Fall 2018

Caltech magazine

An eye on innovation

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Left: Caltech graduate student Giuliana Viglione traveled to the Southern Ocean to study how Antarctic sea currents affect climate.

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Caltech magazine

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Left: The *Caltech Catalog* for the current academic year is available online at **catalog.caltech.edu/current.**

Letters

For more letters visit us online at magazine.caltech.edu/post/letters3

Stranger than [science] fiction

As one of the original officers of SPECTRE, I really enjoyed the article on the science-fiction library ["Subterranean Sci-Fi," Summer 2018]. SPECTRE is indeed named after James Bond's nemesis. We tried to turn it into an acronym (Science Phiction Enthusiasts at Cal Tech mumble mumble), but never really got one to work. But our science-fiction book-club membership was in the name of Ernst Stavro Blofeld [the villainous head of SPECTRE].

Caltech graduate students were heavily involved in the starting of the club, most notably Mark Looper (PhD '93) who was the first president and the driving force for the first few years. I helped out where I could, and got permission to set up the library in the basement and got ASCIT to fund purchase of the original bookcases. Much of the starting collection was donated by Mark, myself, and others. We also had science-fiction authors come and give talks, including David Brin [BS '73] (a Caltech grad whom I still keep in touch with), Gentry Lee, Somtow Sucharitkul, and others.

I am really glad that the library has been resurrected and hope that it continues to bring joy and relaxation to Caltech students for many more years.

Eric Christian (PhD '89)

Absolutely fabulous cover! [Summer 2018]

With respect to the article on the science-fiction library, when I was there, what was in the basement of Fleming was a whole series of rooms full of discarded stuff—desks, supplies, you name it. We called it "the infinite storeroom." And when I was a senior living in Fleming something down there caught fire. I remember waking up when my door burst open, and standing there was a Pasadena fireman, complete with oxygen mask. After the fact, I thought, "why couldn't this have happened at finals?"

Bob Parker (BS '67)

Wait, what?

I'm sorry to admit that sometime when I wasn't paying attention, you completely redesigned the magazine!

I was no longer able to ignore your feat when I picked up the Summer 2018 issue. The spectacular cover, the big and bright images everywhere, the SoCaltech section (especially Dr. E's book), the personal profiles, the Feynman memories, and on and on. Even the straightforward feature "Fictional Caltech" is more beautiful than its content might require: stunning layout and design, plus excellent fonts and text darkness.

I'm a physicist, not a designer, so I'm especially drawn to the content of the articles. However I must say that your design blows me away. Thanks for making the magazine appealing on so many levels!

Art Chester (PhD '65)

Feynman fandom

It was a magical time in 1965 on the Caltech campus when it was announced that Richard P. Feynman had won a Nobel Prize in Physics for his work on quantum electrodynamics. Professor Feynman was already a famous and well-respected figure around campus, and all the undergraduates started their Caltech experience with his Lectures on Physics. I was a lowly graduate student, and I would see him in the cafeteria and look at him in awe.

One of my hobbies was to draw Snoopy cartoons with my own little captions. (Apologies to Charles M. Schulz.) They had philosophical thoughts or comments, or just a joke. I would post these on the door to my dorm room in David X. Marks House.

The campus was abuzz about Feynman and his prize, so I did a cartoon where Snoopy is lying on his doghouse and thinking, "I would have won the Nobel Prize for quantum electrodynamics, but nobody could understand dog notation."

One of the physics grad students loved it and asked if he could have it to put on Feynman's office door. I said that I would make another for him, but being reticent about what kind of reaction Feynman would have, I decided not to sign it with my usual "Ryk" initials.

Off the cartoon went to be taped on Feynman's door. He loved it! He said that he would add it to his Nobel Prize scrapbook. And I was ever so regretful that I had not had the nerve to sign my artwork. I always sign my work now.

Ralph Y. Komai (MS '67)

Errata:

Hana Keller ("#SoCaltech," Summer 2018) is set to graduate from Caltech in 2019, making her a junior when the article was written, not a sophomore.

Robert Leighton died in 1997, not 1977 as stated in "Feynman at 100" in the Summer 2018 edition of the magazine. Thank you to Neil Sheeley (BS '60, PhD '65) for pointing out the error.

A team of artists represented campus and JPL at the Pasadena Chalk Festival, held in June at the city's Paseo Colorado (see story at right). Their artwork, titled *Out-of-This-World,* featured past, present, and future space missions including Juno, OCO-2, and Mars InSight. The paintbrush-wielding astronaut (above) is drawn in the style of Alan Bean, the late astronaut who was also an artist.

SoCaltech

Chalk One Up for Science

"I loved the idea of an art-and-science collaboration. My two worlds coming together!"

That was Sarah Flores's enthusiastic response to an invitation from the Pasadena Chalk Festival this past spring to work on a chalk mural with colleagues from the Caltech campus and from JPL, where Flores is a software engineer.

Flores—who, in addition to her scientific day job, has been a street painter for 15 years and took art classes in high school and college—is no stranger to the annual June chalk fest, having participated in it since 2010. But the idea for an art-and-science collaboration came from Tom Coston, president of the Light Bringer Project, the nonprofit art organization that runs the festival.

With the chalk mural, titled *Out-of-This-World,* Flores says she and Coston hoped to convey the idea that art and science are "both important, and it's exciting when they collaborate." Art, she adds, "can inspire the next generation to dream about what can be possible."

Putting together a team of artist-scientists was easy, Flores says. "Engineering and science, by nature, require a lot of creativity and problem solving. I'm not surprised that so many JPLers are also artists."

continued on page 6

For more SoCaltech, go to **magazine.caltech.edu/socaltech**

Irena Li and James Keane spent hours crouched on the concrete at the Paseo Colorado bringing life to their chalky solar system.

Chalk One Up for Science

continued from page 5

Irena Li, a mission operations systems engineer at the Lab who has a background in chalk art, signed up first, and introduced Flores to Caltech planetary science postdoc James Keane, who regularly turns his hand to science illustration. Keane's partner Aaron Rodriquez, a graphic designer, came on board as well, and the team was completed with Jamie Molaro, a JPL planetary scientist who advised on the design of the mural, and Eugenie Song, a JPL Mars operations engineer with arts training.

Starting out with a simple solar-system concept during the design phase, the group decided ultimately to showcase missions past, present, and future, including Juno, the Orbiting Carbon Observatory-2 (OCO-2), and Mars InSight. A late addition was the astronaut wielding a paintbrush, drawn in the style of Alan Bean—an Apollo 12 astronaut and the fourth person to walk on the moon—who passed away in May of this year. After retiring, Bean had pursued an interest in painting and become a full time artist.

As they set to work at the Paseo Colorado site, each member of the team focused on different elements. As they progressed in filling in the mural, says Li, "we referenced each other's work or asked to trade areas so it ended up being a blend of all our individual artistic styles. I had a lot of fun learning new chalk techniques from the rest of the team."

For Keane, working in chalk posed some unique challenges. "I usually use pen and pencil for my artwork, on nice, smooth paper," he says. "Sidewalk chalk is a lot messier and more physically demanding. You're on your knees for hours at a time, blending and breaking chalk into the rough concrete. I needed to ice my knees after each day of work. Also, the sheer size of the piece was daunting compared to my usual pen-and-paper sketches."

The effort was worth it, though, he says. As festival visitors strolled by, they stopped to ask questions about the planets and missions in the mural. "I hope they left with a sense of excitement for the work going on at Caltech and JPL, and for how beautiful the solar system is."

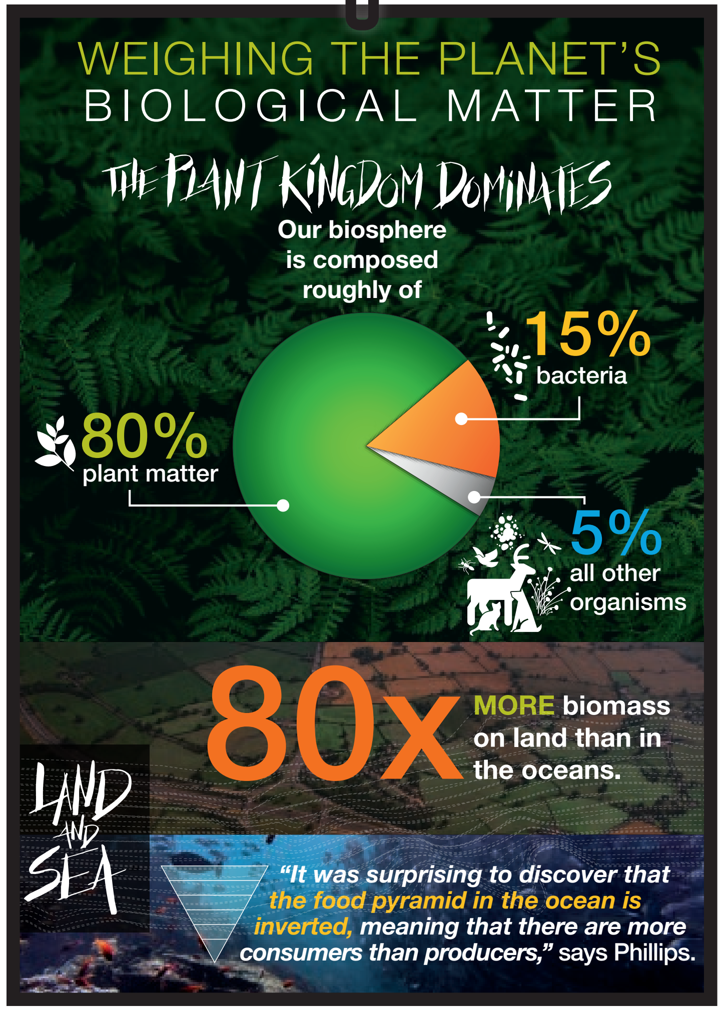
On a more practical note, says Keane, "the crowd was pretty good about not stepping on the artwork—except for the occasional rogue toddler or curious puppy."

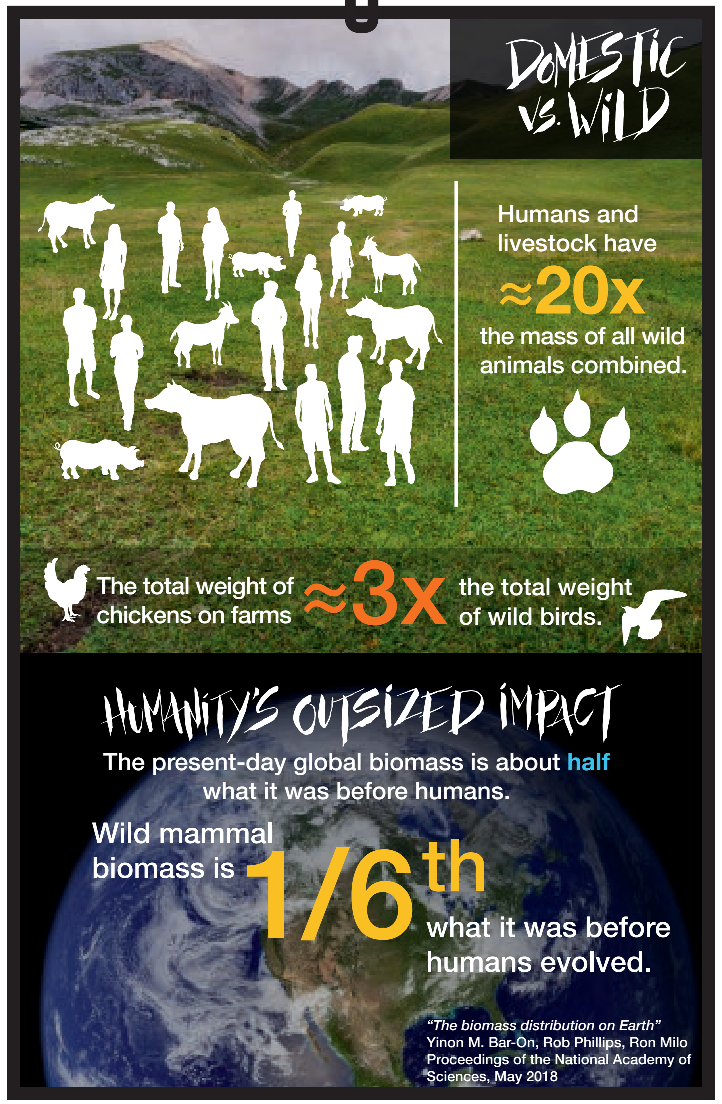
> **"I know each and every one of you are committed to science, to technology. I urge you also to study the way of peace. Study the way of love. Study the philosophy of nonviolence, the teaching of Gandhi and Thoreau. And help humanize that little planet, that little spaceship we call Earth. I say to you, as you leave this beautiful campus, go in peace. Be unafraid."**
>
> — *Representative* **John Lewis,** *Caltech Commencement 2018*

EARTH IN THE BALANCE

Just how much living matter is actually on this planet? A recent study—a collaboration between Yinon Bar-On and Ron Milo of the Weizmann Institute of Science in Israel and Rob Phillips of Caltech—tried to answer that question by making the first global estimates of the total weight, or biomass, of life on Earth.

"Understanding these numbers," says Phillips, the Fred and Nancy Morris Professor of Biophysics, Biology, and Physics at Caltech, "is crucial for understanding what I like to call the 'human experiment': How exactly are we shaping the planet?"





Four Questions for:
Hillary Mushkin

Now in her seventh year at Caltech, Hillary Mushkin is a research professor of art and design in mechanical and civil engineering. She teaches critical thinking about visual perception to future engineers and scientists.

1. What is the value of ensuring that scientists and engineers take art into account in their work?

First, to be clear, it's not art in the sense of aesthetics; I'm not talking about bringing a nicer-looking graphic design to people's posters. It really has more to do with critical thinking and thinking through ideas about perception. So, for example, researchers in Caltech's Data Visualization Summer Internship Program use perception and visual strategies to understand, interpret, and organize their data for themselves and for their colleagues. Along with the other program organizers, I collaborate with researchers and mentor interns so that they can create more effective interactive visual tools to answer questions about their data. What we offer is expertise in gleaning understanding about the world through visual practice.

2. It sounds like it's a question of communication.

That's right. And not just in public but also among themselves. I think when people talk about communication, usually it's outward, like, "How can I explain myself to the public?" But it doesn't take into account that researchers interpret their data, and they have to make sense of it for themselves and their colleagues before they make it public.

3. Does that have the potential to shift how they think about their projects?

Yes, absolutely. I've been teaching this class called New Media Art History and Projects. It focuses on artists who have been working with the new technology of their time. I go back to the turn of the last century to talk about Marcel Duchamp and the sculptures he called "Readymades." He selected factory-made objects and then displayed them in an art gallery. The first one was a urinal that he called *Fountain*. He talks about the artist as somebody who needs to have ideas, rather than skills, to do their craft.

As an artist working and collaborating with nonartists, I continually ask the question, "What is the role of the artist in society?" One role is to be a conceptual thinker, to be a provocative thinker, to be somebody who does not necessarily think with utility in mind but who thinks outside of that and can push the margins of how we expect things to function. I encourage scientists and engineers to think similarly. Creative thinking is often risky and impractical at first. It may, in the end, solve a problem, but it's not because you started off that way. Sometimes it was because you started off thinking in a much more blue-sky way. For example, "What kinds of ridiculous things can we do with this?" or "What kinds of possibilities are there for critiquing the way technologies are currently used in culture?"

4. How does the "maker" class that you started last year fit into your overall vision?

It's related to the new media arts class in that it asks questions about the role of the engineer or the technologist in society. The term "maker" is interdisciplinary; a maker can be a designer, a craftsperson, an engineer, or a scientist. The maker term, and the maker movement, is very broad and also fairly new. The class is looking closely at what science and engineering students can gain from maker culture and is also looking at the limitations of mainstream maker culture and how we can understand the relationship between technology and society more broadly.

MOONS, an exhibit currently on view at ArtCenter College of Design's Williamson Gallery, draws on both art and science to explore the lure of celestial bodies. Conceived in conjunction with Pasadena's City of Astronomy partnership—in which Caltech plays a leading role—the exhibition (on view through December 16, 2018, and curated by Williamson Gallery director Stephen Nowlin) includes contemporary artwork as well as artifacts from Mount Wilson Observatory, The Huntington Library, Art Collection, and Botanical Gardens, and the Caltech Archives, among other institutions. Pictured here is *Thumbsucker*, by locally based artist Tim Hawkinson, which features a moonscape created from lips and mouths alongside a floating thumb-astronaut.

Michaëlle Mayalu

Postdoctoral scholar

#SoCaltech is a social media series designed to celebrate the diverse individuals who give Caltech its spirit of excellence, ambition, and ingenuity. A postdoctoral scholar in computing and mathematical sciences, Michaëlle Mayalu arrived at Caltech in the fall of 2017 after a decade on the East Coast, during which she earned her bachelor's, master's, and PhD degrees at MIT. Hailing from Tucson, Arizona, Mayalu—who is a 2017–2018 AGEP scholar—is working on ways to use mathematics and control theory to model how genetically engineered cells execute new decision-making behaviors.*

One piece of advice I received about becoming a professor is that you want to be able to see how people learn from different viewpoints, different perspectives; to see how people teach, how problems are solved. Here at Caltech, at least in the lab of Richard Murray [control and dynamical systems and bioengineering professor], I've noticed there is more emphasis placed on doing research for discovery and scientific advancement than on doing research for publication. Instead of publishing right away you can think of alternatives to solve a problem and have maybe a more complete paper that might be potentially more impactful because you're getting different perspectives and ideas.

** The California Alliance for Graduate Education and the Professoriate (AGEP) was established to provide a path for underrepresented minority PhDs from California's top research institutions to aspire to and populate the ranks of the postdoctoral population, the faculty at competitive research and teaching institutions, the federally funded national laboratories, and scientific think tanks.*

For more #SoCaltech, go to magazine.caltech.edu/post/michaelle-mayalu

Modern **Math**

Since 1960, when Caltech's math department first took up residence in Sloan Laboratory, the physical space had remained essentially unaltered. So when Ronald (MS '62, PhD '64) and Maxine Linde endowed The Linde Center for New Initiatives at Caltech, renewing that historic structure was a top priority.

The new Ronald and Maxine Linde Hall of Mathematics and Physics includes spaces for both teamwork and quiet contemplation and—because the building will be home to more than 125 mathematicians—an abundance of blackboards throughout. Lest an eager scholar's chalkboard chatter become too vigorous, each board is backed with sound-absorbing material.

"The new Linde Hall will be transformative for our mathematics program," says Fiona Harrison, Benjamin M. Rosen Professor of Physics and Kent and Joyce Kresa Leadership Chair for the Division of Physics, Mathematics and Astronomy. "It will help us attract the best and brightest faculty, students, and postdocs, and will provide interactive space for collaboration."

Cosmic Craft

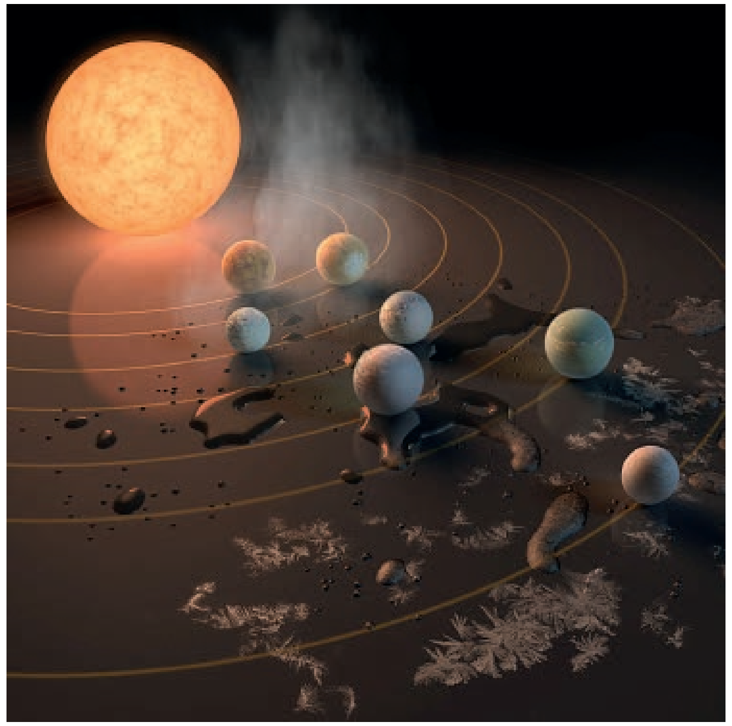
In June, some of the world's top space artists met on campus to exchange ideas at AstroViz 2018, a conference put together by IPAC, Caltech's science and data center for astronomy.

"The idea was to reestablish a community of practice for astro-visualization professionals," says Janice Lee, an astronomer at IPAC and an organizer of the event, which was facilitated by NASA's Universe of Learning education and outreach program.

Keynote speaker Rick Sternbach, an astronomical visualization expert who worked on Carl Sagan's 1980 TV series *Cosmos,* described how he and his group built models of the planets and then took pictures of them for the show. Around that same time, the Voyager mission started sending back stunning pictures of the planets, changing everything the group thought they knew. "Our special effects were being made obsolete every week," said Sternbach.

IPAC visualization scientist Robert Hurt says this still happens. "You do the best you can given the current data, and then, yes, sometimes you have to go back and change the artwork when more data are captured." Hurt and multimedia engineer Tim Pyle created artwork to illustrate the Spitzer TRAPPIST findings—information about the first known star system to host seven Earth-size planets. The pair had to redo all of their TRAPPIST artwork after Spitzer and other telescopes gathered more-precise data on the planets' compositions.

"The level of creativity and inspiration displayed at the conference was truly awesome," says Hurt. "From swapping ideas and techniques to showing off innovative ways that data can be heard or touched, we all have a lot of new tools in our arsenal for communicating the wonders of the universe."



In Robert Hurt's concept of the **TRAPPIST-1** system of exoplanets, the idea of a "habitable zone" is captured through water splashes that vaporize when too close to the star and freeze when too distant.

Watch videos of conference sessions at magazine.caltech.edu/astrovids

Introducing Bechtel

The Bechtel Residence—Caltech's first new student residence in more than two decades—is due to open its doors on September 23, 2018. Located on the north side of campus along Del Mar Boulevard, Bechtel adds 211 beds to campus housing; this means that, for the first time in Institute history, all undergraduates will be able to live on campus.

A landscaped central courtyard will allow students to make the most of the sunny SoCal climate, while study rooms throughout the building, along with larger community lounges and kitchens, round out the living experience.

All student rooms in the residence are singles, but most are configured to create suites for four, six, eight, or 12 undergrads. Each suite includes a lounge, refrigerator, and bathrooms, while the individual rooms boast—along with the requisite beds, dressers, desks, and chairs—polished-cement flooring and roll-up window shades as well as a thermostat.

70 Years (and Counting): At 70, Palomar Observatory's 48-inch Samuel Oschin Telescope is still in the prime of its life. One of the most productive survey telescopes ever built (construction started in 1938 and finished a decade later), it has completed a dozen sky surveys since the 1950s. After several upgrades over the years, the telescope now has wide-field imaging capabilities that can scan large regions of the sky to search for transients—objects that change apparent brightness and/or position—such as fast-moving solar system objects, variable or pulsating stars, flares, novae, supernovae, gamma-ray bursts, and other stellar explosions. Currently, the telescope operates robotically: its newest instrument, the Zwicky Transient Facility, scans the skies nightly and returns vast amounts of astronomical data.

Watch a video created for the telescope's anniversary at magazine.caltech.edu/post/palomar-vid

In the Community

Under the Stars

Essentially, it is a tent: 5 meters across, dark-blue canvas, dome shaped. What happens inside though, is truly cosmic. That is because this particular tent is an inflatable planetarium designed to bring the majesty of the solar system to children across L.A.

Conceived by Caltech research astronomer Jessie Christiansen along with Jeff Rich, outreach coordinator and astronomer at the Carnegie Observatories, this roving planetarium project came into being as a way to make astronomy more accessible to youngsters, especially those who might not be able to travel to a conventional planetarium. That's why the duo has focused on taking their star show to pediatric hospitals—two, so far, with hopes of adding more.

Christiansen says her own astronomical "aha" moment happened while gazing at the night skies as a child in rural Australia. "I didn't need a planetarium; I could just step outside and see the shooting stars and the nebulae." Being able to bring a similar sense of wonder to children here is rewarding, she says. "You get one kid to go 'Wow!' and you're like, 'Yes, that's why we're here.'"

To watch a video about the planetarium project, go to **magazine.caltech.edu/post/under-the-stars**

Origins

The Most Beautiful Experiment

Every life starts out as a single cell containing an entire genetic blueprint, or genome, in the form of DNA. That cell divides from one into two, and then from two into four, and so on, each new cell receiving a copy of the genome.

This process—how DNA replicates itself—was a topic of debate in the mid-1950s, including at Caltech. In 1958, two Caltech researchers conducted an experiment that definitively settled the question and, in the process, revolutionized the fields of biology and genetics.

This year marks the 60th anniversary of the publication of a paper describing the effort. "The Meselson-Stahl experiment has been called the most beautiful experiment in biology for the elegant logic of its deceptively simple design," says Judith Campbell, Caltech professor of chemistry and biology.

At the time, there were three leading theories for how DNA copies itself into new cells:

1. Conservative: The parent double-helix DNA is copied in its entirety, and the new cell's DNA is entirely a copy of the old.
2. Dispersive: DNA is chopped up into pieces; these little pieces are copied and then reassembled in combination with the old pieces.
3. Semiconservative: The double-stranded DNA separate from their helix shape, and each makes a copy of itself. The new cells then contain one strand from the parent cell and one newly synthesized strand.

Many scientists, including Caltech professor and soon-to-be Nobel Laureate Max Delbrück, did not believe the semiconservative model possible, because they reasoned that a tightly bound double-stranded helix of DNA should not be able to separate into its two constituent strands.

While working one summer at the Marine Biological Laboratory in Woods Hole, Massachusetts, Caltech graduate student Matthew Meselson met fellow visiting graduate student Franklin Stahl, who—as they tell it—was sitting underneath the shade of a tree, selling gin and tonics to passersby. The next year, when Stahl was at Caltech conducting postdoctoral research, they designed an experiment to discover how DNA replicates itself.

First, the researchers grew a strain of bacteria in an environment with a type of "heavy" nitrogen, ^{15}N, that contains an extra neutron. Since nitrogen is a key part of DNA, each bacterial cell now contained heavy DNA. When placed in a centrifuge—a device that spins and separates out molecules by their density—this DNA settled near the bottom.

Then, these cells were placed in an environment with light nitrogen, ^{14}N. After one generation of cell division, the new DNA was also placed in the centrifuge. Its density showed that it was composed of half heavy nitrogen and half light, ruling out the theory of conservative DNA replication, which would predict that the new DNA would have had to be copied in its entirety, using the light nitrogen in the cell's new environment.

As the cells continued to divide, the DNA of each generation was also centrifuged, each group getting progressively lighter than the last as more and more cells contained only light nitrogen. This proved definitively that the method of DNA replication is semiconservative: one strand of a new cell's DNA derives directly from the old and is used as a template to synthesize a complementary new strand.

Discovering exactly how DNA replicates revolutionized biology by explaining that genetic inheritance is based on separation of the two strands of the double helix and faithful copying of each strand, thus preserving genetic information from generation to generation.

Matthew Meselson, one of the pair of Caltech researchers who, in 1958, definitively settled how DNA replicates itself.

The experiment addressed a question that constituted a century-old roadblock to understanding how the structure of DNA led to its functions—inheritance, mutation, and information storage for protein synthesis. "While it was conceptually simple—simply distinguishing old from new—it was technically original and elegant, and more importantly it gave a clear answer," says Campbell. "Meselson and Stahl's findings also provided insight into how to experimentally trace genetic information, eventually even paving the way for whole-genome sequencing."

—Lori Dajose

Watch an animation at **magazine.caltech.edu/post/beautiful-experiment**

STUDIES OF

Montecito

First came the fire, then the rain, and, finally, the deadly debris flow.

by Robert Perkins

In the wake of the largest wildfire in California's history, the December 2017 Thomas Fire, a powerful storm that dumped about five inches of rain on the denuded hillsides of Santa Barbara County, triggered debris flows on January 9, 2018, that killed 21 people and destroyed hundreds of homes in the Montecito and San Ysidro Creek areas.

Seismologists at Caltech noticed that the rumble and roar of the debris flow was detected by a seismometer about 1.5 kilometers away from the worst of the damage. Significantly, they found that the seismogram generated by the event reveals information about debris-flow speed, the width of the flow and the size of boulders it carried, and the location of the event. These results suggest that the current generation of seismometers in the field could be used to provide an early warning of an incoming debris flow to residents in debris-flow-prone areas.

The research, which was published online in May in *Geophysical Research Letters,* shows that seismometer readings could potentially have offered some of the residents of Montecito between five and 10 minutes of warning on January 9. The work was led by Caltech's Victor Tsai (BS '04), professor of geophysics.

Tsai has long been interested in exploring what information can be gathered from seismometers. "The motion of the ground can indicate a lot of things, from the detonation of a warhead to the motion of a glacier. The trick is determining what the signal means," he says. As such, he had already started working on a model that predicted what a debris flow should look like on a seismometer based on existing models of sediment transported by water.

Graduate student Voon Hui Lai gathered data from the three seismometers located within a few kilometers of the debris flow to search for the signal predicted by Tsai's model. Due to proximity and technical issues, two of the seismometers did not robustly record the slide. The third, however, did. "It wasn't immediately obvious, but after a while, we found it," Lai says.

The signal, a rumbling lasting for nearly 20 minutes, showed up in the 5–10 hertz frequency band, which is at the lower threshold of human hearing. The team was able to determine that the signal was indeed the debris flow based on its timing and by ruling out other potential sources. It almost perfectly matched the predictions made by Tsai's model.

Tsai and Lai were further able to show how the signal could be used to estimate key elements of a debris flow (size, speed, and intensity) based on how they influence the shaking of the ground. The signal indicated that the debris flow "snout" (where the largest-sized boulders are) covered about a 50-meter-by-50-meter area; that the boulders carried by the flow reached up to around 1.3 meters in diameter; and that the flow speed was about 2.4 meters per second.

Now that they know what to look for and have a model for what the seismogram is indicating, scientists can use this to develop an early warning system based on existing seismometers, Tsai says. "Debris flows move much slower than earthquakes, so we could potentially develop an early warning system that would offer important warnings for residents and first responders," he says.

"Like earthquakes, debris flows occur infrequently and are dangerous to observe directly," adds co-author Michael Lamb, professor of geology. "By measuring ground shaking at a safe distance, our study shows that seismology has great potential to improve our understanding of when, where, and why debris flows happen."

In addition to Tsai, Lai, and Lamb, other co-authors of the study—"The Seismic Signature of Debris Flows: Flow Mechanics and Early Warnings at Montecito, California"—include Thomas Ulizio, laboratory manager and research assistant, and Alexander Beer, postdoctoral scholar in geology. Their research was supported by the National Science Foundation and the Swiss National Science Foundation. [C]

From Solid Propellants to Social Justice:

A Conversation with Alumnus Bill Hutchinson

When Congressman John Lewis visited Caltech last spring to speak at the Institute's 124th commencement exercises, the words of the renowned civil rights leader had special resonance for one audience member.

As a black man who had grown up in Birmingham, Alabama, Bill Hutchinson (MS '57, PhD '60) had a ringside seat as issues of racism and social justice played out in the middle decades of the last century, and he forged his own role in the struggle for housing rights and social justice.

Hutchinson was at Caltech at a time when there were few black students, all graduate students and all male. As he says, "Having 10 fingers, I never lost count of the total. I never had to use my toes!" Aiming for a life as an academic, he switched course when the space race opened up jobs previously inaccessible to black people. He spent his career in Southern California's aerospace industry—including three years at JPL—and settled in Altadena with his wife, LaVerne, and three daughters. Only his eldest, an ophthalmologist, followed him into the world of science, while his other two children opted for careers in the corporate arena. Two of his grandchildren currently study at Stanford.

Caltech *magazine met with Hutchinson, a widower for the past 23 years, to talk about learning from Linus Pauling, living in the Old Dorm, meeting Dr. Martin Luther King Jr., and what it was like to have a career he could not talk about.*

Caltech magazine [CM]: Do you visit campus often?

Bill Hutchinson [BH]: Well, as a matter of fact, I was down on campus this past Friday. My roommate from graduate school was in town, so I took him to lunch at the Athenaeum, and we sat around and talked with a couple of guys who were faculty members at Caltech; one of them is Steven Frautschi, who lives a couple of doors down the street. Steven and I have been neighbors for 40-odd years, and we're always down on the campus. We've been going to the free concerts at the Beckman Auditorium for 25 or 30 years. The music is good, and you can't beat the price!

CM: What drew you to science as a child?

BH: I grew up as the younger of two sons; my father was a physician and my mother was a teacher. They had met as college students in the 1920s, he at Morehouse College and she at Spelman College, both in Atlanta, Georgia. My dad remained a physician in Birmingham, Alabama, until his death in 1947, when I was 13.

As a kid, after my father's death, I enjoyed reading books from his office library. I assume that reflected my earliest scientific interests. I was also competitive with my brother as I followed him through school. Now deceased, he became a very successful cardiovascular and thoracic surgeon.

CM: Why did you come to Caltech to pursue your graduate studies?

BH: There were several reasons: I had earned my undergraduate degree in chemistry and mathematics from Morehouse in 1955, and my major professor there suggested I apply for a fellowship that he had seen published for graduate study at Caltech. I had been intrigued by the May 16, 1955, *Time* magazine cover story about Caltech's then-president Lee DuBridge, and I wanted to study where Linus Pauling, a recent Nobel Prize winner, taught. In the end, I was awarded the fellowship for which I had applied.

CM: Tell us about arriving at Caltech. Were there any surprises?

BH: It was the first time I'd ever flown on a plane. When I landed at the L.A. airport, I ended up catching a bus and transferring several times. Finally, I got to Pasadena—I think the bus let me out on the corner of California and Lake. So I walked over to campus with my suitcase, looking for the Old Dorm, where I was supposed to stay.

> "One day, I walked into a hardware store on Colorado Boulevard … and there's Linus Pauling buying some chains. … I don't know what possessed me, but I walked up to him and said, 'Hi, Dr. Pauling. I'm just wondering, why are you buying chains?'"

By that time, it was so late everything was closed. I was wandering around wondering where I would sleep. I was so tired I started looking at piles of leaves on the ground! I ran into a fellow who arranged for me to stay that night in the loggia [the upper-level outdoor sleeping porch] at the Athenaeum, which was quite an experience. It was a chilly night in September, but it was salvation to me. I eventually found out that the fellow was James Bonner, professor of biology.

One strange surprise was my discovery of the mountains above Pasadena one day after the smog cleared. I think this was after my second week in Pasadena. The smog was terrible back then. You'd go out in the afternoon and people were burning trash in their yards, and your eyes would tear up from the exhaust gases the cars were exuding.

CM: Who most influenced you at Caltech?

BH: I was impressed first by my fellow students. They were from all over! Living in the Old Dorm, it was like a United Nations. There were people from all over the world.

Once I began a research effort, my friendships and interactions centered around Jerry Vinograd, the professor who headed the group I worked in and with whom I developed a good relationship, and the others in the group. And of course, there was Linus Pauling, who had always impressed and influenced me.

CM: What was the subject of your PhD research?

BH: I identified which of the two polypeptide chains of the sickle cell hemoglobin molecule contains the amino acid substitution that leads to the clinical manifestations of sickle cell disease.

I had chosen to work on sickle cell anemia because I had a cousin who had the disease. In fact, I encouraged him to come to California just so I could have him around and he could be involved as I did the work. I used a lot of his red blood cells in my research, and by the time he got married, we had developed a test to determine whether or not a baby would develop sickle cell anemia at birth. His first child was the first person we ever did that test on.

CM: Was it intimidating to be in the presence of luminaries like Linus Pauling?

BH: I thought his feet hardly touched the ground when he walked! There's one funny story I can tell about Linus Pauling. This was after I completed the experimental work for my PhD and had begun to write my thesis. One day, I walked into a hardware store on Colorado Boulevard up from the campus, and there's Linus Pauling buying some chains. I recognized him, and I don't know what possessed me, but I walked up to him and said, "Hi, Dr. Pauling. I'm just wondering, why are you buying chains?" And he said, "Well, young man, some of my associates have done some very interesting work, and I'm going to use the chains to talk about it on cable television tonight." And I said, "Well, what work is that?" He proceeded to tell me about the work … and it turned out to be my PhD thesis work! I was so intimidated and fascinated by his explanation of my work that I never acknowledged that he was talking about my work.

CM: You were at Caltech when Dr. Martin Luther King Jr. visited campus in 1958. Do you have any memories of that visit?

BH: King earned his PhD from Boston University in 1955, the same year I completed my undergraduate work at Morehouse. While I was at Morehouse, the faculty would often discuss Morehouse alums like MLK [who had earned his bachelor's degree at the Atlanta college] who were studying for advanced degrees throughout the country as a way to inspire us to continue our studies. So, I was familiar with King before he became well known and visited Caltech.

After his public talk at Caltech, King met with a small group of students for an informal session; I was one of those students. I raised my hand and asked him, "When are you going to take your movement to Birmingham, Alabama?" I told him that, having grown up there, I was concerned about what Negroes were subjected to there. I told him about the blatant racism, rampant police brutality, and the bombing of the homes of blacks by racists. I added that the police took no actions to find and convict those responsible for the bombings. After hearing my plea, King said that he would take his movement to Birmingham "when the time was right." That time came in 1963. The Birmingham visit culminated in the bombing of the 16th Street Baptist Church on September 15, resulting in the killing of four girls attending Sunday school. That was my family's church. My grandfather was actually the superintendent of the Sunday school back in the '20s and the '30s. When my mother died in 1997, my brother and I donated our family home to the church.

Hutchinson was a guest at the luncheon held for Rep. John Lewis after the U.S. congressman's speech at Caltech's June 15, 2018, commencement.

CM: How did your career take off after your time at Caltech?

BH: I had thought that I'd get a PhD and go to teach at some college down south. The launching of Sputnik by Russia in 1957, and the ensuing space race, changed everything. Job opportunities until then unavailable to blacks suddenly appeared in the new aerospace industry. I worked in areas bearing little relation to the chemistry of my graduate studies. First, I took a job at Aerojet General in Azusa, California, developing solid propellants for the Polaris missile. Then I moved to JPL, where I studied the mechanical properties of polymers used as binders for solid propellants. From JPL, I went to McDonnell Douglas, where I studied and analyzed the effects of nuclear weapons on rocket propulsion systems and developed techniques to harden such systems to enable them to fly through a nuclear environment to deliver their payloads. After that, I went to the Rocketdyne division of Rockwell International in Canoga Park, California, to develop high-energy lasers for applications as weapons.

After my first two or three years in the industry, my work was pretty much all classified. I don't even know if I can talk about it now. There's nothing like doing something really interesting that you can't tell anybody about. We frequently ended up going to places that were very much off the beaten track. I often think how my wife would have been surprised if something had happened to me on one of those days and I had gotten injured. She'd have wondered, "What in the world is he doing there?" When I came home from work, I just never mentioned where I'd been. That's just one strange aspect of the work that I did.

CM: How have racism and discrimination affected you?

BH: My racially ambiguous appearance has often protected me from racial discrimination, though I have experienced overt racism when my race was realized. Because of that, I fought and won an important legal precedent against

When Dr. Martin Luther King Jr. visited Caltech in 1958, Hutchinson was among the students who met with the civil rights leader, though his meeting with King took place at the Caltech Y, with no photographers present.

discrimination in housing in the State of California shortly after graduate school.

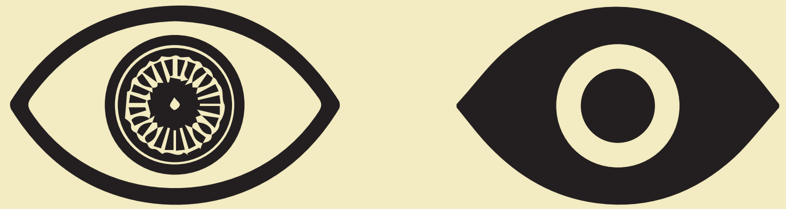
To shorten my commute to my first job in Azusa, I moved from Pasadena to an apartment in Monrovia. For a month, I lived there without a problem, until a friend—a fellow who had attended Morehouse with me—stopped by for a visit one evening. While he was there, the manager of the apartment building came to my apartment and told me that my next-door neighbor had seen a "n----r" enter my apartment and that he wanted my friend to leave. I told the manager that I saw no reason that my visitor should leave because he had done nothing to warrant his being asked to do so. The manager said that my neighbor had raised a question about my race. I then asked the question, "What if I'm a Negro?" to which he responded that I would have to leave.

I told the apartment manager that I would fight any effort to evict me. In the following weeks and months, I was harassed. My utilities were regularly cut off and tenants above my apartment would bang on the floor throughout the night to disturb my sleep. The managers would try any trick in the book to get me in some situation where I'd be compromised and they'd have good grounds for evicting me. After several months of my refusal to move, I was sued under California law in an unlawful detainer action [a legal procedure to evict someone from the place where they live]. The case was heard in the municipal court in Monrovia. I was allowed no defense against the eviction and the unlawful detainer, and was ordered to vacate the apartment.

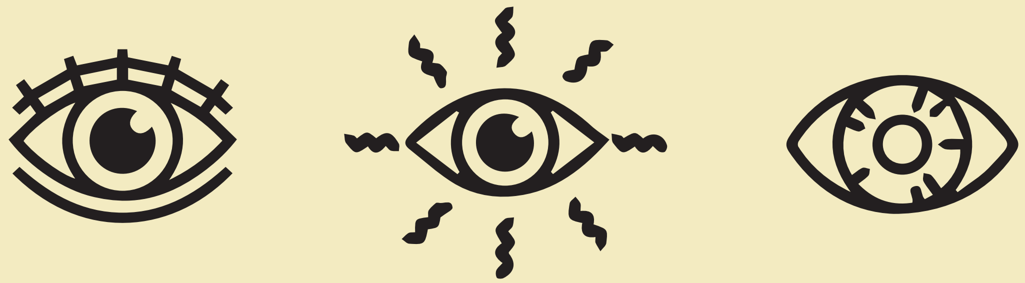
I appealed the eviction with the argument that the apartment owner had used the court system and the resources of the State of California to deny my right to equal protection under the law as accorded me by the 14th Amendment of the U.S. Constitution. For years before this ever happened, I had been talking with other fellows at the Morehouse Club in Los Angeles about strategies to fight housing discrimination, so I just happened to fall into a situation where I could actually do something about it. And I was always interested in law, having seen my parents strategize for years about what could be done about the racism in Birmingham. The appeal moved to higher appellate courts of California, where I won. My case, Abstract Investment Company v. Hutchinson, remains the controlling case in current housing litigation in California.

I continued to fight racism and discrimination over the years—coming along when I did before affirmative action, I often had to fight battles for myself and others. But to protect my family, I tried not to draw attention to those efforts. I'm not claiming heroics or anything like that, but as a black man I could get myself into trouble almost without even thinking about it. And I'd have to figure my way out of it. So, this was just my way of coping with the situation. [C]

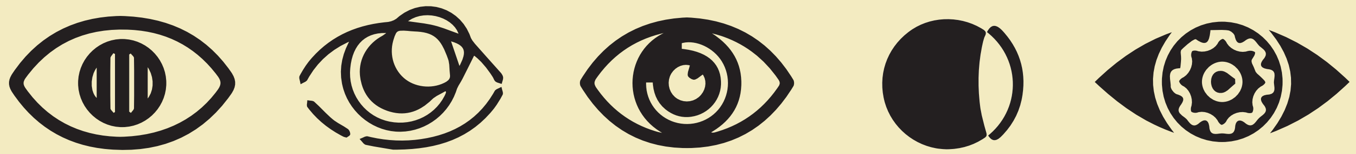
An eye on innovation



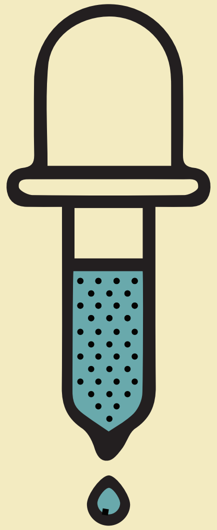
Caltech researchers are looking for



technological solutions to some of the most



common causes of blindness or vision impairment.



Though silent and usually painless, the onset of blindness is devastating. As the world slips away, blurs, or fades, the resulting loss of independence takes both an emotional and physical toll on an affected person's life.

For those facing the threat of blindness or whose vision is being compromised by age- or disease-related changes in their bodies, the promise of technologies that will prevent those changes or reduce that threat is about more than just a clear image. It is about being able to navigate through the world, relive the memories in a box of old photographs, or gaze upon a newborn grandchild.

Caltech scientists and engineers are working across disciplines—from biology to fluid dynamics, chemistry to electrical engineering—to develop technological solutions to vision-related issues that can affect the way in which the human eye takes in information and turns it into perception, into vision. They are considering the causes of blindness and their connection to common diseases. They are probing the eye's mechanics, optimizing treatments, and developing devices that can do what the eye itself no longer can.

Clearing the lens

Vision starts when light enters the eye through the cornea, the eye's outermost layer; the eye's colorful iris, the next structure the light encounters, then dilates the pupil to control the amount of light coming through. Next, the light passes through the eye's lens—a transparent, flexible membrane made of water and proteins. The lens focuses the light, allowing for a clear image to ultimately form.

At least, that is what the lens is meant to do.

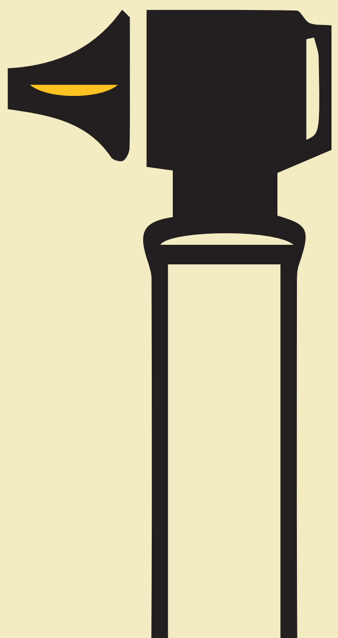
Cataracts are caused by proteins that clump together in an eye's lens; the lens becomes cloudy and vision becomes blurred. The good news is that surgery to replace cataract-clouded eye lenses with artificial lenses is both common and generally highly successful. In fact, it is one of the most frequently performed surgeries worldwide.

The less-good news? Traditionally, many patients have needed to wear glasses even after surgery, for a variety of reasons. It can be difficult, for instance, to predict exactly the shape an artificial lens will need to have in order to provide for perfect vision; also, implanted lenses can slip or shift subtly during the healing process, which will affect their ability to focus light.

That is why Caltech researchers and their colleagues created a new type of implantable intraocular lens that can actually be adjusted to a patient's eye and vision needs after surgery, ensuring that the patient ends up with 20/20 vision.

The idea for the lens started with UC San Francisco eye surgeon Daniel Schwartz, who was looking for a solution to these post-cataract-surgery vision problems. Schwartz looked to members of the Caltech faculty including Julie Kornfield, professor of chemical engineering, and Robert Grubbs, the Victor and Elizabeth Atkins Professor of Chemistry and a 2005 Nobel Prize winner in chemistry. Their collaboration ultimately led to the founding of a company that produces the adjustable lenses.

The lenses' ability to reshape themselves after implantation—and after enough time has passed that the eye has healed from the surgery—is made possible by molecules in the lens called macromers. (Macromers are the basic structural units that comprise polymers—the chemicals that make up plastics and other chemical compounds.) The macromers in these particular lenses were chosen because they will reshape themselves in predictable ways in response to beams of focused ultraviolet light. The lenses are so responsive to the UV light that each can be reshaped and refined until it produces the desired individualized visual results.



"The key thing we've learned out of this is that you need to have both doctors and scientists or engineers involved from the very beginning," says Grubbs. "Otherwise—if you're a scientist or an engineer—you may not have all the clinical information you need, and you'll solve the wrong problem. And if you're a clinician, you may not have the expertise and the resources to be able to do the science and prove your concept."

Lighting up the retina

Once they have been optimized, these newly unclouded, well-shaped lenses—like the lenses in the eyes of people without cataracts—send the now-focused light to the back of the eyeball. There it hits the retina, a thin layer of tissue containing millions of light-sensing nerve cells—the very nerve cells that are needed to convert light into electrical impulses for their journey to the brain.

Those nerve cells can be put at risk by a number of disease conditions, including diabetes. Hundreds of millions of people suffer from diabetes worldwide, and each of them may become susceptible to a type of creeping blindness, called diabetic retinopathy, that is associated with the disease in its more advanced stages.

High levels of glucose in the blood—like that caused by diabetes—is known to lead to damage to blood vessels; diabetic retinopathy is the consequence of such damage in the tiny blood vessels in the eye, which reduces blood flow and thus restricts the oxygen supply getting to the nerve cells in the retina, resulting in their eventual death.

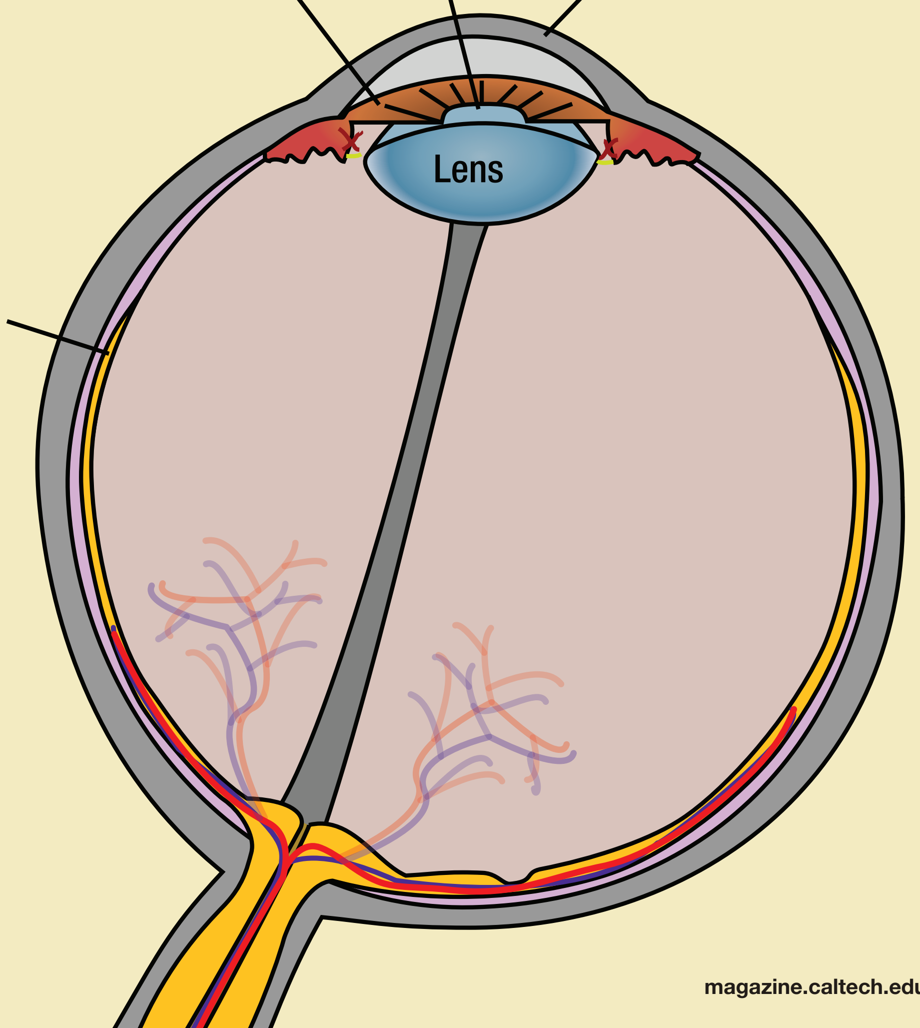
As the disease progresses, the body attempts to counteract the effects of the damaged blood vessels by growing new ones within the retina. But these vessels tend to develop imperfectly and often bleed into the clear fluid inside the eye, obscuring vision; the body then repairs the damage these bleeds can cause by building scar tissue on the retina, rather than new light-sensing cells. Over time, diabetic retinopathy leads to a patient's vision becoming blurry and patchy, before fading away completely. Existing treatments, though effective, are painful and invasive, involving lasers and injections into the eyeball.

Caltech graduate student Colin Cook (MS '16)—along with other researchers in the laboratory of Yu-Chong Tai, Caltech's Anna L. Rosen Professor of Electrical Engineering and Medical Engineering and holder of the Andrew and Peggy Cherng Medical Engineering Leadership Chair—has developed a much less invasive solution: a glow-in-the-dark contact lens.

The idea behind the lens is that if insufficient oxygen causes much of the retinal damage in diabetics, reducing the retina's oxygen demands should slow or stave off further eyesight loss. In laser treatments, for instance, burning away nerve cells in the peripheral parts of the retina allows the available oxygen to be used by the more important cells in the retina's center.

The new lens also reduces the metabolic demands of the retina, but it does so by concentrating on the retinal rod cells, the cells that allow us to see in low-light conditions. The less light the rod cells are exposed to—for instance, while we sleep—the harder they work and the more oxygen they need.

"Your rod cells, as it turns out, consume about twice as much oxygen in the dark as they do in the light," Cook says.



Glow-in-the-dark contact lenses, on the other hand, reduce the retina's nighttime oxygen demands by giving its rod cells the faintest amount of light to look at while the wearer sleeps. The illumination comes from tiny vials—the width of just a few human hairs—filled with tritium, a radioactive form of hydrogen gas that emits electrons as it decays. The electrons are then converted into light by a phosphorescent coating. The vials in the lens are laid out like the rays of a cartoon sun, creating a circle just big enough to fall outside of a wearer's view when their pupils constrict, as when exposed to sun or artificial light. In the dark, however, the pupils expand enough that the faint glow from the vials can illuminate the retina.

Early testing of the lenses conducted in collaboration with physicians at the University of Southern California shows promising results, with the lenses reducing rod-cell activity in the dark by as much as 90 percent. Next will come testing to see if the lenses' ability to reduce retinal metabolism will translate into the prevention of diabetic retinopathy. Says Tai: "This is an innovative solution with a potentially huge impact on diabetic retinopathy."

Reaching the macula

The retina's peripheral rods surround the nerve cells, called cones, that are concentrated in an area at the center of the retina called the macula. The macula is responsible for sharp central vision and detecting fine details. When the macula is damaged or begins to break down, as it does in a condition known as macular degeneration, vision disturbances and loss of vision can follow.

UCSF's Schwartz—who worked with Kornfield and Grubbs on the lens for use in cataract surgery—has also been concerned with finding a better way to treat macular degeneration. One such treatment involves the use of a medication that works to stop the growth of new blood vessels that causes most of the macular damage in what is known as the "wet" form of the disease.

The problem with this treatment, however, is that the medication does not always make it to the right spot in the right concentration to do the job well.

And so Schwartz contacted Caltech's Morteza Gharib, the Hans W. Liepmann Professor of Aeronautics and Bio-inspired Engineering, whose research focuses (in part, at least) on fluid dynamics. Since the eye itself is essentially a bag of fluid, Gharib thought he could discern what was stopping the medication from making its way to the macula.

"When we started to do experiments, we found that the movement of the fluid within the eye may actually prevent this medication from getting to where it needs to be," Gharib says. "There are certain flow loops in the eye due to the movement of the eyeball itself, and if you happen to inject the drug into a wrong position within these loops, the drug may stay in that loop and never get to the desired location."

The next step is for Gharib and Schwartz to create a way to avoid the vortexes during treatment, and then to test that concept. "Basically," Gharib says, "we're figuring out how and where to best inject the medicine."

Protecting the optic nerve

The connection between the eye's retina and the brain's vision center is the optic nerve. It is, in many ways, the last bridge that the incoming light—now an electrical impulse—must cross on its way to becoming a perceptible image.

Glaucoma can collapse that bridge. The second-most-common cause of blindness, after cataracts, glaucoma affects 65 million people worldwide. It is the result of fluid buildup in the eye putting pressure on the million or so nerve fibers that make up the optic nerve, ultimately damaging or destroying them.

For patients with glaucoma, knowing what their intraocular pressure is—and, especially, when it is elevated and for how long—can be essential when trying to preserve vision. That's why people with glaucoma make regular visits to an ophthalmologist, where a device called a tonometer is used to measure eye pressure. The problem is that eye pressure fluctuates throughout the day, and thus even regular office-visit measurements may not detect dangerous pressure spikes.

The need for even more precise tracking of the state of a glaucoma patient's eyes led to a collaboration between Yu-Chong Tai and Azita Emami, Caltech's Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering and a Heritage Medical Research Institute Investigator. The result: an implantable pressure sensor that can reside in the human eye for years at a time and wirelessly transmit data about that eye's health to a patient or their medical professionals.

"With our wireless implanted device, a patient could read their eye pressure any time," says graduate student Abhinav Agarwal (MS '14), co-author of a 2018 paper describing the implant. "Catching elevated eye pressure early would allow the doctor to modify the therapy if necessary to prevent further loss of vision."

The device is a little smaller than a dime and is implanted in a spot on the white of the eye where it will not interfere with vision. It consists of a pressure sensor, control circuitry, and an antenna. The implant has no battery, making it long lasting. During a reading, radio waves from a handheld scanner are received by the antenna and generate a small voltage that temporarily powers up the device, which takes a pressure reading and sends the signal back to the reader using the same antenna. By encapsulating their device in a specialized coating that consists of a silicone-oil bubble surrounded by a biocompatible polymer called parylene, the Caltech team projects that its device could last up to four years.

The device might even be modified to provide treatment by adding a valve that would release small amounts of the excess fluid as tears. "We would create a 'smart' glaucoma-drainage device in which a single implant could measure eye pressure and relieve excessive pressure," says graduate student Aubrey Shapero.

Their goal—like that of the other Caltech research groups that are focusing in on the eye—is to collaborate in human testing of their device within the next several years, and ultimately to get FDA approval for its use in patients. [C]

Mass Spectrometers

A Caltech History

Since the invention of the mass spectrograph nearly a century ago, scientists and engineers have worked to refine this versatile piece of instrumentation, and recent advancements in mass spectrometry have yielded new insights across and within a wide range of fields.

For example, the lab of John Eiler, Caltech's Robert P. Sharp Professor of Geology, has designed a prototype mass spectrometer, Thermo IRMS 253 Ultra, that allows researchers to determine the temperatures at which mineral samples from the distant past formed. The way rare isotopes bond with each other—or clump—depends on temperature, so measuring the clumping of specific isotopes provides a means of estimating the temperature of the environment in which a mineral was formed. With support from Caltech trustee Charlie Trimble (BS '63, MS '64) and a partnership with Thermo Fisher Scientific, Eiler and his team have determined that the temperature of early Mars would have been conducive to life, and that sauropods—the largest land animals to ever have lived on Earth—were not cold-blooded, as previously believed.

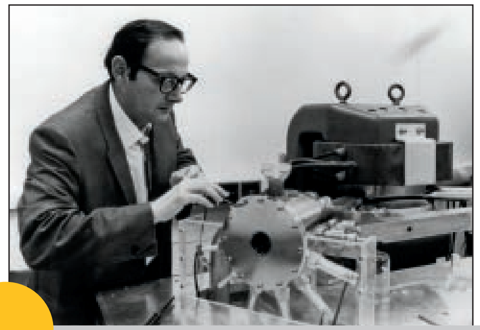
In another field, Michael Roukes, the Robert M. Abbey Professor of Physics, Applied Physics, and Bioengineering, is working on yet another iteration of mass spectrometry. Roukes and a team of researchers from France and from Caltech's Kavli Nanoscience Institute have created the first-ever mechanical device that can measure the mass of individual molecules, a development that may eventually help diagnose disease or measure air pollution.

1919

Francis Aston builds the first mass spectrograph, an apparatus that separates out charged ions.

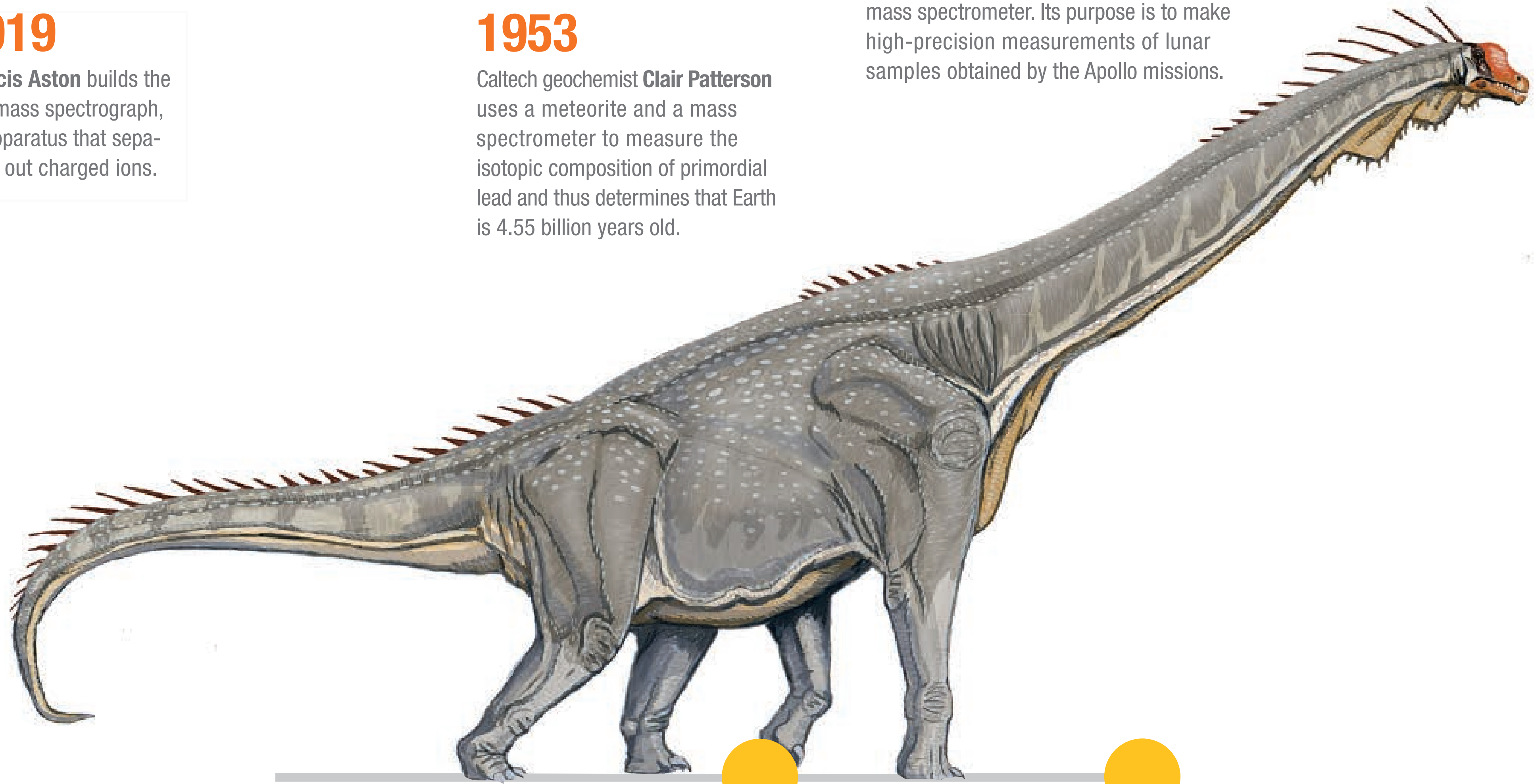
1953

Caltech geochemist **Clair Patterson** uses a meteorite and a mass spectrometer to measure the isotopic composition of primordial lead and thus determines that Earth is 4.55 billion years old.



1968

Caltech geologist **Gerald Wasserburg** completes **Lunatic I**, the first fully digital mass spectrometer. Its purpose is to make high-precision measurements of lunar samples obtained by the Apollo missions.



2011

Researchers in the lab of geochemist **John Eiler** design a prototype mass spectrometer that shows that sauropods were not cold-blooded.

2015

Physicist **Michael Roukes** and colleagues develop a nanodevice that can weigh a single molecule.

Robots in the Deep

By Giuliana Viglione

To find out more about Antarctic sea currents and their effect on climate, a Caltech grad student takes to the seas to drop two robotic gliders into the frigid depths of the Southern Ocean.

It's 62 degrees south, the temperature is hovering just below freezing, and the Research Vessel Laurence M. Gould is bobbing up and down on calm seas. On board, we anxiously huddle around our computers checking for vital signs from the robotic ocean glider that slipped beneath the waves 15 minutes ago. The Antarctic seas are notoriously fickle and a failure here means losing a $200,000 robot and wasting the past few months of work.

The glider surfaces and pings its hello to us via satellite, sending us scrambling to download and analyze the data so we can make small changes to the flight parameters of the glider before sending it back into the ocean depths.

Gliders are one of a multitude of new tools that scientists like me use to study some of the most remote places on the planet, including the frigid waters surrounding Antarctica, known as the Southern Ocean. Traditionally, ocean research has made its greatest leaps forward through enterprising scientists setting out on ships to make observations of the natural world. It can be lonely, isolating work—Fridtjhof Nansen famously froze his ship into ice for several years in an attempt to reach the North Pole—but technology like gliders means scientists can collect much more data with much less time spent actually aboard a ship.

Our mission on this journey is to seek out signatures of small-scale currents that we believe play an outsized role in affecting our climate. This particular trip involves 10 days at sea to deploy two robotic gliders, which will collect measurements of temperature, salinity, and oxygen for the next four months once we return to our safe, warm office in sunny Pasadena.

The Southern Ocean is one of the most vital regions of the planet when it comes to studying the ways in which ocean dynamics impact Earth's climate. Here, the other major ocean basins meet and mix together, transporting heat and carbon dioxide between them. In addition, the icy margins of Antarctica are some of the only places in the world where water can get dense enough to sink to the bottom of the ocean.

As a result, nearly 20 percent of the carbon dioxide humans release annually from burning fossil fuels gets taken up by the Southern Ocean before being transported to the ocean depths. The ocean has always played a vital role in maintaining the delicate balance of the carbon cycle, but this is a balance that is now being disturbed, and with unknown—and potentially disastrous—consequences.

Despite the unique properties of the region, there are comparatively few measurements in the Southern Ocean,

The Southern Ocean is one of the most vital regions of the planet when it comes to studying the ways in which ocean dynamics impact Earth's climate.

While *Star Trek* has taught us that space is the final frontier, there is plenty about our own plane—and our presence on it—that we don't yet understand. Our gliders are helping us discover what's going on at the far edges of the earth from the convenience of our own offices.

and when a storm rolls in and sets the ship pitching back and forth violently, it's not hard to see why. Scientists (and the crew that supports them) have to contend with biting winds, freezing temperatures, and the occasional storm so bad there is no choice but for the entire ship to hide behind an island and wait it out. With extremely limited time for each group on board to conduct its science, a particularly bad storm can spell disaster for a science mission that may have been years in the making.

On this particular trip, we have some good luck—the storm doesn't hit until both gliders are safely in the water and we can retreat toward the nearest island. After a day of hiding, the captain puts his head together with Professor Andy Thompson, my advisor, to devise a new plan for our remaining science days (observational oceanography, especially in the Southern Ocean, requires flexibility above all else). We set a course that skirts around the storm, and the remainder of the cruise is spent in relative relaxation as we complete our science and head back north.

Once we disembark in Punta Arenas, the southernmost city in Chile, however, we are snapped back into the realities of life on land. I've gotten used to the gentle rocking of the sea, the near-perpetual sunlight, the close quarters, and even the mushy vegetables (the salad bar ran out of "freshies" a few weeks in and it's been frozen vegetables ever since). While the longevity of the gliders in the water is a huge boon in terms of the amount of science we can do, it means the next four months will be spent carefully monitoring every dive to make sure nothing has gone wrong. We often joke that watching over the glider is like having a young child—when it's your turn to take care of it, you can't sleep for more than a few hours at a time before you have to check on it.

Four months later, with the gliders safely on the deck of the ship, the real work of analyzing the data and interpreting the results can commence. The sheer amount of data means we have three graduate students in my lab tackling different problems using the same information. Based on the temperature and salinity data in the upper few hundred meters of the ocean, I am trying to understand how small-scale currents (~1 km in width, which may not seem small to you but is tiny when compared to the vastness of the ocean!) can affect the depth to which the ocean here is well mixed (aptly known as the mixed layer). This layer is critical because this is where the ocean can actually take up the carbon dioxide from the atmosphere before exporting it into the deep ocean.

I've found that motions of this scale can occur very differently from one place to the next, even if the places are separated by only a few degrees of longitude. Between the two gliders, I observed mixed layers as small as tens of meters and as deep as 300 meters. This occurs on scales that are not resolved by the models we use to predict future climate, hampering their accuracy (although they remain our best tool for making projections about the future). My results can be used to help inform how we model these motions and hopefully will assist us in making better predictions of and better strategies for addressing future climate change.

Next up, we are pushing farther south with our gliders to explore an ocean current known as the Antarctic Slope Front that runs along the continent. We think it may be the key to understanding why some glaciers are melting faster than others—it can serve as a barrier preventing the transport of warm waters up toward the ice. While *Star Trek* has taught us that space is the final frontier, there is plenty about our own planet—and our presence on it—that we don't yet understand. Our gliders are helping us discover what's going on at the far edges of the earth from the convenience of our own offices.

Still, there's something special about being at sea. For all the advances that gliders and other robots have made over the past 15 years, nothing can quite compare to the feeling of waking up amid giant icebergs, or the first time you see a humpback whale breach the ocean surface. My first scientific cruise is what really solidified my love of the ocean—and I hope to be doing it for years to come. [C]

Giuliana Viglione is a graduate student working with environmental science and engineering professor Andrew Thompson. She studies physical oceanography using a variety of numerical and observational techniques, including underwater robots. This essay was first published in *Caltech Letters*, a new online publication (www.caltechletters.org) produced by Caltech graduate students that aims to help members of the Caltech community share their research and ideas about the intersection of science and the wider world as well as to nurture discussion among readers.

Mars's Tough Organic Molecules and Mysterious Methane

The Curiosity rover recently found new evidence preserved in rocks on Mars that suggests the planet could have supported ancient life as well as evidence in the Martian atmosphere that relates to the search for current life on the Red Planet. While not necessarily evidence of life itself, these findings are encouraging for future missions exploring the planet's surface and subsurface.

The new findings—"tough" organic molecules in 3-billion-year-old sedimentary rocks near the surface—appeared in two papers published in the June 8 edition of the journal *Science*.

Organic molecules contain carbon and hydrogen, and also may include oxygen, nitrogen, and other elements. While commonly associated with life, organic molecules can also be created by nonbiological processes and are not necessarily indicators of life.

This is not the first time that organic molecules have been found on the Red Planet. The Sample Analysis at Mars (SAM) instrument suite on Curiosity made the first definitive detection of organic molecules on Mars in 2013 at Gale Crater. This new detection finds larger and more complex molecules, and indicates organic carbon concentrations on the order of 10 parts per million or more, about 100 times greater than prior detections.

"With these new findings, Mars is telling us to stay the course and keep searching for evidence of life," says Thomas Zurbuchen, associate administrator for the Science Mission Directorate (SMD) at NASA Headquarters, in Washington.

Although the surface of Mars is inhospitable today, there is clear evidence that, in the distant past, the Martian climate allowed liquid water—an essential ingredient for life as we know it—to pool at the surface. Data from Curiosity reveal that billions of years ago, a water lake inside Gale Crater held all the ingredients necessary for life, including chemical building blocks and energy sources.

"The Martian surface is exposed to radiation from space. Both radiation and harsh chemicals break down organic matter," says Jen Eigenbrode of NASA's Goddard Space Flight Center in Greenbelt, Maryland, who is lead author of one of the two *Science* papers. "Finding ancient organic molecules in the top five centimeters of rock that was deposited when Mars may have been habitable bodes well for us to learn the story of organic molecules on Mars with future missions that will drill deeper."

In the second paper, scientists describe the discovery of seasonal variations in methane in the Martian atmosphere over the course of nearly three Mars years, which is almost six Earth years. This variation was also detected by the SAM instrument suite on Curiosity.

Water-rock chemistry might have generated the methane, but scientists cannot rule out the possibility of biological origins. Methane previously had been detected in Mars's atmosphere in large, unpredictable plumes. This new result shows that low levels of methane within Gale Crater repeatedly peak in warm summer months and drop in the winter.

These latest results give scientists confidence that NASA's Mars 2020 rover and the European Space Agency's ExoMars rover will find even more organics, both on the surface and in the shallow subsurface.

"There's always been a nagging concern that organic molecules might be destroyed by geological processes on Mars. But the fact that we're finding them still present in surface rocks makes it more likely that—if there is indeed a record of ancient life on Mars—it may have been preserved, and that we may be able to find and sample it," says Ken Farley, project scientist for Mars 2020 and W. M. Keck Foundation Professor of Geochemistry at Caltech.

Mars 2020 is the first part of a proposed campaign to collect, cache, and ultimately return samples of rocks from Mars.

"Are there signs of life on Mars?" asks Michael Meyer, lead scientist for NASA's Mars Exploration Program at NASA Headquarters. "We don't know, but these results tell us we are on the right track." C

The Jet Propulsion Laboratory, managed by Caltech for NASA, oversees the Mars Science Laboratory Project for NASA's SMD and built the project's Curiosity rover.

This self-portrait of NASA's Curiosity Mars rover (created by stitching two images together and removing the rover's arm) shows the vehicle at the site from which it reached down to drill into a rock target called "Buckskin" on lower Mount Sharp.

Making Sure...

by Emily Velasco

To test the integrity of the election process, Caltech political science professor Michael Alvarez started locally.

The hotly anticipated 2018 midterm elections are just around the corner, and when the flurry of Election Day activity dies down, it is likely, if the past is any indication, that countless questions will be raised about the integrity of the voting process.

Experts generally agree that voter fraud is almost nonexistent in the United States, but elections in recent years have been plagued by long lines at polling stations, polling places that were unexpectedly closed, glitchy voting machines, and recount after recount of disputed ballots. There have also been allegations of hacking by foreign powers, conspiracy theories about noncitizens being bused to polling places, and claims that the names of deceased people are being used to cast illegal votes.

Into that environment comes a new partnership between Caltech and Orange County that is offering the county's voters an unprecedented ability to assess the integrity of their own elections.

Beginning with the primaries in June, the partnership began collecting and analyzing massive amounts of election data to look for any sign of untoward activity. The project's organizers also made available an online election-integrity dashboard that presents users with statistics and analytics related to voter rolls, large-scale changes in voting behavior, and firsthand reports about problems and wait times at polling places.

The project is led by Michael Alvarez, a professor of political science at Caltech, and Neal Kelley, Orange County's registrar of voters. It is an outgrowth of research conducted by the Caltech/MIT Voting Technology Project, which was formed in the aftermath of the controversial 2000 presidential election with the aim of improving the voting process in the U.S. and abroad. Assistance with the project is coming from social science doctoral students Nick Adams-Cohen, Silvia Kim, and Yimeng Li, along with Caltech SURF student Spencer Schneider, a sophomore majoring in computer science and business, economics, and management.

"We're developing and applying a wide array of techniques that we've been studying since the origins of the Voting Technology Project," Alvarez says. "The idea is to determine which combination of these tools work well to help us understand the election process, and the goal is to scale up the tools to use across California and maybe the nation in 2020."

The project is making its debut at a time of increasingly strident partisan rancor over how elections throughout the country are conducted. Cases of double voting have been cited as evidence of widespread voter fraud, and officials have faced controversies over the location of polling places, the forms of ID that they require, and how they choose to remove voters from the voting rolls.

"Questions about the integrity of elections arise in periods of history when elections are close," Alvarez says. "We are now in one of those periods. I think everyone anticipates that this fall we are going to see a number of very close elections for the House and Senate."

Test bed OC

Many close elections, both national and local, are going to take place in Orange County, and that fact, along with Kelley's eagerness to be innovative, makes the county a good test bed for the project, Alvarez says. The June primaries worked as an excellent trial run.

"Things went very well," Alvarez says. "We were able to collect a great deal of really useful data, analyze that data quickly, and produce reports that went to the OC registrar."

Before the primaries, Alvarez predicted that they would not find any evidence of malfeasance during voting, and they did not. He was surprised, however, by how smoothly everything went across the county.

"To be honest, I expected to see that there might be more issues on Election Day," he says. "My experience in the past is that we often see lots of little problems arising that can inadvertently disenfranchise people. We saw none of that on Election Day. The fact that there were no serious problems was surprising in a really positive way."

Alvarez credits Kelley for that.

"I think what we saw largely has to do with the fact that Orange County has a truly fantastic registrar," Alvarez says. "He's very forward-looking, and he's put together a wonderful administrative team."

Kelley says he has been looking for a way to check the "health" of Orange County's elections systems for some time, and he is pleased to be partnering with Caltech.

"We will continue to look for ways to improve our services and how we conduct elections in Orange County," Kelley says. "There is no finish line to this process and Caltech's expertise—and third-party review—aids us in this endeavor."

The monitoring process

The project collected information about Orange County's voting system and elections in several ways:

- **Voter-registration analysis:** The team took periodic snapshots of voter-registration files and analyzed them to look for changes that could indicate that voters are being purged from the rolls or that multiple voters are being fraudulently added at single addresses.
- **Voter fraud:** The team ran a near real-time analysis of election returns in search of statistical anomalies that might be caused by administrative issues, procedural glitches, or fraud.
- **Social media:** The team looked at social media data in search of complaints from voters about problems such as excessively long lines at their polling place or absentee ballots that never showed up in the mail. They have developed a tool that collects tweets and classifies them according to geography, positive or negative sentiment, political orientation of the poster, and the nature of the problem the poster experienced.
- **Observers:** Caltech students were trained to serve as election observers, report problems, to look for and report unusual activity. They did this on Election Day and during early voting as well.

The data collected, along with analysis, was made available to the public through a dashboard hosted on the project's website, Monitoring the Election (www.monitoringtheelection.us).

Lessons learned

Alvarez says his team learned lessons during the June primaries that they are carrying forward with them to the upcoming midterms. One improvement includes streamlining and further automating their data-collection processes to help them develop their analyses more quickly.

Besides helping voters to be informed, the real goal of the project, Alvarez says, is to serve as an example of transparency for election officials across the country. He hopes that as they prove their system works, they will be able to expand it to other Southern California counties and eventually to other states.

For now, though, he is looking forward to the excitement he is expecting to see during the midterms.

"We're seeing nationally that there's a high level of voter engagement on both sides, and I think there is going to be a lot of interest and engagement by voters this fall," he says. "I think the congressional districts up for grabs in Orange County are going to continue to be some of the most competitive in the country." [C]

Funding for this project has been provided by the John Randolph Haynes and Dora Haynes Foundation.

"Questions about the integrity of elections arise in periods of history when elections are close. We are now in one of those periods."

—Michael Alvarez, *Caltech political science professor*

Revisiting Fictional Caltech

FURTHER TALES OF THE INSTITUTE

The magazine's recent article, "Fictional Caltech" (Summer 2018), which focused on novels that feature the Institute in some manner, elicited many responses from Caltech's community of readers. The article discussed 10 works of fiction, including such well-known titles as *The Hunt for Red October* and *The Martian*. Caltech-connected book sleuths dug up half a dozen more and explained the Institute's connection for each.

The Black Cloud

Fred Hoyle

(William Heinnemann Ltd., 1957)

DISCOVERED BY: Wayne Ryback (BS '65)

Yes, that Fred Hoyle. As far as I know, he was the only world-class cosmologist to write science fiction, and his work, though dated now, was pretty good stuff at the time. Caltech is a major setting for the early part of the story, and I always thought that the character of Dave Weichart was based on Richard Feynman.

Instantanés pour Caltech (Natacha #8)

Etienne Borgers, François Walthéry, and Jidéhem

(Dupuis, 1988)

DISCOVERED BY: Bard Cosman (P '14)

It may be obscure, but here's a piece of fiction with Caltech (rendered correctly) in the title! It's the 1981 Belgian comic book *Instantanés pour Caltech* (Snapshots for Caltech), number 8 in the series *Natacha, hôtesse de l'air* (Natasha the Stewardess) by Borgers, Walthéry, and Jidéhem. Originally published in French, it was reprinted in German, Norwegian, and Swedish, but unfortunately never in English. The Caltech connection? Our flight attendant heroine snaps photos of a supposed UFO during an oceanic flight and takes them to the Institute for interpretation. She soon finds herself in the midst of international intrigue, running for her life. Good European comic-book fare.

The Tea Girl of Hummingbird Lane

Lisa See

(Scribner, 2017)

DISCOVERED BY: Glen Herrmannsfeldt (BS '80)

Not to give away too much of the story, but one character is a Caltech biology professor in 1996. She is supposed to be smart, but that isn't an especially important part of the story. Her adopted daughter does go to Stanford, though.

I tend to like fictional stories where the characters feel real. (Or else completely fake, like *Star Wars* and *Harry Potter.*) In some stories, the characters have too much luck, such that it doesn't feel right. This one felt right to me.

Time Travel for Love and Profit

Jeff Abugov

(J-Stroke Productions, 2017)

DISCOVERED BY: Dave Zobel (BS '84)

A former screenwriter (*Roseanne, Cheers, Two and a Half Men*) turned novelist, Abugov wanted to get all the nuances of his novel's Caltech setting just right, so he not only toured campus twice but also got technical advice from an instructor, an alumnus, and director of admissions Jarrid Whitney.

Turns out there's more going on in that overlooked maintenance closet in the Sloan Annex than meets the eye.

The Treasure of the Sierra Madre

B. Traven

(Buchergilde Gutenberg, 1927)

DISCOVERED BY: David Lewin (BS '70)

I was rereading B. Traven's *The Treasure of the Sierra Madre* some time ago, when I noticed that the mining engineer who joins the three prospectors introduces himself as, so-and-so, "Tech, Pasadena." Since the book was written in the 1920s, I concluded that he was referring to Caltech.

Stopover: Tokyo

John P. Marquand

(Little, Brown and Company, 1957)

DISCOVERED BY: James E. Hanson (PhD '90)

A mention of a Caltech student that made me smile was in John P. Marquand's *Stopover: Tokyo* (reprinted in later editions as *Right You Are, Mr. Moto*), the last Mr. Moto book, from 1957. As the two American spies are preparing to head off to Tokyo for their mission, they meet by chance (or is it?) a young man. He is a "graduate of Cal. Tech," but is he also something more? Just a cameo but very nice. [C]

Endnotes

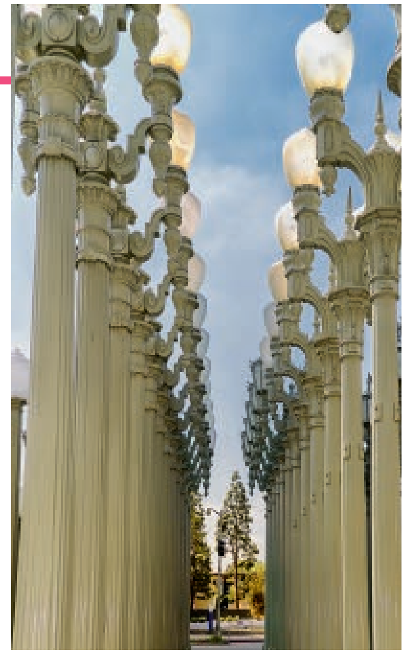
What should be on every Caltech senior's bucket list?

Nothing. They're too young to make bucket lists.

Michael Wilson (BS '77)
HINESBURG, VT

Get out of the bubble! Enjoy beach days, clubs on Sunset, movie palaces on Hollywood Blvd., neighborhoods like K-town and WeHo, art at LACMA, food trucks. You're in one of the world's great metro areas, explore it!

Deepi Brar (BS '92)
OAKLAND, CA



Work in a soup kitchen. The world's brightest young people should see and experience one of the world's most intractable problems.

Michael Udell (PhD '95)
ANNAPOLIS, MD

Take a goofy class. I took springboard diving and was the only one who signed up.

Amy (Peterson) Fisher (BS '01)
ROBBINSDALE, MN

Create a stack for Ditch Day. I thought I was too busy, so I skipped it, and it's a lifelong regret now. I wish I had given back to the community in honor of all those seniors who did dedicate the time to make sure we underclassmen had fun!

Anandi Raman Creath (BS '95)
EL DORADO HILLS, CA

Join the Flying Club and get your pilot's license for a fraction of what it would cost otherwise.

Cecilia Yu (BS '08)
SAN FRANCISCO, CA

Take an introductory class in an area that you haven't explored. As a biologist I took intro to geology and I still treasure that experience.

David Marvit (BS '84)
SAN FRANCISCO, CA

Have a conversation with at least one Nobel laureate.

Philip Neches (BS '73, MS '77, PhD '83)
NEW YORK, NY

Get a good night's sleep. ;)

Mason A. Porter (BS '98)
LOS ANGELES, CA

Connect with us

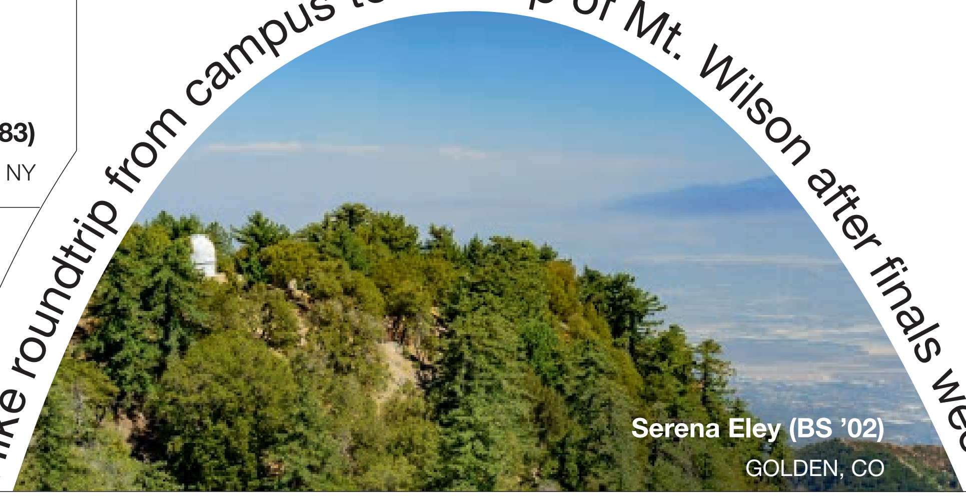
Join the conversation

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

And remember to get social:

For more Endnotes responses, go to **magazine.caltech.edu/post/endnotes-bucket-list**

Hike roundtrip from campus to the top of Mt. Wilson after finals week.



Serena Eley (BS '02)
GOLDEN, CO

Caltech
magazine

1200 East California Blvd., Pasadena, CA 91125

Birds of a feather: Inspired by the 2009 near-disaster in which a US Airways plane struck a flock of geese above the Hudson River shortly after takeoff, Caltech's Soon-Jo Chung, an associate professor of aerospace and Bren Scholar, decided to research ways to keep birds away from busy airspaces. Ultimately, Chung and his colleagues developed an algorithm that a single autonomous drone can use to herd an entire flock of birds away from an airport. The group—which includes postdoctoral scholar Kyunam Kim, pictured at right—is now exploring ways that multiple drones can guide multiple flocks to safety.

Find out more at
magazine.caltech.edu/post/birds-of-a-feather