post-fire research continues to support the local community and beyond.



By Lori Dajose (BS '15)

More than a year after the 2025 Los Angeles fires, Caltech labs are pressing forward with research projects to provide answers in service of public health and safety. Through investigations such as testing for heavy metal contamination, monitoring air quality, and assessing the burn area's erosion hazards, Institute scientists immediately launched into action in the days and weeks following the fires, bringing scientific tools and expertise to tackle fundamental questions for the broader public—even as many of these researchers were impacted by the fires themselves.

“Our community came together to help each other with housing and all manner of other needs, while simultaneously directing our skills and energy as scientists at societally important problems created by the fires—the unique and poorly understood sources of pollution, life-threatening debris flows, and more,” says John Eiler, the Robert P. Sharp Professor of Geology and Geochemistry and Ted and Ginger Jenkins Leadership Chair of the Division of Geological and Planetary Sciences (GPS). “This was possible only because our small size and close connections with each other allowed us to mobilize for science in service to the community.”

Measuring Heavy Metal Contamination

A few miles north of Caltech's campus, the 14,000-acre Eaton fire burned thousands of structures, most built before 1978, the year the government started regulating lead in building materials. Lead and other toxic heavy metals were released into the air as those older structures burned. Lead is highly toxic to young children; Environmental Protection Agency (EPA) regulations allow for only 5 micrograms of lead per square foot of dust on floors and 40 micrograms per square foot on windowsills.

After evacuating his family from his Altadena home, Caltech's François Tissot, professor of geochemistry and a Heritage Medical Research Institute Investigator, reached out to his lab members. “I asked my team to let me know if anyone was interested in using our resources to help assess the hazards from the fire, ash, and smoke,” he says. “Everyone immediately said, ‘Yes.’”

When Tissot looked for articles or studies related to the pollution caused by these types of wildfires, he came up empty. He soon realized that his lab's work would begin to fill a huge gap in knowledge. As he said during his January 2026 Watson Lecture: “There is no systematic study of this kind of urban fire. It's a new type of fire.”

Clad in safety gear, **François Tissot** surveys his damaged home after the Eaton Fire.

In their cosmochemistry laboratory, the Tissot group typically uses sophisticated instrumentation to measure concentrations of elements in meteorite samples that date back to the formation of our solar system. After the blaze, the team opted to use its technology to study bulk ash samples taken outdoors as well as finer dust samples taken from surfaces in homes in and around the burn area. Led by graduate student Merritt McDowell and postdoctoral research associate Theo Tacail, the team worked with local residents to collect and process over 300 samples from 52 homes—including Tissot's—within five weeks after the fire; Tissot's lab provided these measurements free of charge thanks to support from the Caltech GPS division.

“The tools we have in the lab are extremely complex, but the first measurement we always make is a concentration measurement,” Tissot says. “We need to know how much of an element is in the sample so that we know what to do with it. How much lead, how much of the heavy metals, how much of the toxic elements have been released by this particular fire? These were the crucial questions.”

The team discovered unsafe levels of lead, above the EPA limits, in homes as far away as 7 miles from the burn zone; the farthest they tested. The researchers returned to the same homes in January 2026 to resample the same areas and compare lead levels a year after the fire. As for Tissot's own house, because the structure is too contaminated for remediation, he and his family are still waiting to see if their insurance company will allow them to rebuild. “There is no cleaning it,” he said in response to a question at his Watson Lecture. “Ninety-nine percent of everything we owned was thrown away.”

Tissot has begun collaborations with colleagues in atmospheric chemistry and atmospheric dynamics to combine their lead data with a model of dust dispersion and transport. The goal is to build a tool that can be used for other urban firestorms to assess risks from heavy metals, particularly lead, carried by smoke plumes.

“The fires are going to become an important project within my group for the next few years,” Tissot says. “It takes time for the data to be impactful, for us to have interactions with policymakers and government officials. We need to make sure the data we produce has an impact beyond just helping people locally and improves responses for all future fires, because they will continue to happen. We want to get our data in front of the people who have the power to make decisions.”

Assemblymember John Harabedian represents the fire-affected foothill communities of Altadena, Pasadena, and Sierra Madre in the California legislature. In the weeks and months following the Eaton Fire, he and members of

his staff have met with Tissot and other Caltech scientists to monitor and understand new findings.

“University research plays a critical role in response and recovery,” says Harabedian, who has advanced legislation to expand access to health care, stabilize housing, and assess environmental hazards in the aftermath of urban wildfires. “Scientific data helps us protect human health and build more resilient communities as we work to prepare for, and ideally prevent, future disasters.”

Monitoring Air Quality

The Eaton fire destroyed many existing air quality monitors in the Altadena area, which prompted researchers in the laboratory of Paul Wennberg, Caltech’s R. Stanton Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering, to launch a new project to provide air quality data to the community in the fire’s aftermath.

Led by graduate student Haroula Baliaka and associate research scientist Coleen Roehl, the team deployed a network of moderate-cost solar-powered sensors throughout Altadena called PHOENIX (Post-fire airborne Hazard Observation Environmental Network for Integrated Xposure-monitoring). These sensors detect and measure the concentrations of particulate matter in the air based on the particles’ sizes, which range from 1 to 10 micrometers across.

The sensors were installed on top of homes and other local buildings, and community members were eager to

Did You Know?

Caltech professor Arie Haagen-Smit first linked air pollution to automobile exhaust and other industrial fuel combustion in the 1950s.

participate. Within a month after the fire, the team had worked with 28 different business owners, residents, and schools—including Roehl herself—to install PHOENIX sensors. “As an Altadena resident and atmospheric scientist, I was strongly compelled to participate in the PHOENIX project and to help in providing critical air quality data to my community,” Roehl says.

The PHOENIX data in the weeks after the fire showed that, on average, low levels of particulate matter in the air were recorded for the majority of each day, with concentrations classified as “good” by the EPA. However, the sensors showed that concentrations tended to spike into unhealthy levels at certain times of day for up to 60 minutes, usually in the morning. Baliaka says this phenomenon was potentially associated with cleanup activities and construction trucks kicking up dust and other particles as they rumbled through town. “PHOENIX was the most rewarding thing I did during my PhD,” Baliaka says. “It was very community driven, speaking to the residents and hearing their stories. It’s rewarding to be able to provide them with the data they need to make decisions for their health.”

Even before the fires, Baliaka’s research focused on air quality measurements. In particular, she utilizes a nationwide network of sensors, called ASCENT (Atmospheric Science and Chemistry mEasurement NeTwork), each composed of multiple instruments that detect not only particulate concentrations but the composition of those particles. The Los Angeles node of ASCENT is located in Pico Rivera, 13 miles from the burn area. ASCENT is funded by the National Science Foundation and was created by Caltech alumna Sally Ng (PhD ’07), the Institute’s Elizabeth W. Gilloon Professor of Environmental Science and Engineering.

In the aftermath of the Eaton fire, Baliaka looked at the data from the Pico Rivera ASCENT site and was surprised to find that potassium levels in the air, usually a signal of a wildfire, were not as high as she expected. However, ASCENT measured peak lead levels 110 times higher than usual for the area, confirming that the burned buildings did in fact release lead into the air throughout the Los Angeles region.

As Altadena rebuilds, the team is continuing to monitor air quality during construction. “We want the members of our local Pasadena community to have access to trustworthy air quality data,” Wennberg says. “We anticipated that having high-quality data available would help build confidence in the quality of the cleanup work undertaken by the Army Corp of Engineers.”

Graduate student **Haroula Baliaka**, left, from **Paul Wennberg’s** lab, and volunteer **Nikos Kanakaris** assemble a PHOENIX air-quality monitor.

Erosion and the Fire–Flood Cycle

The Los Angeles area is one of the most well-studied examples of the fire–flood cycle, in which a burned landscape produces a burst of flooding and erosion during its first major rainstorm following a fire. In the aftermath of the Eaton fire, researchers knew that the region could expect heavy debris flows with the next rainstorm.

In the 1930s, after a major winter storm sent a deadly wave of mud and rock cascading down from the San Gabriel Mountains through the Crescenta Valley, Los Angeles County built large basins at the foot of the mountains to trap and contain the surging debris flows before they reach residential neighborhoods. Today, there are about 120 of these basins along the San Gabriel Mountains. After the Eaton fire, the question emerged: Would these engineered debris basins be sufficient to contain the coming debris flows or would residents need to evacuate?

“In February, after the fire, the weather report was indicating a major rainstorm was coming, and we were particularly worried that the catchment above the Sierra Madre Dam might be too small to contain the coming debris flows,” says Emily Geyman, a graduate student in the Caltech laboratory of Michael Lamb, a professor of geology. As an ultrarunner, Geyman had run through the San Gabriel Mountains every weekend during her three years at Caltech prior to the fire; now, she returned to the trails to measure their erosion.

Lamb, a geomorphologist, studies how mountains erode and how to translate that science into the development of hazard assessments for public safety. The San Gabriel Mountains are among the fastest-eroding mountain ranges in the US, and urban development has spread right up against the mountain front. After the Eaton fire, Lamb, Geyman, and Zhiang Chen, then a Caltech postdoc, tested a new model of how fire leads to increased erosion in the San Gabriel Mountains, calculating the expected sizes of upcoming debris flows by using drones to measure the amount of dry sediment that had accumulated in the channel network. The work was carried out with support from local, regional, and federal government agencies—including the Los Angeles County Department of Public Works, the California Geological Survey (CGS), and the United States Forest Service. Indeed, their model correctly predicted the volume of debris flow during the next rainstorm—more than 677,000 cubic meters, or enough to fill more than 270 Olympic-sized swimming pools with mud, sand, and boulders.

The predictions also proved correct for the Sierra Madre Dam. Before the February 2025 rainstorm, county crews worked around the clock to excavate the dam and create more space to catch the debris. While the basin did fill up and slightly spill over its capacity, it protected the nearby residents from catastrophic levels of debris flows.



Michael Lamb surveys an area of possible debris flow in the San Gabriel Mountains.

“These results supported emergency management agencies by prioritizing debris-basin cleanouts, calibrating and validating debris-flow models for the burned catchments, and forecasting potential debris-flow risks for upcoming storm events,” says Don Lindsay, supervising engineering geologist at the CGS. “CGS continues to work with Michael Lamb’s group collecting lidar data to track sediment supply and vegetation recovery with time to reassess potential post-fire hazards and communicate our findings to Los Angeles County for consideration in its response plan.”

The team is now developing a method that can be applied to other fire-prone mountain ranges. This project will involve scanning mountains with drone laser altimeters (sensors that use laser light to measure elevation) in the immediate aftermath of a fire and calculating how much sediment could fuel an upcoming debris flow.

“Our work at Caltech is building on decades of studies from others, most notably state and federal government scientists, and the Herculean efforts by LA County Public Works to literally move mountains of rocks,” Lamb said during his January 2025 Watson Lecture following the fires. “Collectively, the continuation of government-supported science and debris-basin defenses is needed for us to live in the beautiful landscapes at the foothills of the San Gabriel Mountains.”

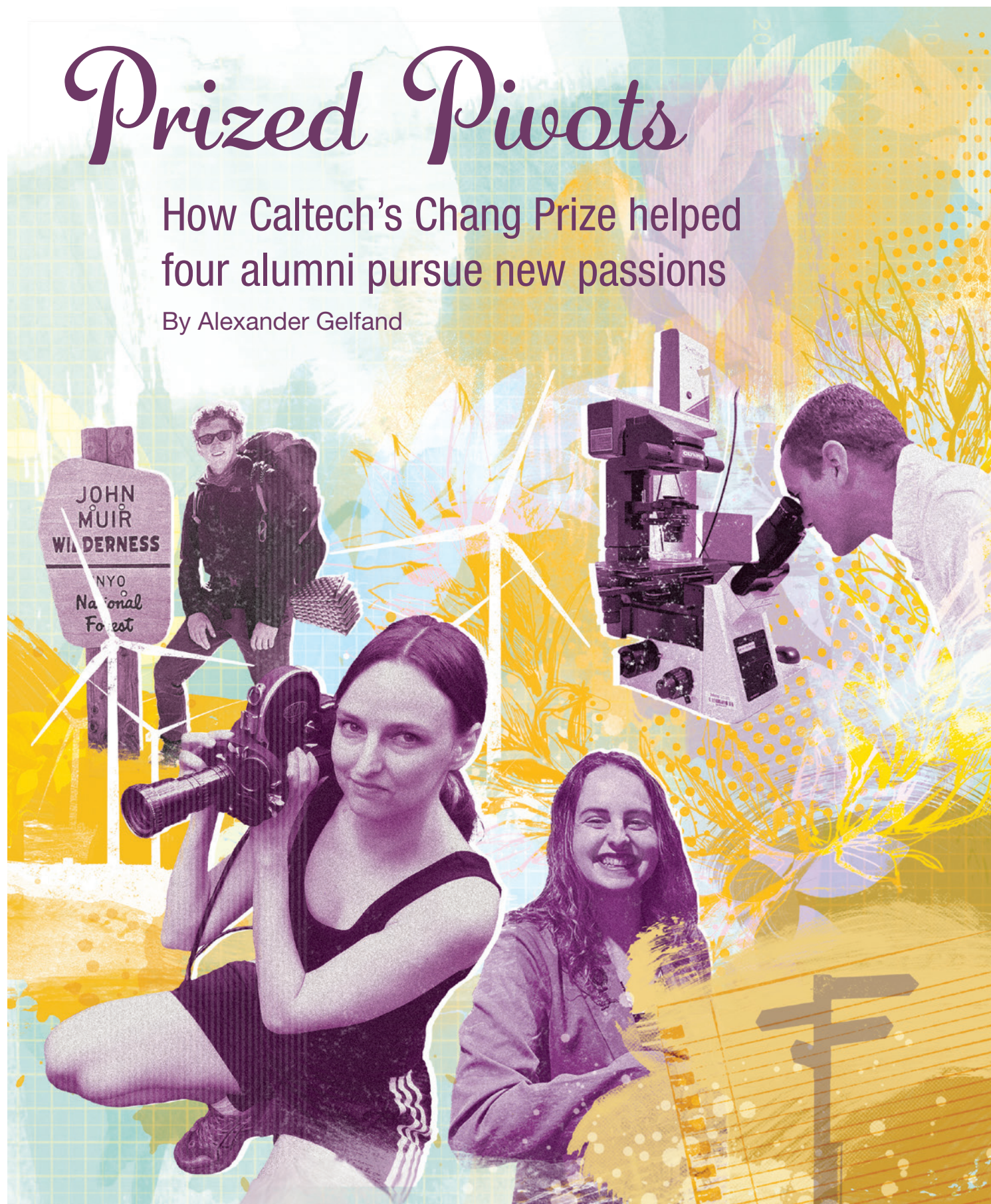
For more on how Caltech researchers jumped into action following the 2025 Los Angeles fires, listen to the *After the Fires* podcast produced by the Caltech Science Exchange.



Prized Pivots

How Caltech's Chang Prize helped four alumni pursue new passions

By Alexander Gelfand



The Milton and Rosalind Chang Career Exploration Prize rewards big swings. The prize, awarded by the Caltech Alumni Association, provides up to \$65,000 to help graduates who received their degrees within the last decade to pursue interests outside of their careers through innovative projects with meaningful societal impact.

"This award is about allowing people to take a really big detour in life—to do something that challenges and scares them," says Tara Gomez-Hampton (PhD '11), who chairs the Chang Prize committee, adding that proposals are assessed for audacity as well as merit.

Here are four recipients who have used the prize to pursue unapologetically ambitious goals.



Daniel Araya

(PhD '16, aeronautics)

When Araya found out that he had won the prize in 2024, he was moved to tears. Araya's wife, Carolina, had succumbed to cancer just months earlier—but not before she had encouraged Araya to apply to help him shift his career from aerospace engineering to immunotherapy. "Of all the treatments my wife went through, the only one that actually reduced her tumor burden was immunotherapy," Araya says. "That really piqued my interest in the immune system."

Araya's proposal, which focused on exploring how the immune system can be used to combat cancer and autoimmune diseases, had two components: a self-study track that involved scouring existing literature and taking online courses in immunology, and an experiential one working with researchers in a lab. The latter, which required cold-calling scientists he did not know in a field he had not trained in, proved more difficult. "There were a lot of polite 'nos,'" Araya says.

Araya's literature search led him to real-time cell microscopy and a pioneer of the field: Eric Betzig (BS '84), winner of the 2014 Nobel Prize in Chemistry. Betzig arranged for Araya to visit the Advanced Imaging Center at Howard Hughes Medical Institute's Janelia Research Campus in Virginia, where Betzig is a senior fellow. Araya observed imaging of live immune cells, a crucial step toward developing better immune-based therapies.

While he still works part time at the Johns Hopkins Applied Physics Laboratory, Araya now also helps a pair of Johns Hopkins researchers advance a tumor-imaging project called AstroPath that uses sky-mapping algorithms developed for astronomy to create and analyze detailed microscopic maps of tumors. The goal is to help predict which cancers are most likely to respond to specific immunotherapies, and Araya uses his data-science skills to improve the project's image-analysis pipeline.

Araya is now pursuing a career in medicine and has spent time shadowing physicians, an experience that brought him back to the same cancer center where his



wife was treated. "It was kind of surreal being on the other side of that same waiting room," he says. "But it also really cemented that this is what I want to do. I'm deeply grateful to Caltech and the Chang Prize Committee for kick-starting my journey."



Klavdia Zemlianova

(BS '14, mathematics)

Zemlianova first heard about the Chang Prize while pursuing her undergraduate degree and kept the award in mind as a possible means to explore filmmaking. Because she had to apply within 10 years of earning her degree, Zemlianova realized that she would have to direct her proposed film while simultaneously completing her PhD in neuroscience at New York University.

Now a postdoc at the Center for Theoretical Neuroscience at Columbia University, she has finished a rough cut of a film that explores the complexities of collective memory through the lens of Russia's war in Ukraine, an experience that has left her eager to make more movies. As someone from Russia with Ukrainian friends, Zemlianova found the escalating war preoccupied her thoughts as she submitted her Chang Prize proposal in 2023.

She had previously collaborated with an experienced director on a short documentary (*A Sentimental Science*, available on YouTube) that posed the question, "How many neurons do you need to recognize your mother?" But to complete her Chang project, Zemlianova needed additional training. She spent a year taking night classes in cinematography, directing, and film editing at the New York nonprofit Mono No Aware while writing her NYU dissertation and starting work on her directorial debut.

Zemlianova interviewed Ukrainian friends who had been forced to flee their nation as well as Ukrainians who are currently running archival projects in the country. She also conducted reenactments of events that served as visual metaphors for memory formation, like a friend's

childhood recollection of gathering wild walnuts that stained her fingers black.

The film is an exploration of how people create and preserve shared historical memories through storytelling. “We each individually have experiences, but collectively we choose what to save and retell going forward,” Zemlianova says.



Corey Husic

(PhD '23, chemistry)

Less than a year into his job at one of the world's largest chemical companies, Husic decided he wanted something different. “The Chang Prize came at the perfect time in terms of mental health and career interest,” says Husic, who won the prize in 2024 and is now a visiting assistant professor of chemistry at Lafayette College in Pennsylvania.

Well aware of America's long history of industrial contamination—including a toxic waste site near his hometown that was eventually transformed into a nature refuge—Husic wrote a proposal to explore the topic through science journalism. Initially, he planned to develop a podcast about rarely discussed examples of chemical pollution across the US, bringing a scientific perspective to the topic while raising awareness at the national level. “I came into this project thinking, ‘I want the whole country to know about this,’” he says.

But after speaking with residents of a West Virginia town that was devastated by the release of PFAS, or “forever chemicals,” from a local chemical manufacturing facility, Husic realized that even local community members did not fully grasp the scientific details or their long-term consequences.

He shifted his focus to community outreach and education, writing articles in local newspapers and magazines, and giving public presentations at libraries, Rotary Clubs, and other venues to help those in the area understand what had taken place. “As somebody who wants to pursue science communication for the betterment of people and communities, that felt like a more pressing place for my attention,” he says.

Husic spent the rest of his prize money replicating those efforts at contaminated sites across the country—including a former ore smelter in Colorado that was being used as a homeless encampment despite dangerously high levels of lead in the soil.

Husic views his post-prize transition to teaching as the logical extension of the journey he began in West Virginia. That journey now has him pondering how he can bring issues of environmental and social justice into the classroom.

“I want to figure out how to continue sharing these stories with students and inspire them to be concerned about these things,” he says.



Ariel Hasse-Zamudio

(BS '20, physics)

For Hasse-Zamudio, the benefits of her 2025 Chang Prize had more to do with the committee's belief in her dream than the prize money. Her proposal involved launching a career in sustainable science policy through the creation of the Alaska Energy Infrastructure (AEI) project, an initiative aimed at helping her home state transition to renewable energy.

“I had the skills, and I had the background,” says Hasse-Zamudio, who researched next-generation renewable energy materials as an undergraduate and advised Alaska Senator Dan Sullivan on environmental policy as a Beckman Science Policy Fellow in Washington, D.C., the summer before she graduated. “But the Chang Prize is what gave me the confidence and the ability to pursue this project.”

Hasse-Zamudio wanted to understand Alaska's renewable energy options as well as what Alaskans thought about energy policy and how it affected them. She spoke with state legislators, Indigenous leaders, and members of the electric co-op boards that govern local energy generation; established partnerships with renewable energy and environmental conservation organizations; and led roundtable discussions in various communities to better understand the concerns of ordinary Alaskans.

Those relationships helped Hasse-Zamudio establish the Alaska Energy Regeneration Network, a component of the AEI, which supports collaboration between communities, researchers, advocates, and policymakers. She also crafted community survey questionnaires about policies such as net metering, which allows Alaskans to sell electricity they generate using technology, such as solar panels, back to the grid.

After her funding expires, Hasse-Zamudio intends to continue to use both her data and her platform to promote evidence-based renewable energy policies. She plans to present her findings at the Alaska Sustainable Energy Conference and will serve as a science policy advisor to Stand Up Alaska—a nonprofit that works for environmental, economic, and social justice—in the run-up to statewide elections later this year. “I wanted to see what working on policy would look like at a professional level,” she says. “Thanks to the Chang Prize, I could bring my expertise into the room.”

In Memoriam

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

Annette J. Smith (1924–2025)



Smith, a professor of literature, emerita, passed away on October 18, 2025, at age 100. Smith joined Caltech as visiting professor of French at Caltech in 1970 and was appointed associate professor with tenure in 1982, and was promoted to full professor of French in 1985. She retired in 1993.

Smith researched and wrote *Gobineau et l'histoire naturelle* (*Gobineau and Natural History*), published in 1984, about 19th-century poet, novelist, and memoirist Arthur de Gobineau, who spent time as a diplomat in Persia, Greece, Brazil, and Sweden. Smith also translated nearly the entire corpus of Aimé Césaire's poetry into English—mostly in collaboration with Clayton Eshleman, an American poet—and published it in several different volumes beginning in the early 1980s. During her time at the Institute, Smith joined with other instructors and staff members to demand better salaries and benefits for women working at Caltech, and helped to mentor the first women to attend the Institute as undergraduates in the early 1970s.

George Rossman (PhD '71, 1944–2026)



Rossman, a professor of mineralogy, emeritus, passed away on February 6, 2026, at age 81. Rossman came to Caltech to pursue graduate work in inorganic chemistry, joining the lab group of Harry Gray, now the Arnold O. Beckman Professor of Chemistry. At that

time, Gray's group studied the electronic structures of compounds containing transition metals, and Rossman contributed to that effort through his thesis research on the spectroscopic and magnetic properties of molybdates and other transition-metal materials. After receiving his PhD, he was immediately recruited by the late Robert P. Sharp (BS '34, MS '35), professor of geology, and the late Eugene Shoemaker (BS '47, MS '48), professor of geology and planetary science and chair of the Division of Geological and Planetary Sciences (GPS) at the time, to serve as lecturer in mineralogy. He became an assistant professor of mineralogy that same year and was awarded tenure in 1977, promoted to full professor in 1983, and served as the McMillan Professor of Mineralogy

from 2008 to 2015. He was the division academic officer for GPS from 1999 to 2008. A major aspect of Rossman's research was his exploration of the distribution of small quantities of dissolved water and other forms of hydrogen in the minerals that are abundant in the deep earth. His studies led to transformations in our understanding of Earth's water cycle, melting, and volcanism, and the creeping flow of rocks that makes plate tectonics possible. In 2004, he received the Richard P. Feynman Prize for Excellence in Teaching, Caltech's highest teaching prize.

Yuk L. Yung (1946–2026)



Yung, professor of planetary science and Jet Propulsion Laboratory (JPL) senior research scientist, passed away on March 16, 2026, at age 79. Yung joined the Caltech faculty as an assistant professor of planetary science in 1977, and he received tenure in 1986. In 2011, he was named the Smits Family Professor. He became a JPL research scientist in

2014 and a senior research scientist in 2015. Yung served as a co-investigator on the Ultraviolet Imaging Spectrograph (UVIS) experiment on NASA's Cassini mission to Saturn, and a team member on the NASA Orbital Carbon Observatory 2 (OCO-2) mission to map carbon dioxide concentrations on Earth. Yung's research spanned planetary atmospheres, atmospheric chemistry and radiation, planetary evolution, astrobiology, and global climate change, with a strong emphasis on connecting theoretical models to observations. His work led to pioneering insights into the current properties and behavior of solar system atmospheres as well as their historical evolution. His models of the chemistry of planetary atmospheres have been widely used to interpret the results from spacecraft missions.

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Endnotes

In his first address to the community, Caltech’s incoming president, Ray Jayawardhana, talked about Caltech’s “intrepid community that continues to push at the edges of what we know.”

How would *you* describe the Institute, its culture, or its people?

The culture is built on a basis of scientific integrity. The pursuit of knowledge is nurtured by both curiosity and meticulous honesty.

–Robert Blair (PhD ’82)
LOMBARD, IL

curious

Vital.
Now more
than ever.

–Tim Cotter (BS ’88)
SUNNYVALE, CA

Caltech has one of the most collaborative cultures of any school I’ve been in; seeking help from fellow grad students and professors from other departments is almost always met with enthusiastic curiosity. This freedom to work across disciplines makes the research experience truly exceptional.

–Wei Lin Tan (PhD ’19)
SINGAPORE

collaborative

I had lots of different impressions of the Institute when I was there and in the years after graduating. But over time, my impressions have narrowed down to the two that I think are the most important: the Honor code and the interdisciplinary atmosphere. These are the essence of why I thought Caltech was an extraordinary place to study and is still an extraordinary place to be connected to.

–Stephanie Charles (BS ’73)
MOUNTAIN VIEW, CA

We Techers are the most curious group of individuals to which I have ever belonged.

–Bruce Reznick (BS ’73)
URBANA, IL

I would describe Caltech as the place where I learned how to learn. The Institute always pushed us to learn new things and extend our knowledge of how and why things were as they were.

–John Haworth (BS ’61)
RESEDA, CA

Challenging, inspirational, ethical, and in search of truth—The Friday Evening Demonstration Lectures hooked me in 1955; Ernest Watson himself taught our 1958 autumn physics course until a heart attack sidelined him to bring in Richard Feynman. Lucky us. Indeed “lucky us” for any Techer at any part of their life. Profound creativity, perseverance, and skepticism are both valued and meted out in equal proportions. Today, with experience at many of the finest colleges and universities across the globe, I can easily aver that the Caltech experience and its community are unique. As my Berkeley PhD wife said to me somewhat incredulously after her first Caltech alumni dinner: “Who are these people?” Today, she still is in awe of what she’s seen. Lucky us, the Techers.

–Charles House (BS ’62)
SACRAMENTO, CA

Honest, honorable, diverse, innovative, not without faults, but consistently seeking to evolve and improve.

–Will Grossman (PhD ’79)
WALPOLE, NH

Its size and its history of excellence drive significant collaboration and productivity between and among the faculty and students. Cross-pollination of new ideas and research strategies takes place everywhere at Caltech: Undergraduate and graduate students mix with faculty all the time in a small campus environment. The result is continuous improvement and creativity.

–John Cummings (BS ’69, PhD ’73)
PUEBLO, CO

creative

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A Love Letter to Caltech

To mark the anniversary of the devastating January 2025 LA wildfires, *Architectural Digest* published a tribute to the City of Angels and tapped a variety of subjects to note the places that mean the most to them. In a video filmed on campus, the actor Joseph Gordon-Levitt explains why the Institute has so much meaning for him. “Americans would not have gone to the Moon if it hadn’t been for the work done here and at the Jet Propulsion Laboratory, which was spun out of this institution here,” he says.

Watch the video:

