Fall 2019

Caltech magazine

Untangling ENTANGLEMENT

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Toward an HIV vaccine

Why science history matters

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Left: This sampling of lightbulbs is from a collection of more than 400 at The Huntington Library, Art Museum, and Botanical Gardens that traces the bulb's evolution from the 1890s to the 1960s.

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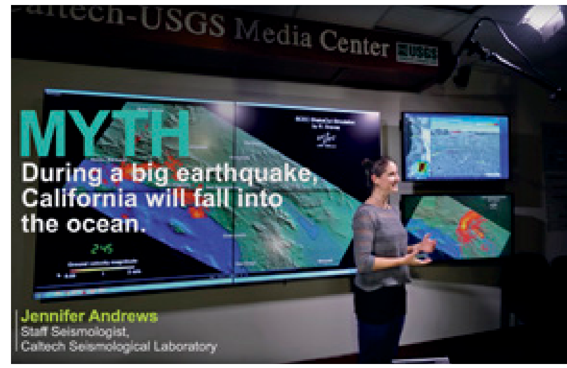
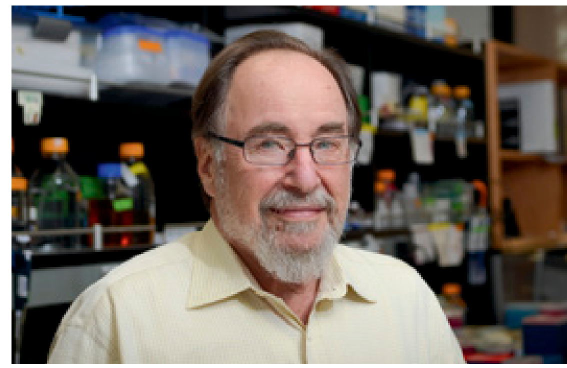
France Córdova's path to science [video]

Earthquake myths debunked [video]



David Baltimore on HIV vaccine progress [podcast]



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Signaling the start of fall, this Caltech turtle sports a distinctly leafy look.

Letters

Credit Crisis

In "Four questions for Jean-Laurent Rosenthal and Philip T. Hoffman" (Summer 2019), Jean-Laurent Rosenthal said, "Building banks when the information system is deficient will lead to little lending or, worse yet, financial crises."

The same is true if government policies force financial institutions to ignore information they have used for decades.

The 2006 credit collapse began in 1994, with the *Buycks-Roberson v. Citibank* lawsuit. Citibank lost and was required to extend a loan to the plaintiff. Attorney General Janet Reno extended the principle nationwide. The result was that banks were required to extend loans to borrowers who they knew could not repay them. The problem was covered up by three federal agencies (FHA, FNMA, FHMLC) buying the worthless loans and repackaging them as "credit default swaps," which encouraged unscrupulous lenders. The Bush administration tried six times to rein in this program but was thwarted at every turn. When the 2006 credit collapse occurred, the Bush administration was blamed.

Van Snyder
Mathematician and Software Engineer, JPL

Fictional Caltech

I recently listened to the audiobook of a novel, *Lost and Wanted* by Nell Freudenberger, whose main character is a theoretical physicist on the faculty at MIT who grew up in Pasadena but did *not* go to Caltech. However, several other characters are involved with LIGO, and Caltech is mentioned frequently. The expository bits about physics are quite good.

David Lewin

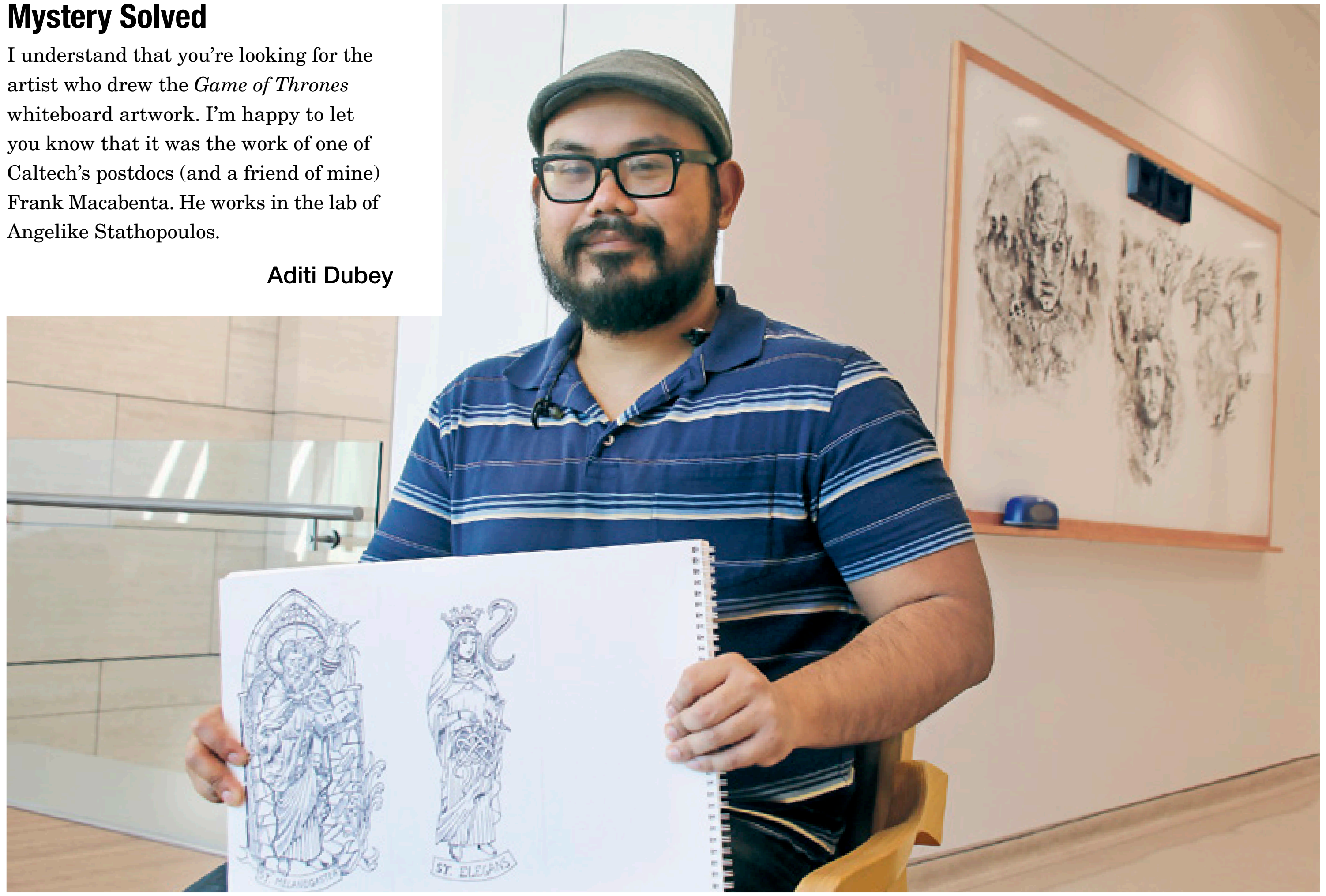
Classic HBG! That is truly a fantastic fountain, though. I spent many lunches in the tranquil BI courtyard @caltech listening to the gentle sounds of water falling. #GrayNation

Julian West
@pushingarrows

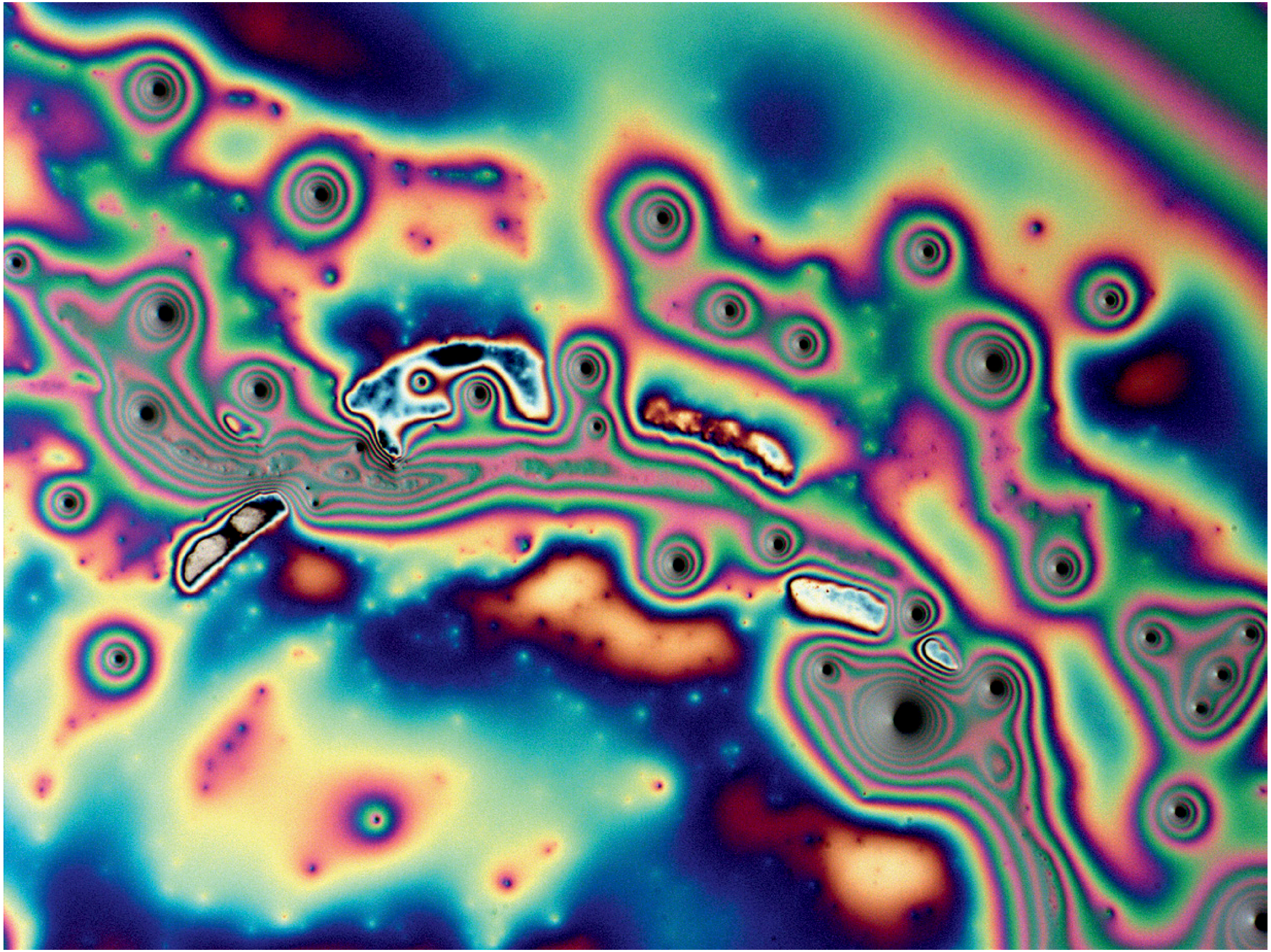
Mystery Solved

I understand that you're looking for the artist who drew the *Game of Thrones* whiteboard artwork. I'm happy to let you know that it was the work of one of Caltech's postdocs (and a friend of mine) Frank Macabenta. He works in the lab of Angelike Stathopoulos.

Aditi Dubey



Frank Macabenta, a postdoc in biological engineering, in front of his *Game of Thrones* artwork. In his sketchbook is the start of a new project inspired by drosophila, stained glass, and roundworms.



Micro-archipelago
Polymer on silicon, light microscope

SoCaltech

- Alumni Association changes
- "Before I was a scientist …"
- Teaching philosophy via sci-fi
- The chemistry of wine

The Art of Failure

"I was producing miniature optical components by sculpting very thin films. These films love to detach themselves from surfaces, so in this experiment I was investigating if an adhesive layer would help to hold them down. This process involved a heating step, and to avoid destructive surface tension effects one first had to dry the sample. I forgot to perform this step and watched in horror as my perfect sample tore itself apart on the hot plate. While taking pictures of the sample under the microscope, I was struck by the beautiful iridescent patterns and agglomerates that formed. It was reminiscent of a false-color topographic map of island groups, but these colors were real and breathtaking! I kept this image to remind myself that often failure in one domain can reveal insight or beauty in another. Experiments tend to be rather boring when they work precisely as expected. Mistakes and failure, though, are typically nothing short of spectacular: organic and fractal Rorschach blobs form when nature finds a way to defeat the well-controlled experiment."

Soon Wei Daniel Lim (BS '17), reflecting on the experience that led to the creation of this image while he was a student at Caltech. Lim is currently working towards a PhD in applied physics at Harvard University.

See more artwork created by Caltech students at **www.artofscience.caltech.edu**

Four Questions for:
Chris Bryant

A senior software engineer at the Walt Disney Studios in Burbank, Chris Bryant has been president of the Caltech Alumni Association since 2018. Recently, Bryant oversaw a significant change to the Alumni Association structure whereby all Caltech alums are now members of the CAA; previously membership dues were required. *Caltech* magazine caught up with Bryant to talk about this change and what he hopes to accomplish during the last few months of his term, which comes to an end in June 2020.

1. How did this recent change come about?

The push to make every alum automatically a member of the Alumni Association had been in the works for more than a decade. The CAA was funded by dues, so the majority of our program resources came from members. But, even though our events were open to all alumni, we knew that having dues as part of membership was creating a barrier to people participating, and it was a lot of work to solicit membership to fund our programs. When President Rosenbaum came to Caltech, he put the issue of alumni engagement front and center and, with Brian Lee (then vice president for Advancement and Alumni Relations), partnered with us to create a more permanent funding model that didn't require dues.

2. What do you see as the main benefits?

With the dues barrier removed and dramatically increased membership, we expect alumni to feel the benefit of a stronger, more engaged network. Whether it's via returning to campus, connecting at regional events, or participating in online virtual programs, we expect to see higher engagement levels and more value to alumni from those connections.

3. What do you find most rewarding about working with Caltech alums?

Caltech students and alumni are some of the most collaborative people I've interacted with through my life and career. Working with fellow alumni as CAA president has been extremely rewarding because of that culture of collaboration.

4. What are some goals you have for the Alumni Association?

As long as I've been a part of the board, there has been a consistent desire to have the caliber and strength of alumni programming and engagement be on par with the overall caliber of the Institute in all the things it does. We aim for the equivalent groundbreaking, prizewinning, societally advancing impact in alumni relations and alumni engagement that Caltech has achieved in science and engineering. It is definitely a journey and one that all of the presidents I've been fortunate to work with have each contributed their best efforts to.

Jennifer E. Padilla: A LOGICAL STEP

With a master's degree in mathematics and a PhD in biochemistry, Jennifer Padilla seemed set on the scientific path. She continued that journey as a postdoc at Caltech, studying DNA nanotechnology in the lab of Applied and Computational Mathematics and Bioengineering Professor Niles Pierce and in a second postdoc at New York University. Later, after two years as a research professor at Boise State University, Padilla realized that her passion was for art, not science. Or, rather, the intersection of art and science.

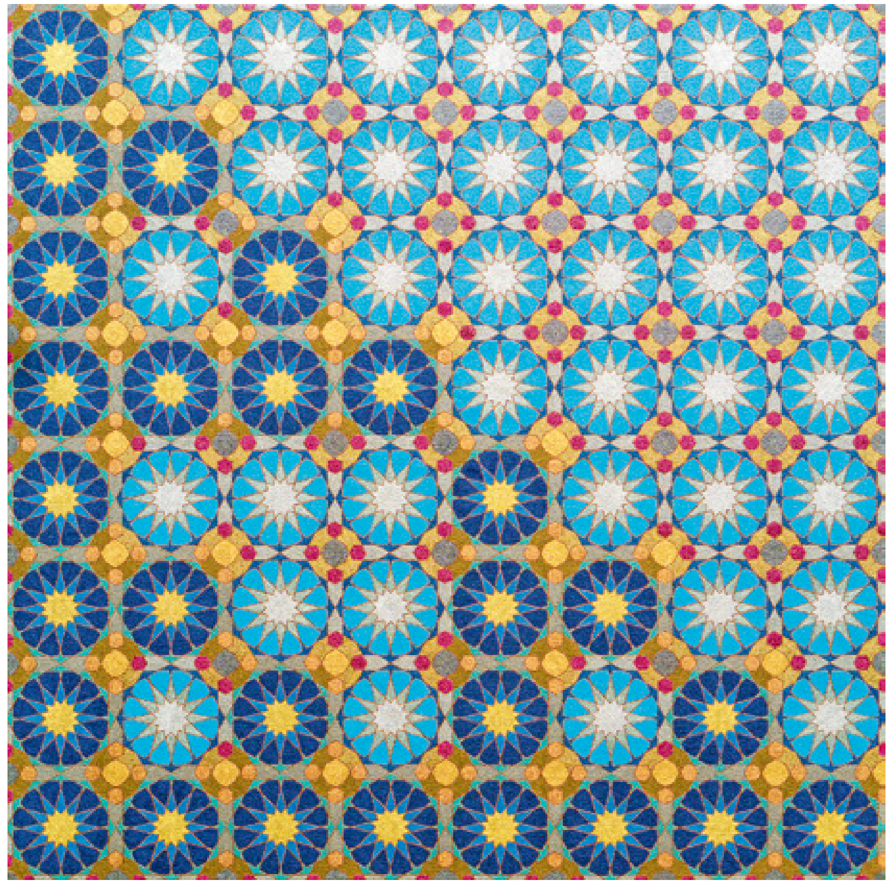
Now based in Altadena, Padilla has been working primarily as an artist for the last three years, exploring the connection between Islamic geometric art and mathematical topics such as Euclidean geometry, algorithmic assembly, and quasiperiodic order. "Much of my research focused on the self-assembly of molecules, how the assembly process could be guided by symmetry, and how it could relate to computation," says Padilla. "The precision and intricacy of the patterns found in Islamic geometric art converse easily with the logic of mathematics."

Artist Jennifer E. Padilla explains her painting, *XOR Logic* (acrylic on canvas), at right, this way:

"Pick a tile and look at the tile below and the tile to the left. Are they both light blue or both dark blue? If so, then the tile you are looking at should be light blue. If instead there is one light blue and one dark blue tile in the positions below and to the left, then the tile you are looking at should be dark blue.

"From this rule, a fractal pattern begins to emerge. It is a manifestation of the 'Exclusive OR' (XOR) logic gate, an element of the computer circuits operating in your laptop or your phone. The pattern is known as the Sierpinski triangle.

"This work explores the early moments of that progression where one can observe the logical XOR rule while just beginning to perceive the triangular Sierpinski fractal pattern."



The Dictionary Definition of Cal·tech

Caltech magazine uses *Merriam-Webster* as its go-to dictionary, its arbiter of spelling and usage. Recently, it became obvious that M-W returns at least some of that regard, given the number of times it uses Caltech references in its usage examples. Here are a few of those instances.

aero·dy·nam·i·cist *noun*

aero·dy·nam·i·cist | \ er-ō-dī-ˈna-mə-sist \

Definition:

one who specializes in aerodynamics

Recent Examples on the Web:

The Rocket Boys' audacity caught the attention of aerodynamicist Theodore von Kármán, who already worked with two of them at Caltech. — Corey S. Powell, *Discover* magazine, "These New Technologies Could Make Interstellar Travel Real," 13 March 2019

drawstring *noun*

ˈdraw·string | \ ˈdrȯ-ˌstriŋ \

Definition:

a string, cord, or tape inserted into hems or casings or laced through eyelets for use in closing a bag or controlling fullness in garments or curtains

Recent Examples on the Web:

In 2012, a Caltech paper detailed a procedure for harnessing an asteroid—proposing a plan for lassoing a valuable asteroid by catching it in a giant drawstring bag. — Rachel Riederer, *The New Yorker,* "A New Space Race, for Lawyers," 18 June 2019

minor planet *noun*

Definition:

asteroid

Recent Examples on the Web:

Caltech's Konstantin Batygin, for one, does not think the Kuiper Belt objects have enough mass to pull minor planets and asteroid out of their orbit. — Jason Daley, *Smithsonian,* "Is the Mysterious Planet Nine Just a Swarm of Asteroids?" 6 June 2018

“Before I Was a Scientist”

There is no single path to becoming a scientist … just ask Caltech’s faculty. Here are some of the varied experiences they had on the road to their current careers.

Jean Paul (Pablo) Ampuero Saenz

Professor of Seismology

- T-shirt graphic artist
- Bass player in punk/metal bands
- Translator at a trade fair
- Jeep chauffeur in Cuba
- Indian food delivery guy

Frances Arnold

Nobel Laureate; Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry; Director, Donna and Benjamin M. Rosen Bioengineering Center

- Jazz club cocktail waitress
- Taxi driver
- Worker in a factory building nuclear reactor parts

Rob Phillips

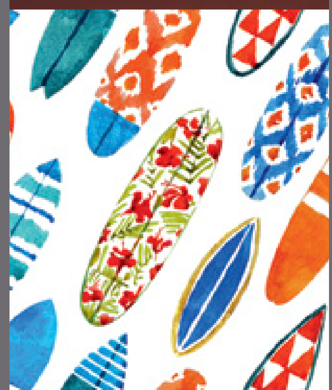
Fred and Nancy Morris Professor of Biophysics, Biology, and Physics

- [Left high school at 17]
- Computer store clerk
- Electrician
- Surfboard shaper

Dean Mobbs

Assistant Professor of Cognitive Neuroscience

- [Left high school at 15]
- Part-time garbage man
- House painter
- Amateur boxer



Turn to page 40 to read about the circuitous paths of other alumni.

“Some people are surprised when they learn I got my undergraduate degree in English. Your focus can change as your horizons broaden, but it is focus that lets you know when that change is important, it’s focus that lets you dream new concepts that will surprise you, focus that ultimately sets your imagination free.”

France Córdova *(PhD ’79), NSF Director, at Caltech Commencement 2019*

Did you find your focus by following a winding path?
Tell us about it!
Tweet using
#BeforeIWasAScientist

Class Act

Philosophy Through Science Fiction

Watching science fiction movies and shows such as *The Matrix, Doctor Who,* and *Black Mirror* may not seem like homework, but such was the case in a new class taught last spring by Caltech assistant professor of philosophy Charles (Chip) Sebens. The goal of Philosophy Through Science Fiction is to introduce students to important philosophical questions using themes such as teleportation, parallel universes, and time travel.

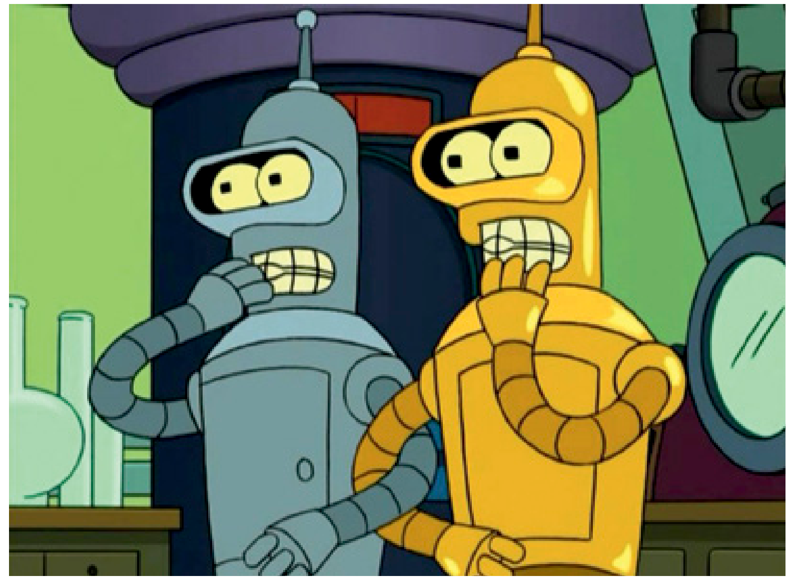
“When students start learning philosophy, they often feel like the scenarios that philosophers discuss are outlandish and not worth taking seriously,” says Sebens. “Framing the course as an analysis of science fiction allows students to put these concerns aside and ultimately realize that philosophy is relevant to their lives and to other fields of academic inquiry.”

Multiple Universes, Multiple Robots

In an episode of the TV series *Futurama,* called “The Farnsworth Parabox,” a character named Professor Farnsworth discovers a way to travel between parallel universes. He soon learns that there are alternate versions of the main characters in each universe, including the robot named Bender (see image below), whose color, gray in one universe and gold in another, had been determined by the flip of a coin. The idea of people or robots living in multiple universes may indeed seem outlandish, but this is a real theme that comes up in quantum physics.

“In the many-worlds interpretation of quantum physics, measurements of a quantum particle can split one universe into many, just as coin tosses split Bender’s universe in the *Futurama* episode,” says Sebens.

In addition to quantum physics, the class also talked about the concept of identity. “Is the Bender that existed before the coin toss the same robot as either the gray or the gold Bender after the coin toss?” asks Sebens.



Beauty is in the Eye of Science

In another section of the class, the students studied a short story by Ted Chiang called “Liking What You See: A Documentary” about a time in the future when scientists have figured out how to render people insensitive to physical beauty. This technology is used to fight “lookism,” a phenomenon where people are discriminated against based on their looks. In the class, the students debated the strengths and weaknesses of the futuristic technology.

“Discussing this piece of science fiction helped them to better understand various kinds of discrimination and the ways we might address them,” Sebens says. “I hope my students will read and watch science fiction differently after taking this class, noticing when philosophical questions come up and being ready to tackle them.”

Sebens will teach the class again in spring 2020.

“The media attention relaxes after a few hours or days, but I’m going to be looking at the data we gathered from these quakes for a long time. It could take months or even years for our group to process all the data. These quakes in particular were interesting, as two perpendicular faults were involved. We can study the rupture dynamics, which you can’t resolve in smaller quakes. Also, having two strong quakes caused variations in fault slip and ground motion that will be important to study and understand.”

– *Caltech staff seismologist* **Jen Andrews** *on her work as part of the Seismo Lab team to analyze the two large Ridgecrest earthquakes on July 4 and 5, 2019*

Siobhán MacArdle (fifth-year graduate student)

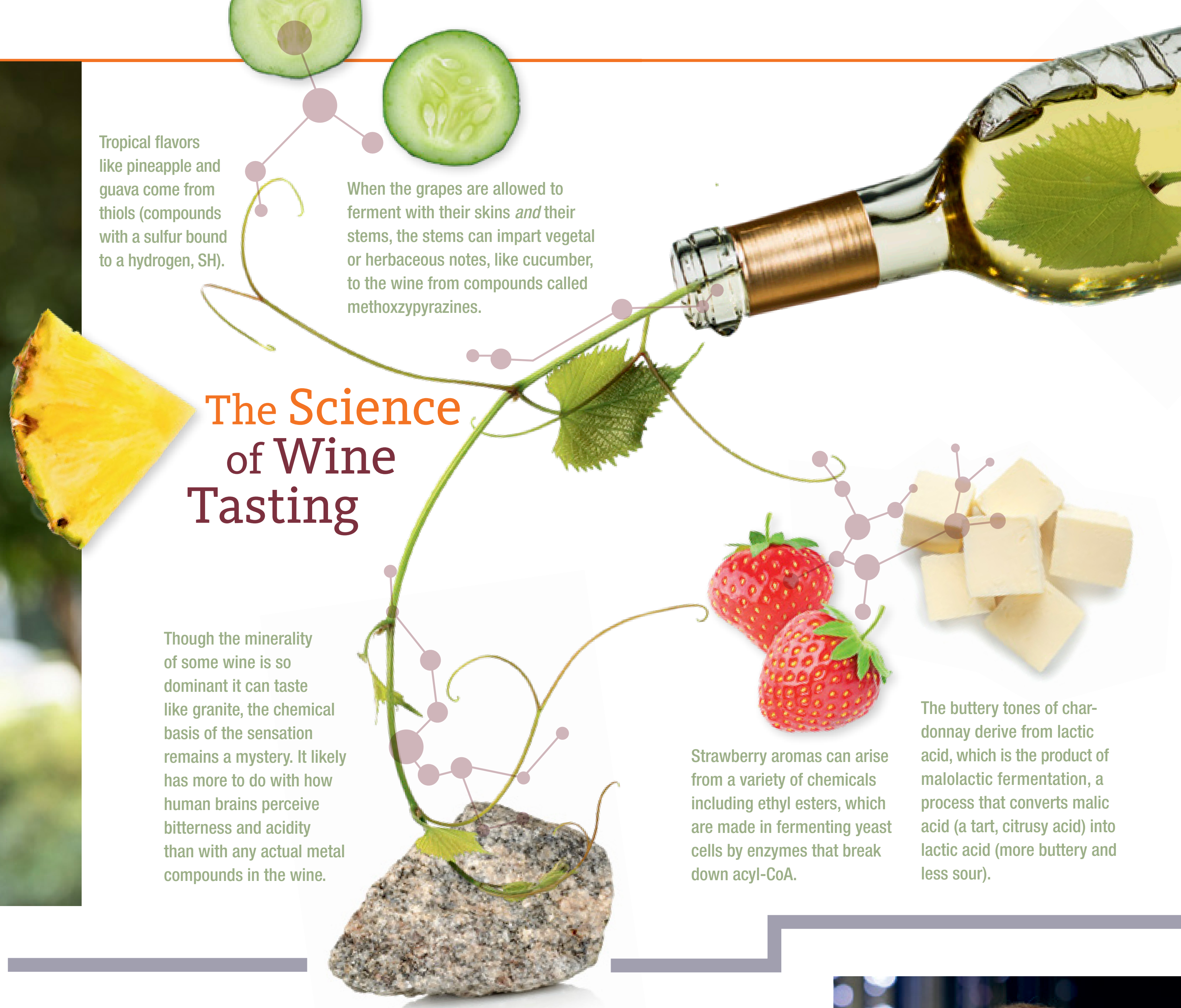
***#SoCaltech** is an occasional series celebrating the diverse individuals who give Caltech its spirit of excellence, ambition, and ingenuity. Know someone we should profile? Send nominations to magazine@caltech.edu.*

Siobhán MacArdle is a Caltech chemistry graduate student working in the lab of Jackie Barton, the John G. Kirkwood and Arthur A. Noyes Professor of Chemistry.

"I've been interested in the chemistry of wine and alcohol for a long time. As an undergrad, I started getting obsessed with fermentation and distillation. I worked at a distillery in Brooklyn, and I was just blown away by how it's all chemistry and biology. More recently, I had been reading academic papers on the science of wine and whiskey, and I felt like I needed an outlet for it, so I created an Instagram account called @PeriodicallyDrinkingChemicals.

It's been so fun for me, and it's reigniting my love of chemistry. When I'm in the lab, I'm making a lot of electrochemistry measurements, looking for peaks in cyclic voltammograms. When you're smelling a wine, you're also detecting some sort of chemical reaction or chemical change but with your nose or your mouth."

For more #SoCaltech, and to hear more from MacArdle go to tinyurl.com/MagSoCaltech



"I look at the rovers on Mars. When we landed Spirit and Opportunity, they were supposed to work only for 90 days, because we were concerned that the dust on Mars would cover the solar panels and we wouldn't get enough power. Well, they worked for almost 14 years, continuously. I wonder how many people have a car—that they cannot bring back to the garage to fix it and repair it—that can work for 14 years."

– **Charles Elachi**, former director of the Jet Propulsion Laboratory, on KTLA's "Frank Buckley Interviews" podcast, July 10, 2019

Summer visitors

Every summer, labs across campus and at JPL (as well as farther afield) host undergraduates eager to hone their research skills. One such avenue for growth is the 10-week program known as SURF (Summer Undergraduate Research Fellowships).

While most SURFers are Caltech students, almost a quarter of the participants visit campus for the summer from other colleges across the U.S.

Mahlet Shiferaw

Harvard University

LIGO

Mentor: Physics Professor Alan Weinstein

Research focus: Shiferaw studied the harmonics of gravitational waves: ripples in space-time produced by cosmic events such as the collisions of black holes. These waves have been detected regularly by LIGO (the Laser-Interferometer Gravitational-wave Observatory) since 2015. Shiferaw wants to know more about higher-order modes of gravitational waves, which are similar to musical overtones. In the same way that the overtones of a piano can sound different from those of a plucked violin string, these higher-order gravitational-wave modes can reveal unique information about their sources: black holes and other objects in space.

While LIGO cannot detect these higher-order modes at its current sensitivity, it should be able to do so in the coming years after planned upgrades to its instruments.

Highlight: "The campus is so beautiful," says Shiferaw. "Sometimes it feels like walking around in a huge botanical garden."

Takeaway: "My research will pave the way for future tests of the general theory of relativity under extreme conditions: near black holes, where gravity is strong and the speeds of particles are close to that of light," she says. "It's mind-blowingly cool."

Amy Windham

Pasadena City College

Division of Humanities & Social Sciences

Mentor: History Professor Jennifer Jahner

Research focus: Windham explored *The Book of Margery Kempe,* which is considered the first autobiography in the English language. The fascinating part, says Windham, is that it was written by a woman who lacked formal training in reading or writing. Kempe, a mystic and pilgrim who lived at the turn of the 15th century, dictated her story to two scribes. Windham is intrigued by what the work reveals about both female literacy and how books developed in medieval times.

Highlight: Jahner and Windham visited the Special Collections at the UCLA Library to look at manuscripts from the period that Windham has been exploring. "Nothing replaces the experience of actually being in the presence of a 700- or 800-year-old book," says Jahner.

Takeaway: "I've become so fascinated with medieval studies," says Windham. "This has definitely helped me shape the direction that I want to move and opened my eyes to a whole other world of how books came to be and even how the English language evolved."

SURF STATS 2019

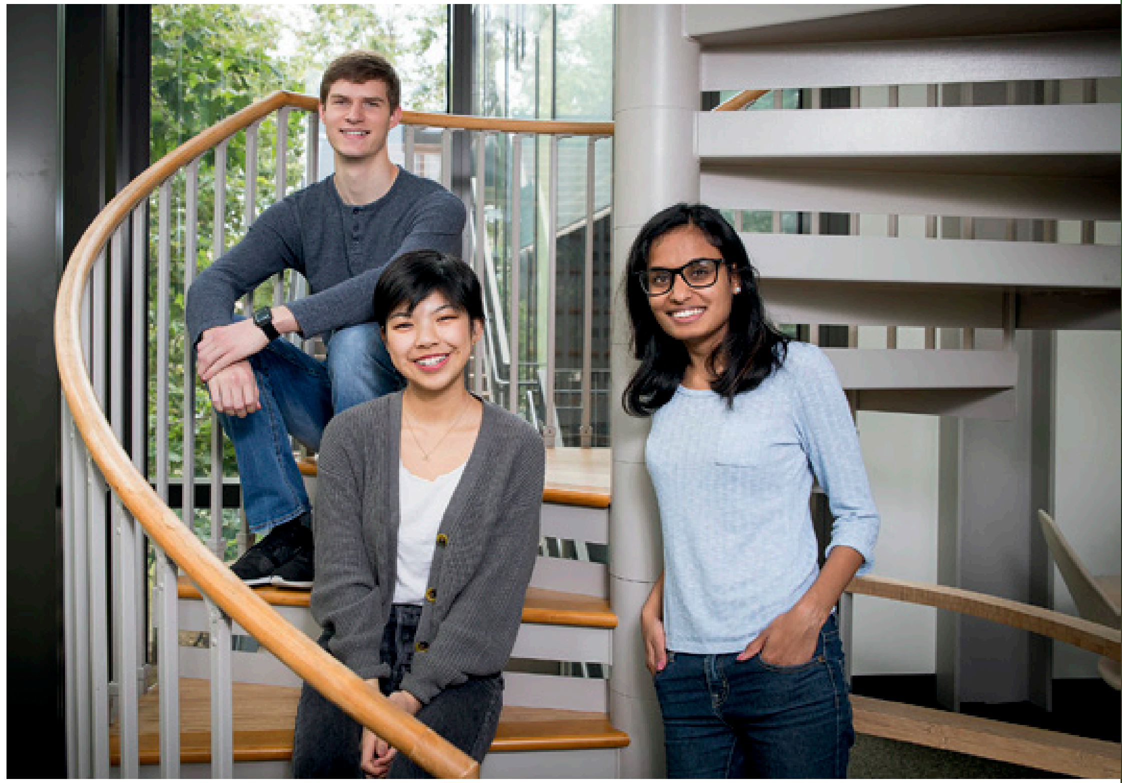
414 students • 313 Caltech students; 101 visiting students • 292 doing research at Caltech; 65 at JPL; 57 off-campus • SURF stipend: $6,350 per student; total stipend payroll of $2.655M • 414 students = 828 written interim reports, 414 abstracts and final papers, 71 final poster presentations, 343 final oral presentations • 241 faculty mentors and 278 graduate student, postdoc, or research staff co-mentors

In the Community

Connecting the Homeless

Among people who are homeless, lack of connection to family and friends poses an often-overlooked obstacle to stability and well-being.

"Homeless people haven't just lost a roof over their heads, they've often lost their ties to loved ones," says Nivetha Karthikeyan (BS '19), who graduated from Caltech last June with a degree in computer science and history. Over the course of the past academic year, Karthikeyan worked with junior Myra Cheng and senior Andrew Hess to help address the problem by developing new technological tools for Miracle Messages, a nonprofit that helps reunite homeless people with friends and relatives.



From left: Senior Andrew Hess, junior Myra Cheng, and Nivetha Karthikeyan (BS '19), who together launched TechReach, a new club that uses computer science to serve community needs.

Founded in San Francisco, Miracle Messages helps homeless individuals record video or audio messages to loved ones they have lost all contact with. Then, using as much information as the individual is able to provide, volunteers scour social media and other digital platforms to find those loved ones and deliver the message. Over the past five years, Miracle Messages has facilitated reunions for more than 200 clients who had been disconnected from their families for around 20 years, on average.

Now, the organization's efforts will be enhanced by a database and web application developed by Karthikeyan, Cheng, and Hess, all students in Caltech's Division of Engineering and Applied Science.

The project grew out of an interest in the intersection of technology and activism, and the potential for computer science to serve as a vehicle for advancing social good. "It's something I really want to explore: how tech interacts with society and how we can use what we learn in the classroom to solve real societal problems," Karthikeyan says.

About a year ago, she and Cheng sent out an email to survey student interest in TechReach, a new club that would focus on using computer science to serve nonprofit and community needs. They received more than 60 interested responses.

On the advice of Claire Ralph, lecturer and director of outreach and partnerships for Caltech's computing and mathematical sciences department, Karthikeyan and Cheng elected to launch TechReach with a pilot project.

For Cheng, the club represents an opportunity to build on similar work she had done with the volunteer organization Code for San Jose. "There are issues I care about independently of computer science," she says. "It's exciting to use tech skills, to write code, in a way that is impacting people."

Hess, too, was drawn to the possibility of applying computer science to a concrete social problem: "I wanted to get real-world experience and to actually help people in a significant way."

As their work with Miracle Messages winds down, the students hope to expand TechReach to five or six new projects involving larger numbers of computer science volunteers and a broader range of issues. They'd also like to develop connections with nonprofits serving local communities.

"Understanding the needs of the client is just as important as the technology," Karthikeyan says. "We want to know more about the issues facing Pasadena to really figure out how our skills might help."

—Jennifer Torres-Siders

Origins

A Decade of Discovery and a Now-Limitless Future

In 2009, the Resnick Sustainability Institute (RSI) was established at Caltech with a $30 million contribution from Stewart and Lynda Resnick and the Gordon and Betty Moore Foundation, and a vision to foster transformational advances in energy science and technology through research, education, and communication. An additional pledge by the Resnicks in 2014 created both the Resnick Institute Innovation Fund and the Lynda and Stewart Resnick Matching Program.

That vision has been realized through advances in the area of energy science and sustainable technology development, as well as in the recent announcement of an unprecedented $750 million pledge to Caltech from the Resnicks to support, in perpetuity, cutting-edge research into environmental sustainability.

"Science and bold creativity must unite to address the most pressing challenges facing energy, water, and sustainability," says Stewart Resnick, chairman and president of The Wonderful Company and a senior member of the Caltech Board of Trustees.

Since its founding, the RSI has supported researchers who develop ways to convert sunlight to renewable hydrogen and carbon-based fuels, and new technologies for generating ammonia and other commodity chemicals. RSI support has led to the discovery of best-in-class catalysts using abundant, non-toxic materials, and enabled researchers to push the efficiency limits of solar photovoltaics and wind systems, advanced research into green chemistry, and helped to modernize the electricity grid.

RSI-supported research has also provided unprecedented insights into carbon-dioxide sequestration in the ocean, opening up a number of possible applications for removing carbon from the atmosphere, and created new techniques for treating wastewater and desalinating saltwater through solar-driven heating, electrochemistry, and the use of nano-structured materials.

During its first decade, the RSI provided seed funds to researchers throughout Caltech's divisions and funded 96 Resnick fellows (graduate students and postdoctoral scholars). Resnick fellows or fellow alums have founded a number of sustainability-focused companies or had projects licensed by existing startups.

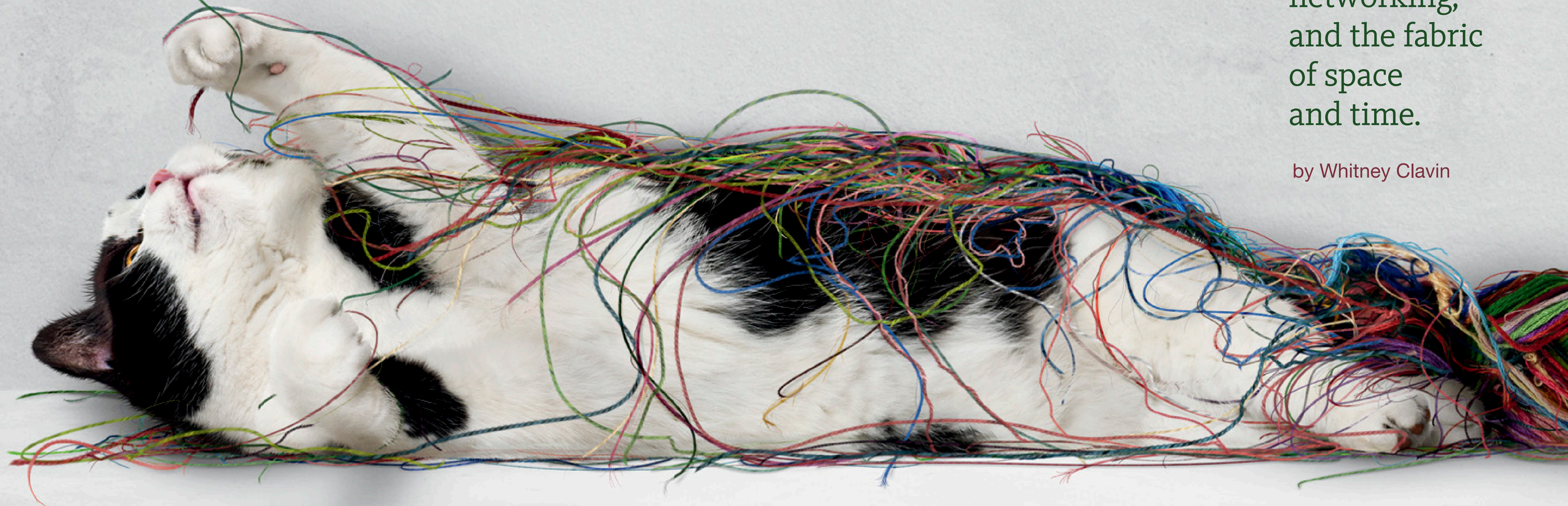
"The RSI has shown remarkable progress," says RSI director Jonas C. Peters, Bren Professor of Chemistry. "This commitment from Lynda and Stewart places hope in science and technology, and also in Caltech, to help chart a more sustainable future for all of us."

For more on the RSI and its work, visit http://resnick.caltech.edu/.

Untangling ENTANGLEMENT

The perplexing phenomenon of quantum entanglement is central to quantum computing, quantum networking, and the fabric of space and time.

by Whitney Clavin



The famous "Jim twins," separated soon after birth in the 1940s, seemed to live parallel lives even though they grew up miles apart in completely different families. When they were reunited at the age of 39, they discovered many similarities between their life stories, including the names of their sons, wives, and childhood pets, as well as their preferences for Chevrolet cars, carpentry, and more.

A similar kind of parallelism happens at a quantum level, too. The electrons, photons, and other particles that make up our universe can become inextricably linked, such that the state observed in one particle will be identical for the other. That connection, known as entanglement, remains strong even across vast distances.

In Erwin Schrödinger's famous thought experiment, a cat is trapped in a box with a bit of poison, the release of which is controlled by a quantum process. The cat therefore exists in a quantum state of being both dead and alive until somebody opens the box and finds the cat either dead *or* alive.

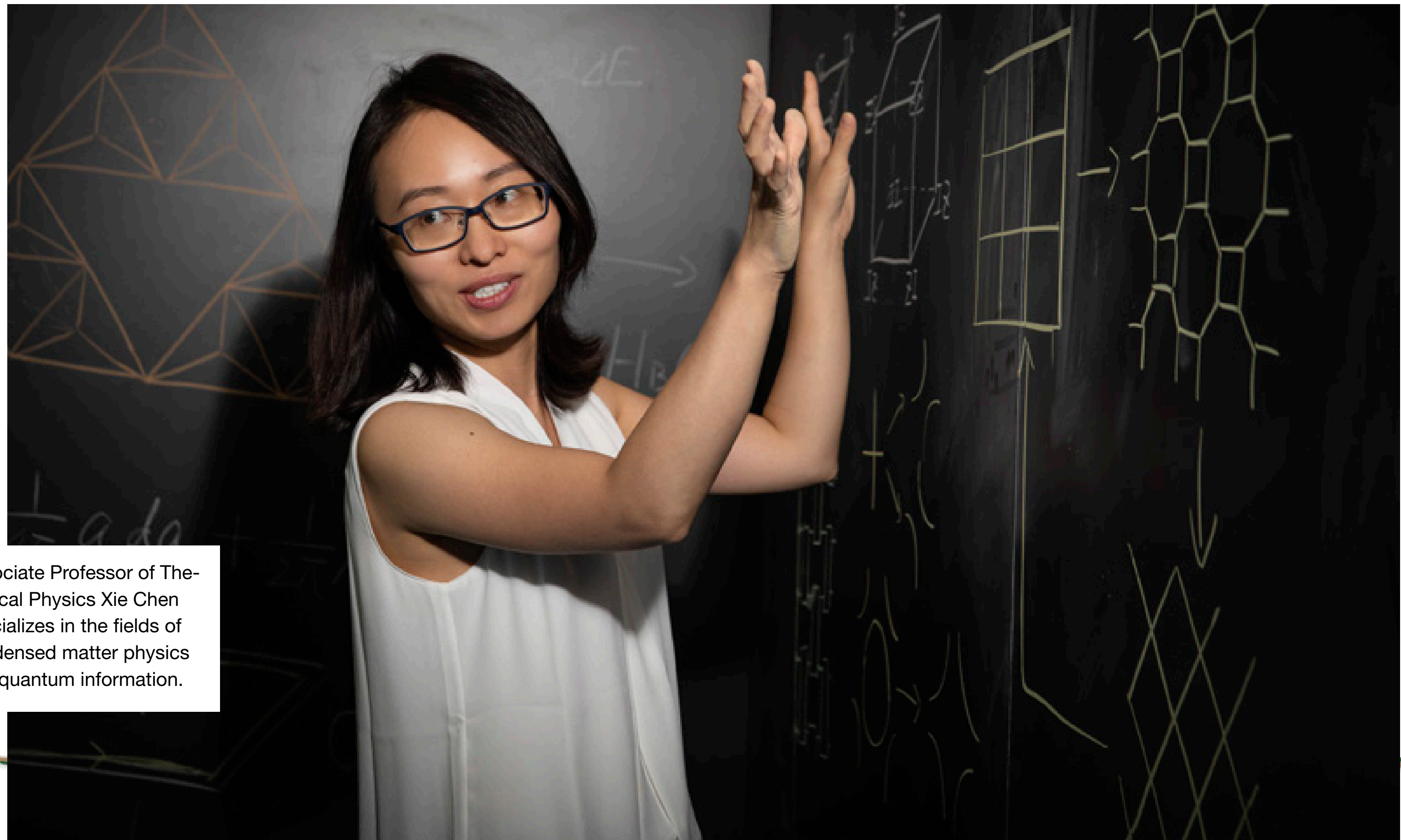
"When particles are entangled, it's as if they are born that way, like twins," says Xie Chen, associate professor of theoretical physics at Caltech. "Even though they might be separated right after birth, [they'll] still look the same. And they grow up having a lot of personality traits that are similar to each other."

The phenomenon of entanglement was first proposed by Albert Einstein and colleagues in the 1930s. At that time, many questioned the validity of entanglement, including Einstein himself. Over the years and in various experiments, however, researchers have generated entangled particles that have supported the theory. In these experiments, researchers first entangle two particles and then send them to different locations miles apart. The researchers then measure the state of one particle: for instance, the polarization (or direction of vibration) of a photon. If that entangled photon displays a horizontal polarization, then so too will its faithful partner.

"It may be tempting to think that the particles are somehow communicating with each other across these great distances, but that is not the case," says Thomas Vidick, a professor of computing and mathematical sciences at Caltech. "There can be correlation without communication." Instead, he explains, entangled particles are so closely connected that there is no need for communication; they "can be thought of as one object."

As baffling as the concept of two entangled particles may be, the situation becomes even more complex when more particles are involved. In natural settings such as the human body, for example, not two but hundreds of molecules or even more become entangled, as they also do in various metals and magnets, making up an interwoven community. In these many-body entangled systems, the whole is greater than the sum of its parts.

"The particles act together like a single object whose identity lies not with the individual components but in a higher plane. It becomes something larger than itself," says Spyridon (Spiros) Michalakis, outreach manager of Caltech's Institute for Quantum Information and Matter (IQIM) and a staff researcher. "Entanglement is like a thread that goes through every single one of the individual particles, telling them how to be connected to one another."



Associate Professor of Theoretical Physics Xie Chen specializes in the fields of condensed matter physics and quantum information.

At Caltech, researchers are focusing their studies on many-body entangled systems, which they believe are critical to the development of future technologies and perhaps to cracking fundamental physics mysteries. Scientists around the world have made significant progress applying the principles of many-body entanglement to fields such as quantum computing, quantum cryptography, and quantum networks (collectively known as quantum information); condensed-matter physics; chemistry; and fundamental physics. Although the most practical applications, such as quantum computers, may still be decades off, according to John Preskill, the Richard P. Feynman Professor of Theoretical Physics at Caltech and the Allen V.C. Davis and Lenabelle Davis Leadership Chair of the Institute of Quantum Science and Technology (IQST), "entanglement is a very important part of Caltech's future."

Entanglement Passes Tests with Flying Colors

In 1935, Albert Einstein, Boris Podolsky, and Nathan Rosen published a paper on the theoretical concept of quantum entanglement, which Einstein called "spooky action at a distance." The physicists described the idea, then argued that it posed a problem for quantum mechanics, rendering the theory incomplete. Einstein did not believe two particles could remain connected to each other over great distances; doing so, he said, would require them to communicate faster than the speed of light, something he had previously shown to be impossible.

Today, experimental work leaves no doubt that entanglement is real. Physicists have demonstrated its peculiar effects across hundreds of kilometers; in fact, in 2017, a Chinese satellite named Micius sent entangled photons to three different ground stations, each separated by more than 1,200 kilometers, and broke the distance record for entangled particles.

Entanglement goes hand in hand with another quantum phenomenon known as superposition, in which particles exist in two different states simultaneously. Photons, for example, can display simultaneously both horizontal and vertical states of polarization.

Or, to simplify, consider two "entangled" quarters, each hidden under a cup. If two people, Bob and Alice, were each to take one of those quarters to a different room, the quarters would remain both heads and tails until one person lifted the cup and observed his or her quarter; at that point, it would randomly become either heads or tails. If Alice were to lift her cup first and her quarter was tails, then when Bob observed his quarter, it would also be tails. If you repeated the experiment and the coins were covered once more, they would go back to being in a state of superposition. Alice would lift her cup again and might find her quarter as heads this time. Bob would then also find his quarter as heads. Whether the first quarter is found to be heads or tails is entirely random.

Similarly, when a researcher entangles two photons and then sends each one in different directions under carefully controlled conditions, they will continue to be in a state of superposition, both horizontally and vertically polarized. Only when one of the photons is measured do both randomly adopt just one of the two possible polarization states.

"Quantum correlations are deeply different than ordinary correlations," says Preskill. "And randomness is the key. This spooky intrinsic randomness is actually what bothered Einstein. But it is essential to how the quantum world works."

"Scientists often use the word correlation to explain what is happening between these particles," adds Oskar Painter, the John G Braun Professor of Applied Physics and Physics at Caltech. "But, actually, entanglement is the perfect word."

Entanglement to the Nth Degree

Untangling the relationship between two entangled particles may be difficult, but the real challenge is to understand how hundreds of particles, if not more, can be similarly interconnected.

According to Manuel Endres, an assistant professor of physics at Caltech, one of the first steps toward understanding many-body entanglement is to create and control it in the lab. To do this, Endres and his team use a brute force approach: they design and build laboratory experiments with the goal of creating a system of 100 entangled atoms.

"This is fundamentally extremely difficult to do," says Endres. In fact, he notes, it would be difficult even at a much smaller scale. "If I create a system where I generate, for instance, 20 entangled particles, and I send 10 one way and 10 another way, then I have to measure whether each one of those first 10 particles is entangled with each of the other set of 10. There are many different ways of looking at the correlations."

While the task of describing those correlations is difficult, describing a system of 100 entangled atoms with classical computer bits would be unimaginably hard. For instance, a complete classical description of all the quantum correlations among as many as 300 entangled particles would require more bits than the number of atoms in the visible universe. "But that's the whole point and the reason we are doing this," Endres says. "Things get so entangled that you need a huge amount of space to describe the information. It's a complicated beast, but it's useful."

John Preskill wrote a song about entanglement and performed it with singer Gia Mora at One Entangled Evening, a 2016 IQIM event. Watch the video at: **iqim.caltech.edu/tag/john-preskill.**

"Generally, the number of parameters you need to describe the system is going to scale up exponentially," says Vidick, who is working on mathematical and computational tools to describe entanglement. "It blows up very quickly, which, in general, is why it's hard to make predictions or simulations, because you can't even represent these systems in your laptop's memory."

To solve that problem, Vidick and his group are working on coming up with computational representations of entangled materials that are simpler and more succinct than models that currently exist.

"Quantum mechanics and the ideas behind quantum computing are forcing us to think outside the box," he says.

A Fragile Ecosystem

Another factor in creating and controlling quantum systems has to do with their delicate nature. Like *Mimosa pudica,* a member of the pea family also known as the "sensitive plant," which droops when its leaves are touched, entangled states can easily disappear, or collapse, when the environment changes even slightly. For example, the act of observing a quantum state destroys it. "You don't want to even look at your experiment, or breathe on it," jokes Painter. Adds Preskill, "Don't turn on the light, and don't even dare walk into the room."

The problem is that entangled particles become entangled with the environment around them quickly, in a matter of microseconds or faster. This then destroys the original entangled state a researcher might attempt to study or use. Even one stray photon flying through an experiment can render the whole thing useless.

"You need to be able to create a system that is entangled only with itself, not with your apparatus," says Endres. "We want the particles to talk to one another in a controlled fashion. But we don't want them to talk to anything in the outside world."

In the 1980s, the late Richard Feynman was one of the first scientists to foresee the advantages of quantum computers over classical computers.

In the field of quantum computing, this fragility is problematic because it can lead to computational errors. Quantum computers hold the promise of solving problems that classical computers cannot, including those in cryptography, chemistry, financial modeling, and more. Where classical computers use binary bits (either a "1" or a "0") to carry information, quantum computers use "qubits," which exist in states of "1" and "0" at the same time. As Preskill explains, the qubits in this mixed state, or superposition, would be both dead and alive, a reference to the famous thought experiment proposed by Erwin Schrödinger in 1935, in which a cat in a box is both dead and alive until the box is opened, and the cat is observed to be one or the other. What's more, those qubits are all entangled. If the qubits somehow become disentangled from one another, the quantum computer would be unable to execute its computations.

To address these issues, Preskill and Alexei Kitaev (Caltech's Ronald and Maxine Linde Professor of Theoretical Physics and Mathematics and recipient of a 2012 Breakthrough Prize in Fundamental Physics), along with other theorists at Caltech, have devised a concept to hide the quantum information within a global entangled state, such that none of the individual bits have the answer. This approach is akin to distributing a code among hundreds of people living in different cities. No one person would have the whole code, so the code would be much less vulnerable to discovery.

"The key to correcting errors in entangled systems is, in fact, entanglement," says Preskill. "If you want to protect information from damage due to the extreme instability of superpositions, you have to hide the information in a form that's very hard to get at," he says. "And the way you do that is by encoding it in a highly entangled state."

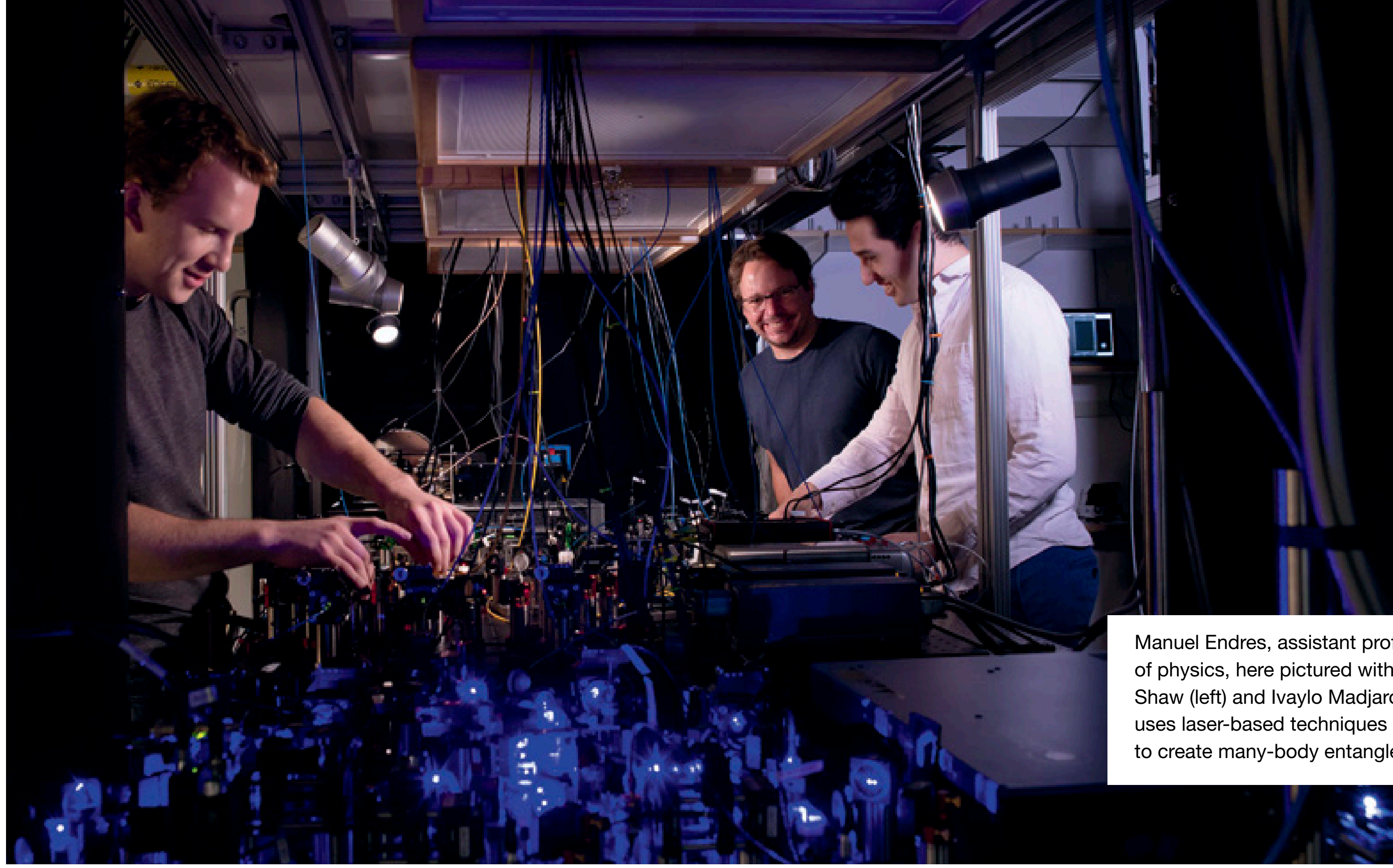
Spreading the Entanglement

At Caltech, this work on the development of quantum -computing systems is conducted alongside research into quantum networks in which each quantum computer acts as a separate node, or connection point, for the whole system. Painter refers to this as "breaking a quantum computer into little chunks" and then connecting them together to create a distributed network. In this approach, the chunks would behave as if they were not separated. "The network would be an example of many-body entanglement, in which the bodies are the different nodes in the network," says Painter.

Quantum networks would enhance the power of quantum computers, notes Preskill.

"We'd like to build bigger and bigger quantum computers to solve harder and harder problems. And it's hard to build one piece of hardware that can handle a million qubits," he says. "It's easier to make modular components with 100 qubits each or something like that. But then, if you want to solve harder problems, you've got to get these different little quantum computers to communicate with one another. And that would be done through a quantum network."

Quantum networks could also be used for cryptography purposes, to make it safer to send sensitive information; they would also be a means by which to distribute and share quantum information in the same way that the World Wide Web works for conventional computers. Another future use might be in astronomy. Today's telescopes are limited. They cannot yet see any detail on, for instance, the surface of distant exoplanets, where astronomers might want to look for signs of life or civilization. If scientists could combine telescopes into a quantum network, it "would allow us to use the whole Earth as one big telescope with a much-improved resolution," says Preskill.



Manuel Endres, assistant professor of physics, here pictured with Adam Shaw (left) and Ivaylo Madjarov (right), uses laser-based techniques in his lab to create many-body entanglement.

"Up until about 20 years ago, the best way to explore entanglement was to look at what nature gave us and try to study the exotic states that emerged," notes Painter. "Now our goal is to try to synthesize these systems and go beyond what nature has given us."

At the Root of Everything

While entanglement is the key to advances in quantum-information sciences, it is also a concept of interest to theoretical physicists, some of whom believe that space and time itself are the result of an underlying network of quantum connections.

"It is quite incredible that any two points in space-time, no matter how far apart, are actually entangled. Points in space-time that we consider closer to each other are just more entangled than those further apart," says Michalakis.

The link between entanglement and space-time may even help solve one of the biggest challenges in physics: establishing a unifying theory to connect the macroscopic laws of general relativity (which describe gravity) with the microscopic laws of quantum physics (which describe how subatomic particles behave).

The quantum error-correcting schemes that Preskill and others study may play a role in this quest. With quantum computers, error correction ensures that the computers are sufficiently robust and stable. Something similar may occur with space-time. "The robustness of space may come from a geometry where you can perturb the system, but it isn't affected much by the noise, which is the same thing that happens in stable quantum-computing schemes," says Preskill.

"Essentially, entanglement holds space together. It's the glue that makes the different pieces of space hook up with one another," he adds.

At Caltech, the concept of entanglement connects various labs and buildings across campus. Theorists and experimentalists in computer science, quantum-information science, condensed-matter physics, and other fields regularly work across disciplines and weave together their ideas.

"We bring our ideas from condensed-matter physics to quantum-information folks, and we say, 'Hey, I have a material you can use for quantum computation,'" says Chen. "Sometimes we borrow ideas from them. Many of us from different fields have realized that we have to deal with entanglement head-on."

Preskill echoes this sentiment and is convinced entanglement is an essential part of Caltech's future: "We are making investments and betting on entanglement as being one of the most important themes of 21st-century science." [C]

ONE STEP CLOSER to Eradicating HIV

by Lori Dajose

Caltech researchers have developed the first component of a possible HIV vaccine,

a step that may mean the AIDS-causing virus could eventually be eradicated worldwide.

When exposed to an invading virus, the human immune system develops proteins called antibodies that become specialized to recognize and prevent infection by that particular virus. Generally, vaccines require a person to be injected with a piece of a virus, an amount insufficient to cause illness but enough to induce the body to create antibodies to the virus. Should a person later be exposed to that same virus again, the antibodies would recognize and fight it.

HIV, though, is particularly difficult to combat. HIV-1, the most common type of HIV, has thousands of variants that have been characterized, and each can mutate rapidly to evade antibodies. Because HIV mutates throughout the course of an infection, the viruses inside an infected person create a viral swarm of different HIV strains. When faced with a viral swarm, antibodies may successfully combat one or even several strains but ultimately fail to clear an infection. Although there are medications to manage the symptoms of HIV infection, an HIV vaccine would prevent infection in the first place.

The goal of any HIV vaccine or treatment is to prevent new infections by blocking the entry of the virus into the target cells. To do this, the human body makes antibodies that target the HIV envelope protein, the sole viral protein on the surface of HIV. Different strains of HIV all have similar envelope structures, and human antibodies are specialized to attack specific regions of the envelope. Antibodies that are effective against many different strains of HIV are called broadly neutralizing antibodies, or bNAbs, for their ability to quell a broad spectrum of HIV viruses.

In a study in collaboration with the Rockefeller University, Caltech scientists in the laboratory of Pamela Björkman, the David Baltimore Professor of Biology and Bioengineering, have developed the first component of a possible HIV vaccine.

Because antibody creation is a complex multistep process executed by the immune system, many vaccines must be administered in several doses known as boosts. The first step in an HIV vaccine must induce the immune system to create bNAb precursors, crucial younger versions of antibodies that will eventually mature into powerful bNAbs. An imprecise precursor will lead to an ineffective antibody.

The researchers aimed to develop an initial vaccine that would induce mice and nonhuman primates to produce bNAb precursors to target V3, a precise region on the HIV envelope. Certain features of V3 are found among a wide variety of HIV viruses, and thus it is a good target for robust bNAbs.

The team first engineered a piece of the HIV envelope to remove glycans, a sugar that HIV uses to shield vulnerable regions like V3 from antibodies. After exposing V3, the researchers then added glycans to other regions that are more variable between strains, covering them up in order to ensure that the test animals would produce antibodies specific to the V3 region. Then, the team placed approximately 70 of these identically engineered envelopes (that contain no viral genetic material) on a carrier particle and injected it into the animal models.

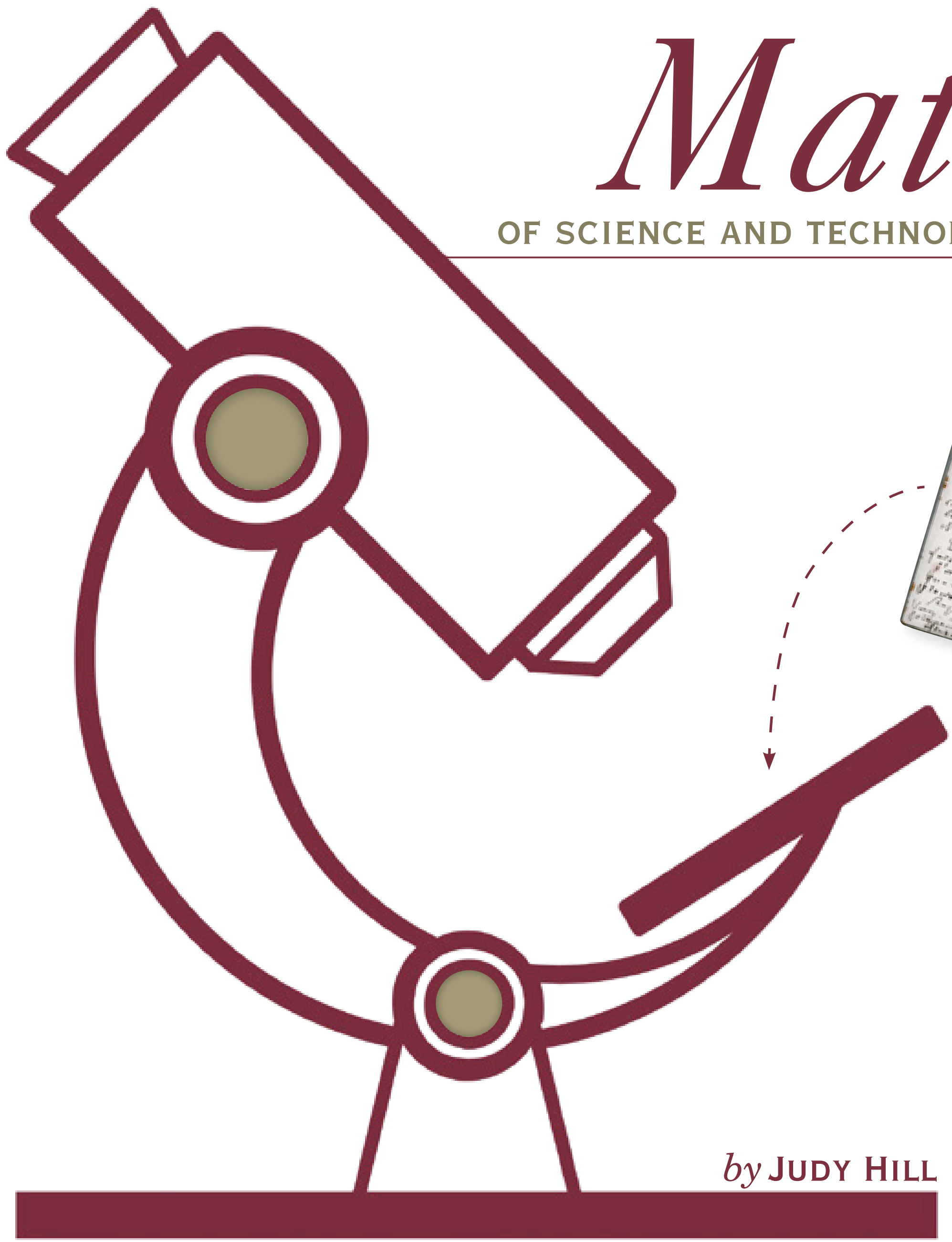
This engineered complex caused the animals to create the correct bNAb precursors specific to the V3 region on HIV. Furthermore, adding the engineered envelope to the carrier particle ensured a large response from the animals' immune systems. When exposed to an actual HIV virus, the precursor bNAbs developed by this initial inoculation were able to see past the virus's shielding glycans to target its vulnerable regions.

The team is now focused on the next step: a dose of the vaccine that would enable precursors to mature into bNAbs. C

Read more about this research at
magazine.caltech.edu/post/eradicating-hiv

Why Science History Matters

A NEW PARTNERSHIP BETWEEN CALTECH AND THE HUNTINGTON AIMS TO GIVE THE HISTORY OF SCIENCE AND TECHNOLOGY A TIMELY BOOST



by JUDY HILL

Across the nation, university history departments have been shrinking in recent years amid a more general conversation regarding the value of the humanities. Within that broader landscape, programs in more specific subject areas, like the history of science and technology, are particularly in jeopardy. And that, say historians from Caltech and The Huntington Library, Art Museum, and Botanical Gardens, makes their recent launch of a new joint research institute both a timely and critical endeavor.

"Irrelevance equals obsolescence"

This latest endeavor builds on a commitment both institutions have made regarding the importance of history and, in particular, the light it can shed on both the past and future of science and technology.

"If you don't know where you've been, you don't know where you are and you don't know where you're going," says Jed Buchwald, Caltech's Doris and Henry Dreyfuss Professor of History and director of the newly formed Research Institute for the History of Science and Technology (RIHST). "And history as a discipline is much older than science as a discipline. Until about the middle of the 18th century, it was actually considered to be the central discipline."

The decline of investment in the study of history on American campuses is a deeply unsettling trend, says Dan Lewis, associate director of RIHST and Dibner Senior Curator of the History of Science and Technology at The Huntington. "We're very presentist, and so we don't understand how to look carefully at history and extract its lessons. As soon as you think something isn't relevant, it's doomed, whether it's archeology or paleontology or religious studies, because irrelevance equals obsolescence."

As a premier institution in science and technology, "we have to be able to communicate to our students where we come from," adds Jean-Laurent Rosenthal, Caltech's Rea A. and Lela G. Axline Professor of Business Economics and the Ronald and Maxine Linde Leadership Chair of the Division of the Humanities and Social Sciences. "If our students are going to spend 40 or 50 years in a discipline like biology, for example, they have to understand that there's a history to biology and that it matters. Thinking about change over time within academic disciplines, especially in the subject areas we're in, is pretty important for us."

Science history at Caltech

The history of science as an academic discipline became a part of Caltech's humanities programming in the mid-1960s with the appointment of Dan Kevles, J. O. and Juliette Koepfli Professor of the Humanities, Emeritus. Kevles is a broad-based historian of science known for his books on American physics and eugenics, and for his scholarship on science and technology in modern societies. Kevles, in turn, encouraged the hiring of Diana Kormos-Buchwald, now editor of Caltech's Einstein Papers Project and Robert M. Abbey Professor of History, who came to the Institute in 1989 as a historian of chemistry.

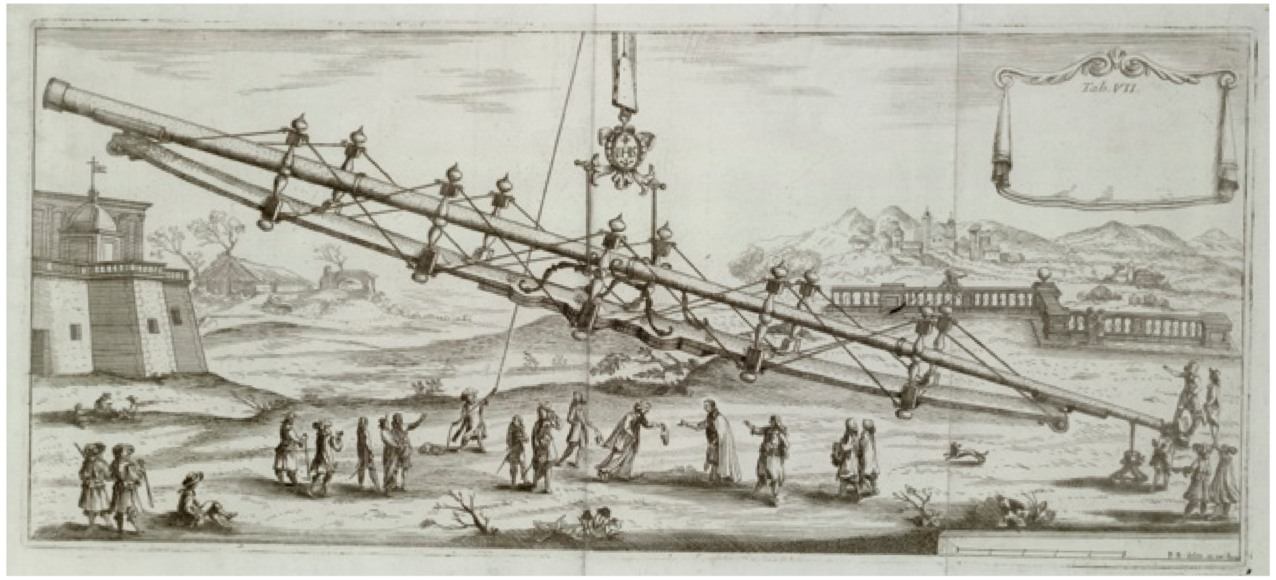
That effort was strengthened in 2001 with the arrival of Jed Buchwald, a historian of physics and the philosophy of physical sciences; Mordecai Feingold, now the Van Nuys Page Professor of History (who studies the rise of science from the Renaissance to the 18th century); and, in 2010, Nicolás Wey-Gómez, who focuses on the role of science and technology in exploration.

With Caltech's influence on the discipline established, the Institute was able to capitalize on the opportunities that its proximity to and long history of collaboration with The Huntington provides. That partnership has led to the creation of the new research institute, which a gift from Stephen E. Rogers will fund for its first three years of operations. Rogers himself epitomizes that collaborative spirit: he is both a member of The Huntington's board of overseers and president of the Caltech Associates.

Steve Hindle, director of research at The Huntington, notes that Caltech's expertise combined with the strength of The Huntington's collection "should make it possible for this collaboration to raise the Caltech-Huntington nexus to the status of the Max Planck Institute in Berlin as a center for the history of science and technology."

Specifically, the new institute will get its start by creating an opportunity each fall over the next three years for a different senior scholar to spend time conducting research in The Huntington's extensive library collections and at the Caltech Archives. The inaugural scholar is Erik Conway, historian at JPL, which Caltech manages for NASA; Conway will be examining the history of electrical technology.

Left (book): *Etudes Sur Le Vin* (with notes on the page facing the title page by the author, Louis Pasteur). Above: Finch from Charles Darwin's *Zoology of the HMS Beagle, 1839–43,* The Huntington Library, Art Museum, and Botanical Gardens.



In addition, and in keeping with RIHST's vision, Caltech plans to hire a professor of the history of technology. "It's equally important as having faculty in the history of science," says Rosenthal, "because many of the things that we're most proud of, such as our telescopes and LIGO [the Laser Interferometer Gravitational-wave Observatory], are engineering feats that involve technology, building things that nobody could build before."

Critical mass

Complementing Caltech's academic strength in the field is The Huntington's extraordinarily rich history-of-science collection, with holdings ranging from a 13th-century Ptolemy manuscript to modern civil engineering reports.

"If you count the Library of Congress and the Linda Hall Library in Kansas City, The Huntington is one of the three major locations of science and technology materials in North America," says Buchwald. And he speaks from experience. During his tenure at MIT during the 1990s, Buchwald directed the Dibner Institute for the History of Science and Technology, a research institute that included the 47,000-volume Burndy Library of scientific and technological history materials, plus hundreds of archival objects. When the Dibner family began looking for a new location for the library in 2004, The Huntington threw its hat into the ring and was selected to be its new home. Serendipitously, notes Dan Lewis, The Huntington had recently finished building the Munger Research Center, a 90,000-square-foot building with 30,000 square feet of collection space. "We were a year into our occupancy of the building," he says, "when this came onto our radar."

"That was our single biggest acquisition of any kind since Henry Huntington's time," Lewis says of the Burndy Library. There were 20,000 reference works, 67,000 books total, and about 2,000 linear feet of manuscript material.

Spanning the 13th century through the middle of the 20th, the Burndy holdings include the largest collection of Isaac Newton materials outside England, hundreds of early works on physics and mathematics, an extensive assemblage relating to bridge and water engineering, materials on color theory and practice, a substantial aeronautics section, and some of the rarest books about Western science published in Japan. The library also includes such archival oddities as a set of glass lantern slides showing the construction of the Panama Canal and 400 lightbulbs from the 1890s to the 1960s.

The Burndy isn't The Huntington's only science-and-technology offering, though. The library also boasts the world's third largest Charles Darwin collection; the Mount Wilson Observatory Collection, with more than thousand books on the history of astronomy and physics; the Los Angeles County Medical Association Collection; one of the largest depositories of materials related to mining and exploratory geology in the U.S.; and the largest collection of history-of-chemistry books west of Wisconsin.

RIHST scholars will also benefit from access to materials in the Caltech Archives, at JPL, and more broadly in Southern California.

Research ready

The authentic experience of engaging with unique material texts is critically important, agrees research director Hindle. "Yes, it's helpful to scholars in Kenilworth or Canberra or Krakow to be able to sit remotely and access material from a distance. However, the real value added in coming into an environment like The Huntington is that you don't just engage with the collections, you engage with the scholarly community that orbits around the collection. Those conversations are often serendipitous and unpredictable, and they can be generative of unique ideas in ways that are far less easy to replicate online."

To that end, the new Caltech-Huntington program will annually convene groups of scholars for two weeks to work together in a residential institute and will also invite short-term visiting scholars, a junior scholar appointed for a two-year term at Caltech, and two short-term research fellows at The Huntington.

"There still is nothing like working directly with the materials," Buchwald says. "And working in a place like The Huntington, which has groups of scholars coming in and working together, is in itself synergistic. If you put that together with our expertise here at Caltech, then you have the possibility of some first-rate research."

RED.

Nº	Names.	Colours.	Animal.	Vegetable.	Mineral.
91	Carmine Red.			Raspberry. Cocks Comb. Carnation Pink.	Oriental Ruby.
92	Lake Red.			Red Tulip. Rose Officinalus.	Spinel.
93	Crimson Red.				Precious Garnet.
94	Purplish Red.		Outside of Quills of Terico.	Dark Crimson Officinal Garden Rose.	Precious Garnet.
95	Cochineal Red.			Under Disk of decayed Leaves of None-so-pretty.	Dark Cinnaber
96	Veinous Blood Red.		Veinous Blood.	Musk Flower, or dark Purple Scabious.	Pyrope.
97	Brownish Purple Red.			Flower of deadly Nightshade.	Red Antimony Ore.
98	Chocolate Red.		Breast of Bird of Paradise.	Brown Disk of common Marigold.	
99	Brownish Red.		Mark on Throat of Red-throated Diver.		Iron Flint.

Above: A long focal-length telescope from Francesco Bianchini's *Hesperi et Phosphori Nova Phaenomena,* 1728. Right: A page from Abraham Werner's *Nomenclature of Colours,* 1821, The Huntington Library, Art Museum, and Botanical Gardens.

A different theme will be explored each year, with the history of electrical technology in the spotlight this year, the history of environmental sciences slated for next year, and early modern science scheduled for the program's third year.

As JPL's Conway notes, "The Huntington's collections are vital to understanding the technological development of the western United States. Electricity and the organizations producing and distributing it were essential infrastructure, and The Huntington's collections help document their role in developing California."

Beyond reading texts for content, Hindle says, researchers also need to imagine how those texts were used by scholars. "It is fascinating to me that we can identify Isaac Newton's own copies of 17th-century books because we know the way in which he dog-eared the pages. Only by looking at the material objects would you be able to get that sense."

Since the history of science and technology is a relatively small field, with scholars dispersed in small centers or departments across the broad higher-education landscape, creating an environment where they can feel like they are part of a broader conversation is important, says Rosenthal. "In most universities you're going to have maybe three or four people doing history of science. We're creating a real intellectual forum and a network of resources that begins with Caltech and The Huntington and extends out from that."

Reviving the dialogue

As Rosenthal sees it, Caltech and The Huntington are uniquely well positioned to advance the history of science and technology as a discipline. "We already have the historical sense of how Caltech and The Huntington came to be, how they both have matured into outstanding institutions. Now, with RIHST and the collections at The Huntington and Caltech Archives, our faculty and visiting scholars will have unparalleled opportunitiess to advance their own research while also furthering the conversation on why the study of history remains relevant." Rosenthal continues, "We hope these efforts will provide renewed momentum to the study of the history of science and technology, a critical field for understanding the advent of modern societies."

This kind of partnership, between an independent research library and a research institute, does not happen very often, notes Hindle. "I think we are offering a model of how two very different institutions might actually be brought into a common vision."

Good neighbors

Caltech and The Huntington, whose campuses are less than a mile apart, have had a close relationship since Caltech's George Ellery Hale encouraged railroad magnate Henry E. Huntington to transform Huntington's library, art, and botanical collections into a research center a century ago.

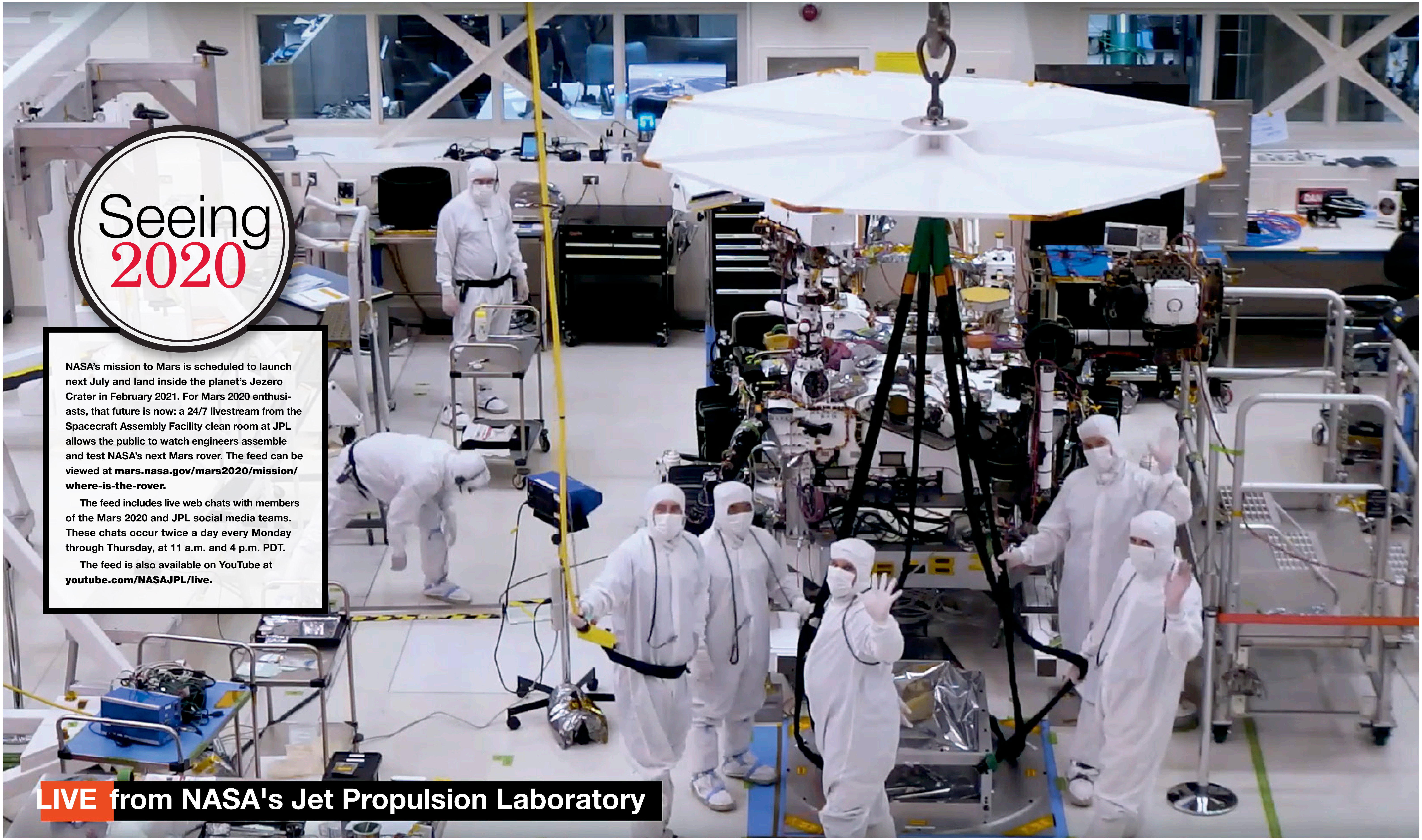
Read more about collaborations between Caltech and The Huntington at **magazine.caltech.edu/post/huntington-collaboration**

Seeing 2020

NASA's mission to Mars is scheduled to launch next July and land inside the planet's Jezero Crater in February 2021. For Mars 2020 enthusiasts, that future is now: a 24/7 livestream from the Spacecraft Assembly Facility clean room at JPL allows the public to watch engineers assemble and test NASA's next Mars rover. The feed can be viewed at **mars.nasa.gov/mars2020/mission/where-is-the-rover.**

The feed includes live web chats with members of the Mars 2020 and JPL social media teams. These chats occur twice a day every Monday through Thursday, at 11 a.m. and 4 p.m. PDT.

The feed is also available on YouTube at **youtube.com/NASAJPL/live.**



HUMANS HAVE LANDED ON MARS

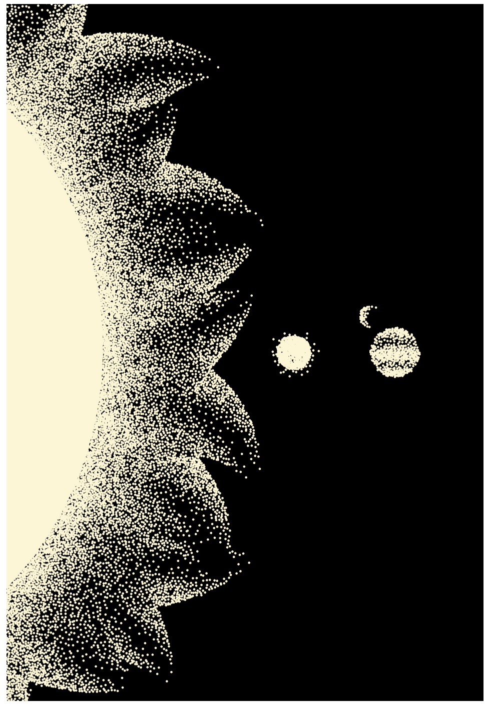
... and 10 other scientific misconceptions debunked

by Lori Dajose (BS ’16)

WHEN someone asks me what I majored in at Caltech, I tend to hesitate. Sometimes the answer, planetary science, draws some puzzled looks from nonscientists. If they misheard me, they might say, “I love plants, I’m actually a vegetarian!” Or, if they heard me correctly: “So, where are the aliens? Can you bring Pluto back?” And so on. Once, a person responded by telling me his favorite planet was Europa: a good effort at conversation, though Europa is not, in fact, a planet.

Misunderstandings abound when it comes to science. Here, eight Caltech scientists correct some common misconceptions people have about areas of research.

Watch Caltech scientists debunking earthquake myths at magazine.caltech.edu/post/scientific-misconceptions



Myth #1:
Solar energy is cheap and clean

"Solar cells convert the sun's energy to electricity in materials called semiconductors. Most solar cells use silicon as a semiconductor. Silicon is a good material; it's efficient, and the field is close to maximizing the material's potential. However, silicon is actually quite difficult to produce. It's expensive and uses some harsh chemicals. For solar cells to keep getting cheaper, we need to find some alternatives to silicon.

"I'm working on making solar cells out of new, ultrathin semiconductors called transition metal dichalcogenides. They can absorb the same amount of energy as a silicon cell, but because they're almost a thousand times thinner, you can make a thousand times as many cells for the same amount of material. This would make solar cells much cheaper to produce."

Cora Went, Graduate Student in Physics

Myth #2:
PEOPLE HAVE BEEN TO MARS

"It's a pretty common misconception for people to think that we have already sent humans to Mars and that we've already brought samples back. We've done neither of these things!

"Retrieving samples from Mars is difficult because getting off Mars is difficult. A craft that lands on Mars's surface also needs to carry a rocket that can launch from there. The components of rockets don't do so well with extreme temperature changes, and on Mars you get 90-degree temperature swings in the course of an average day. Doing that over and over to your rocket is not good for reliability.

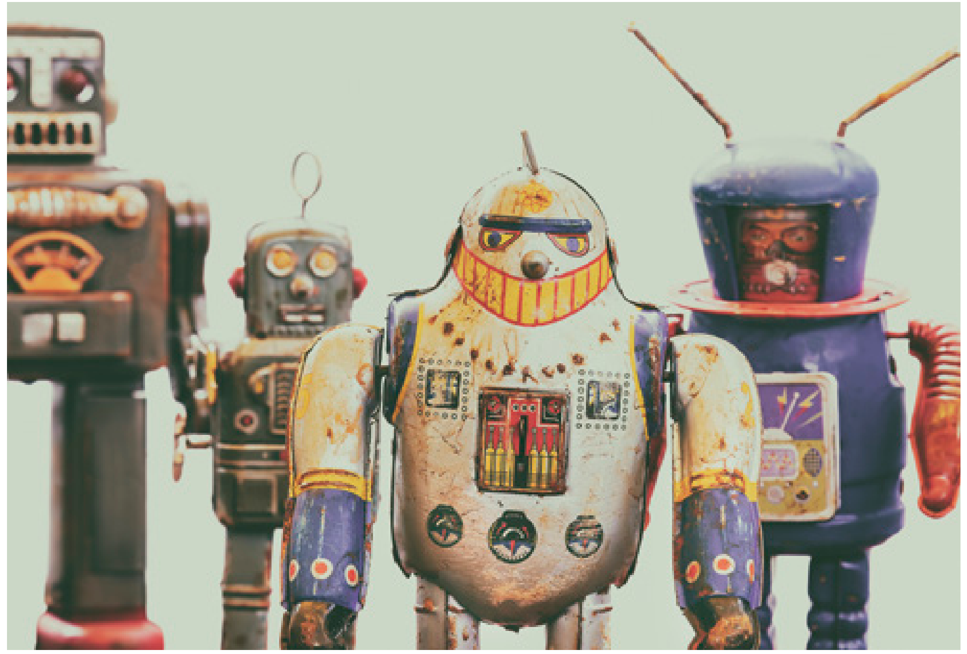
"Putting people on Mars is hard because space is not a hospitable place for humans. A one-way trip to Mars takes seven months, and a roundtrip takes about two years because Earth's and Mars's orbits align only infrequently. So not only do you need to bring enough food, water, and fuel, you have to keep the astronauts protected from cosmic radiation and the microgravity that weakens their bones. Any spacecraft carrying humans would need to be five to 10 times more massive than the Curiosity rover, and getting that heavy a craft to land safely on Mars is a tough task we haven't solved yet."

Bethany Ehlmann, Professor of Planetary Science and JPL Research Scientist

Myth #3:
Stem cell research requires embryonic tissue

"There's a common misconception about stem-cell biology that all of the stem cells used in our research are taken from unborn embryos. In fact, you can make stem cells very easily from any type of adult tissue by just introducing a couple of transcription factors (molecules that modify gene expression). A lot of people react strongly when I say I work on stem cells because they think they come from embryos, but, in fact, I use stem cells from adult skin cells."

Alison Koontz, Graduate Student in Biology



Myth #4:
AI will lead to a robot uprising … or solve the world's problems

"Artificial intelligence (AI) can be heavily distorted as two extremes: the first is the idea that AI will become dystopian and destructive to humanity, and the second is the notion that AI will solve all of the world's problems by making super-intelligent scientific advances. Neither of these are true in the foreseeable future.

"Even though the field has made a lot of progress recently, the simplest of tasks (for humans) are still extremely challenging for AI to tackle. Take computer vision, for example; the process of teaching computers to recognize objects in an image. For a human, identifying discrete objects in an image is so trivial we don't even think of it as a challenging problem. Currently, there is a big difference between the mechanisms that humans use to see and the mechanisms used by computers. For example, say you add a small amount of noise to an image. A person can 'overcome' the noise and still easily perceive what is in the image. But a machine can be completely fooled. Humans have an inbuilt robustness, but artificial intelligence is more brittle.

"We do, however, need to take caution in some aspects of using AI. For example, AI can become biased and unfair toward certain demographics if it learns from biased data. What's more, launching poorly designed systems into the real world, like self-driving cars, can cause fatal accidents because they go wrong in nonintuitive ways. We don't even know when to expect systems to make mistakes because they make decisions so differently from humans."

Anima Anandkumar, Bren Professor of Computing and Mathematical Sciences

Universal Truths

With unfathomable distances, sizes, and incomprehensible timescales, outer space can seem abstract to people who aren't astronomers. **Astronomy graduate student Mia de los Reyes** explains a couple of common misconceptions about the universe:

Myth #5:
Galaxies are basically static

"In the same way a forest seems peaceful but is constantly changing, galaxies are ecosystems that are ever-evolving. Stars are being born and dying, material is flowing around, and galaxies gravitationally interact with one another. When people think of galaxies, they think of static pictures. But galaxies are very much dynamic."

Myth #6:
There is a "center" of the universe

"The phrase 'center of the universe' is used casually, but it's interesting because there actually is no center of the universe. Even though the universe is expanding, it's happening everywhere at the same time. Space itself is being stretched out. The expansion looks the same from any point within the universe because everything is moving away from everything else."

Myth #7:

Genetically modified food is unsafe

"In agriculture, there are two ways to create a genetically modified organism, or GMO. The first is simply to speed up the natural process of breeding: take a gene from one plant and put it in another of the same kind, such as a tomato plant. The other way is to take a gene from one organism and put it into a different type of organism; taking the gene that produces a natural insecticide in a bacterium and transplanting it into a corn plant, for example.

"In order for any of the resulting GMOs to go to market, they first have to be tested extensively by the USDA, the FDA, and the EPA.

"There has been some lobbying to require labels to identify foods that are genetically modified. This is actually rather counterproductive because it gives the erroneous impression that one type of food is 'safer' than another. Take the natural insecticide BT, for example, isolated from a bacteriam called *Bacillus thuringiensis*. Plants can still be labeled 'organic' when they are sprayed with BT. Plants like corn, cotton, and soybeans can also be genetically modified to produce this pesticide themselves, and since they produce it internally, these plants don't need such a high dose for the insecticide to be effective.

"So, in this case, the GMO plant would actually have less insecticide on it than its 'organic' counterpart. People might be afraid to purchase it, though, simply because it is labeled 'genetically modified.'"

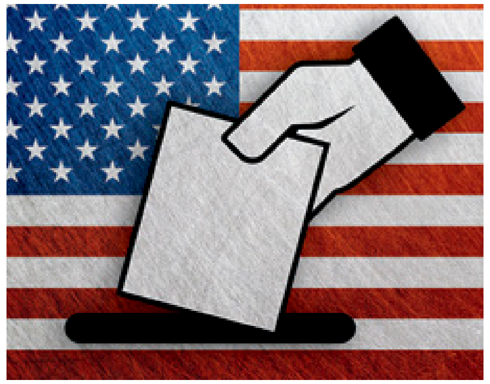
Sarah Cohen, Graduate Student in Biology

Myth #8:

Voter discrimination is a thing of the past

"In 2013, the U.S. Supreme Court held in *Shelby v. Holder* that the most important provision of the Voting Rights Act was unnecessary. In his majority opinion, Chief Justice Roberts asserted that discrimination against African American voters was no longer concentrated in the South and that combating it was now less important than upholding states' rights. My research shows, however, that voting discrimination is still widespread, and that it is, in fact, still concentrated in the South.

"It's also a misconception to think that prejudiced people show prejudice to all groups equally. For example, in the mid-1850s, the Know-Nothing Party in Massachusetts was very anti-Catholic and anti-Irish, but it supported school desegregation for black and white children. Prejudice is not universal and uniform, which complicates the study of discrimination and bias.



"For those of us who study racial discrimination today, it can actually be quite difficult to determine public attitudes. Most racially prejudiced people are not going to admit in a survey that they are racially prejudiced. So, sociologists and social psychologists must devise ways to measure implicit bias in order to identify the attitudes people really hold and whether beliefs align with their behavior."

Morgan Kousser, Professor of History and Social Science

Myth #9:

Math is all about numbers

"Math is not really about calculations and computations. It's the study of different abstract structures and their properties.

"The fundamental pursuit of mathematics is to define a structure consisting of some objects and rules for how they can interact and then try to prove that those structures must behave in a certain way. The system doesn't have to describe the real world, and it doesn't have to use numbers. Systems of logic, not numbers, are the foundations of mathematical construction. For example, you can look at geometric shapes and surfaces, and figure out how they behave.

"Everything in math is about building something. You create something abstract and set some definitions and rules for how it works, and you play with it and see what happens. If you succeed in proving through a logical argument that your abstract system always behaves in a certain way, you also understand the behavior of all the different specific examples."

Jane Panangaden, Graduate Student in Mathematics

Shaky Understanding

Earthquakes are scary, not only because of their potentially destructive effects but because they can happen anytime. **Staff seismologist Jen Andrews** addresses two common seismic issues:

Myth #10:

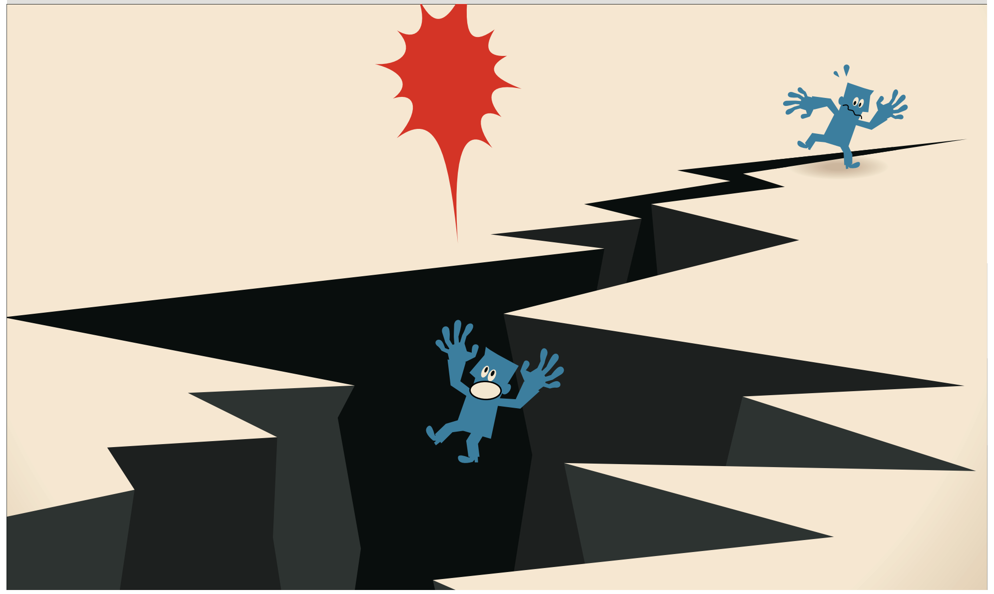
Science can predict when the Big One will happen

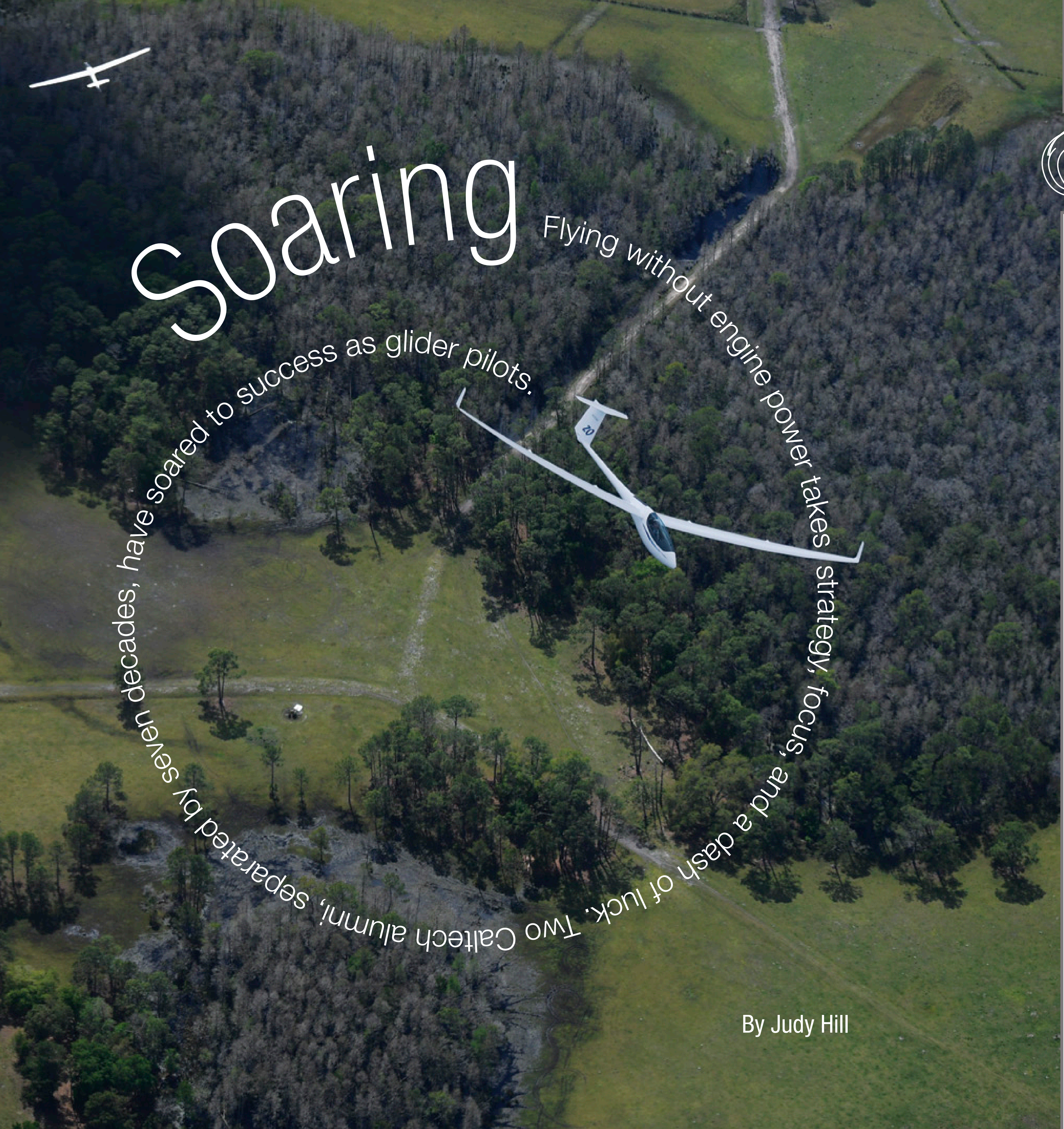
"As seismologists, we're often asked if we can predict when the Big One (a magnitude 7 or 8 earthquake, most likely on the San Andreas Fault) is going to happen. We can't actually predict when it will happen, but we do something called forecasting, which is where we give some idea of the likelihood of certain events of certain magnitudes within specific time frames. The natural cycle of the San Andreas system shows a magnitude 7 or 8 every few hundred years at different sections, and we haven't had one for 300 years in the southern section, so we estimate that there is a 19 percent chance that we will have an event greater than M6.7 within the next 30 years. We also forecast how the faults might interact: an 8 on the San Andreas could stress nearby faults and possibly trigger a 7 on those. But it's not prediction. We don't know when it will happen."

Myth #11:

Earthquakes open up huge chasms in the ground

"Movies can scare people when they portray earthquakes as opening up massive, jagged chasms in the ground. Even though huge earthquakes release lots of energy, the ground physically doesn't move very far. The amount of slip on the fault does correlate with the magnitude of the earthquake. To create a magnitude 7.8, like the earthquake that essentially destroyed San Francisco in 1906, the ground moves on the order of meters, maybe 20 feet or so. But, hows much of the fault is moving a meter matters, too. In the 6.7 Northridge quake of 1994, about 30 kilometers of fault moved 1 meter. It doesn't sound like much, but it has the potential to create enormous damage."





Soaring

Flying without engine power takes strategy, focus, and a dash of luck. Two Caltech alumni, separated by seven decades, have soared to success as glider pilots.

By Judy Hill

On a good day, if he leaves his Pasadena apartment early enough, Michael Marshall (MS '17) can be gliding over the Tehachapi Mountains by 10:30 am. With the baking Mojave Desert out to the east and the San Joaquin Valley's flatlands unfurling to the west, Marshall is in his element. Wedged into the tiny cockpit of his single-seat racing sailplane, he knows that what happens next depends on two things: his skill as a glider pilot and the day's weather conditions.

Those skills are paramount. Without them, a glider will naturally return to the earth in just a few minutes after being towed by an airplane to an altitude of 2,000 to 3,000 feet. To keep the plane buoyant, the pilot has to seek out sources of thermal lift, the buoyancy provided by columns of heated rising air called thermals.

"The big drivers are wind and sun," explains Marshall, a Caltech aerospace graduate student who competed this summer with the U.S. Soaring Team in the Junior World Gliding Championships in Szeged, Hungary. Two years ago, Marshall was awarded the Soaring Society of America's Rudolph W. Mozer Trophy when he won the title of Junior National Champion as the highest-ranking contestant.

On the other hand, Marshall adds, as he continues to explain some of the factors a glider pilot must consider, clouds are a mixed bag: "Some clouds mean rain, some just shadow the ground. Shadows usually mean there's no lift. If you have puffy white cumulus clouds, those are good markers of lift. When it's really hot, you usually get strong thermals."

Mountains also play a role. "In the morning, the eastern-facing slopes of the mountains get more sunlight so they're more likely to trigger a thermal," Marshall explains. "Air usually runs up the slopes and converges at the mountain peaks." When seeking out thermals in the flatlands of the Midwest or East Coast, he is more likely to look for man-made infrastructures, such as a parking lot or a Walmart.

Using these thermals, Marshall can log more than 300 miles on an average soaring day, staying in the air for seven hours or more. A recent flight took him from Tehachapi, up 15,000 feet, and over into the Owens Valley. "That was a short one, just four hours," he says. "I had to get back for a conference call."

The son of a pilot, Marshall made his first solo flight in a glider at the age of 14. By 16, he had earned his pilot's license, and his family had moved to Minden, a town in northern Nevada. "The place was about an hour south of Reno, which is one of the top three or four places in the world to fly gliders," he explains. "Someone would say, 'I

just flew to Mount Whitney and back,' which is 400 miles, and they'd do that in an afternoon! I thought, 'That would be fun. Let's do that!' That's really where it all got started."

Marshall has since flown in about a dozen competitions, in Florida, South Carolina, and across the western United States. But wherever Marshall flies, he relies on a device (now an algorithm) developed by a fellow Caltech alumnus.

The instrument is called the MacCready Ring, and its inventor, the late Paul MacCready (MS '48, PhD '52), was also a glider pilot. He won the National Soaring Championship three times while at Caltech, became a pioneer in human-powered flight during the 1970s (see sidebar, next page), and made a career as an aeronautical engineer, and was the founder of the unmanned aircraft manufacturer, AeroVironment.

People Powered

The late aeronautics engineer Paul MacCready (MS '48, PhD '52) had already won a mile-long human-powered flight competition in 1977, claiming a $100,000 Kremer Prize (part of a series of challenges set by industrialist Henry Kremer in 1959), with his aircraft the *Gossamor Condor,* when two years later, he and his team completed a successful crossing of the English Channel to win a second Kremer Prize.

The aircraft that crossed the Channel was named *Gossamer Albatross* and was constructed from carbon fiber, polystyrene, and Mylar. It was designed to be powered like a bicycle, using pedals that drove a two-bladed propeller.

MacCready not only designed both aircraft but also selected the same man to pilot them: an amateur cyclist from Bakersfield named Bryan Allen, who, as MacCready explained in his 2004 Caltech Archives oral history, fit his list of requirements: "… somebody with light weight ... a good bike racer who could help build the plane, who had some experience in model airplane construction, and who was unemployed, so that he would be available."

A little after dawn on June 12, 1979, Allen powered up the *Albatross* to 75 revolutions per minute and took off from Folkestone, England. "We knew that he could put out enough power to stay aloft for two hours," MacCready said in his oral history interview, "and we were hoping that the wind would be nothing, or that there would even be a slight tail wind. But instead ... it became a headwind."

That two-hour flight turned into almost three. "When his left leg would cramp, he'd pedal mostly with his right. When his right leg would cramp, he'd pedal mostly with his left. Both legs cramped toward the end, and he somehow just struggled through." As the winds calmed again, Allen landed on the beach at Cape Gris-Nez in France, having completed the 22.2-mile crossing in two hours and 49 minutes, achieving a top speed of 18 miles per hour and an average altitude of 5 feet.

Allen would later set world records in distance and duration in a small pedal-powered blimp named *White Dwarf.* Today, he works at JPL, which Caltech manages for NASA, as a software engineer.

"Every glider pilot around the world knows about Paul MacCready," says Marshall. "He came up with the optimal speed-to-fly theory. There have been other people who have added little bits and pieces to it, but at the end of the day, the fundamental theory on optimal speed-to-fly is still MacCready's."

The MacCready Ring was originally a physical device, but the theory behind the MacCready Ring is now implemented in a glider's flight computer. Based on his speed-to-fly principle, it calculates the speed and altitude necessary to glide to a particular destination. The indications for when to speed up and slow down change depending on the rate of climb that is set; with higher climb rates, it is more optimal to fly faster, which consequently uses up more altitude when gliding between thermals.

MacCready's affiliation with Caltech was part of the reason Marshall wanted to come to the Institute, he says. "There's a lot of soaring, aviation, and aerospace history associated with Caltech, and MacCready played a large part in it. I hope to emulate some of his successes one day, in both soaring and aerospace."

MacCready, who died in 2007, achieved early gliding success in a Pasadena-made sailplane called the *Screaming Wiener.* He won national soaring championships in that glider, and its successors, in 1947, '48, '49, and '53. He also competed in England, Spain, and Sweden, winning the World Championship in France in 1956. "I quit soaring after that contest," said MacCready in a 2003 oral history conducted by the Caltech Archives. "It was a very extreme day. … The wind was, oh, 60 miles an hour or more, and you'd get a down-current behind the slope, maybe 100 feet a second down, mingled with currents of 100 feet per second up. And it was luck as to whether you made it there."

Although he achieved remarkable success in soaring, MacCready never saw himself as an instinctive pilot. Instead, he said, "I used my brain power in the important part of the flight. Those contests wouldn't be won by somebody who could do turns effortlessly but by somebody who knew where the next thermal was. I would concentrate very hard."

Marshall, too, says he is not necessarily a natural flyer. "I do think that good glider pilots usually fall into one of two categories: tactical pilots, who understand the fundamentals of soaring and how to apply them, and intuitive pilots, who are very good at reading the sky and sensing the air around them," he says. "I fall more into the former category, though I'm trying to get more over to the other side, too."

The sport, adds Marshall, tends to appeal to mathematicians, scientists, and engineers, and while his graduate research on the dynamics and control of flexible spacecraft has no direct correlation with soaring, he feels sure that he benefits from his analytical background. "I have a reasonably good understanding of how things fly. Just being an aerospace engineer is beneficial. The challenges in engineering and research are similar to the challenges in soaring: they're both difficult problems that you tackle with a set of fundamental principles and judgment formed from experience. It's just that the consequences if something goes wrong in soaring are often higher than the consequences in research."

Preparing for competition means researching the local terrain as well as the likely weather conditions. For instance, he says, flying on the West Coast is not great practice for flying in Europe, since European thermals are slower and the highest a glider pilot is likely to reach is around 5,000 feet, while on an average day in the western United States, a sailplane might reach an altitude of 15,000 feet. And, with fewer mountains in some parts of Europe, features like lakes, forests, and even roads can have a significant effect on gliding conditions.

It also helps to know who else is in the race. "You want to know who the really good pilots are," says Marshall. Equally important, he says, is knowing the pilots who have historically made bad decisions and then both literally and metaphorically steering clear of them.

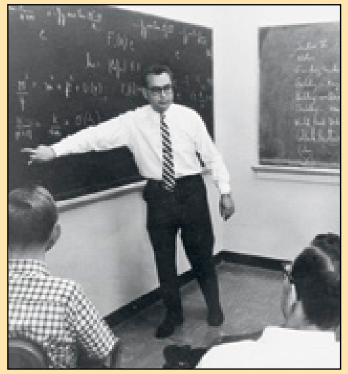
Even with careful planning and smart strategy, every flight holds some surprises. One day in Florida, Marshall recalls, he found himself sharing a thermal with a bald eagle. Another day, during a competition in central Utah, he says, "We were flying down a ridge that was maybe 70 miles long, and it ended up being a pack of gliders all basically hugging the top of the ridge, cruising at like 80 to 90 miles an hour just a couple hundred feet above the ground. We were basically in formation flying down the ridge, a flock of gliders. So that was unexpected but pretty exciting."

When Marshall tells people he's a glider pilot, they often muse about how peaceful it must be up in the skies without any engine noise. "But it's not as quiet as people think," he admits. "You have instruments beeping at you. And then there's the wind noise. It looks peaceful, but sometimes it can be a lot more like a roller coaster."

There is nowhere he would rather be, though, on a day away from his research on campus. "There are a lot of puzzle pieces that need to be put together to do well," he says of his intellectually challenging sport. "I have some of the pieces but not all of them. I don't think you can ever really get all of them."

In Memoriam

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

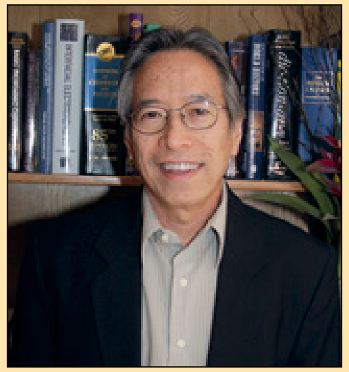


Murray Gell-Mann

1929–2019

Murray Gell-Mann, who was Caltech's Robert Andrews Millikan Professor of Theoretical Physics, Emeritus, and a winner of the 1969 Nobel Prize in Physics, passed away on May 24. He was 89 years old.

Gell-Mann helped bring order to the field of particle physics in the 1950s and 1960s. He devised a new method for sorting the particles into simple groups of eight, based on their electric charge, spin, and other characteristics. He is perhaps best known for developing the theory of "quarks," indivisible components of matter that make up protons, neutrons, and various other subatomic particles.

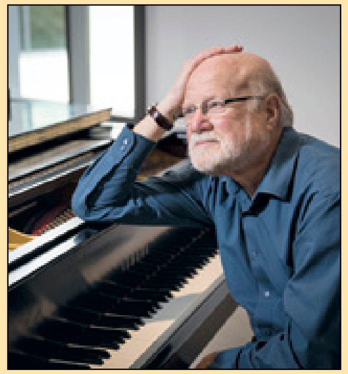


Manuel Soriaga

1950–2019

Manuel "Manny" Soriaga, a research professor of applied physics and materials science, died on July 17. He was 69.

As a principal investigator in Caltech's Joint Center for Artificial Photosynthesis (JCAP), Soriaga studied electrochemical reactions that make artificial photosynthesis possible. His research focused in particular on the discovery and development of the catalysts required to perform those reactions.



Allen Robert Gross

1944–2019

Allen Robert Gross, longtime director of the Caltech Orchestra who retired in May after 36 years at the Institute, died on August 20. He was 75.

During his time at Caltech, Gross also served as music director and conductor of the Santa Monica Symphony Orchestra and of Orchestra Santa Monica, and he led tours of the Santa Monica Chamber Philharmonia. In addition, he worked at Occidental College until 2014, when he retired as emeritus professor of music.

Endnotes

What was the most unexpected job you ever had?

After 25 years working in satellite communications, I took a sharp turn into Chinese traditional medicine and used acupuncture to treat patients.

William Hwang (BS '71)
CARLSBAD, CA

Professional poker player.

Mark Weitzman (MS '90)
LAS VEGAS, NV

Foot model for a book on handknit socks. I had test-knit some of the socks shown.

Bridget Landry (MS '86)
ALTADENA, CA

Teaching beginning ballroom dancing on cruise ships.

Ken Scholtz (BS '60)
LOS ANGELES, CA

I was the Los Angeles Kings (NHL) mascot.

Dwight Berg (BS '90, MS '90)
LANSDOWNE, VA

I counted cars—straight, right turn, left turn—for Pasadena's Traffic Engineering Department; around the Rose Bowl and on north Fair Oaks.

Bob Wieting (BS '74)
SIMI VALLEY, CA

I flew small airplanes to the mountains of south-central Alaska for about 10 years, landing on glaciers, ice fields, gravel bars, etc., to bring supplies to hikers, hunters, and mountain climbers.

Garnett Pessel (MS '60)
PRINEVILLE, OR

I worked for the U.S. Army testing the cooking characteristics of microwave ovens. Cooked a lot of food studded with thermocouples to see how to modify standard cookbooks. Finally, experiments that tasted good.

Bart Gordon (BS '68)
LOS ANGELES, CA

Chicken catcher. I had not realized you could hold eight chickens at once.

Brian Davison (PhD '85)
KNOXVILLE, TN

I was the driving "engineer" on the Griffith Park Railway.

Charles Malone (BS '57, MS '58)
PITTSBURGH, PA

My current one: working as an urban planner.

Karen Kiselewski (BS '82)
DELRAY BEACH, FL

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Polishing floors weeknights in banks in Glendale and building movie sets on weekends in Burbank for John Wayne movies during my first three years at Caltech.

Stan Manatt (BS '55, PhD '59)
LA CANADA FLINTRIDGE, CA

An elevator operator in the Hotel Astor, Times Square, New York City.

Bernard Schweitzer (BS '55)
LOS ANGELES, CA

Manure shoveler at the Central Missouri Livestock Auction.

Steven Crow (BS '62, PhD '66)
BOULDER, CO

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Serotonin's Role in Sleep

Serotonin is a multipurpose molecule found throughout the brain that plays a role in memory, cognition, and feelings of happiness. Researchers have long debated serotonin's role in sleep: now, Caltech scientists in the labs of Biology Professor David Prober and Neuroscience and Biological Engineering Professor Viviana Gradinaru have found that serotonin is necessary for sleep in zebrafish and mouse models. The researchers focused on a region called the raphe nuclei, which has the brain's main population of sertonin-producing neurons. Removing those neurons resulted in less sleep for both fish and mice. The research could shed light on sleep-related side effects of common antidepressant drugs that increase serotonin levels in the human brain.

Find out more at **magazine.caltech.edu/post/serotonin-sleep**