Summer 2018

Caltech
magazine

Richard Feynman's 100th

ALSO:

Multitasking bacteria

Caltech in fiction

Jupiter's jet streams

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Explore Caltech's sci-fi library (video)

Stephen Hawking and Paul Rudd play quantum chess (video)

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Left: The geometric sculpture *PERCEPTION,* designed by trustee Ronald Linde (MS '62, PhD '64) and located adjacent to the Linde + Robinson Laboratory, contains numerous science-based allusions and illusions that can be perceived from different vantage points.

Letters

Mountains? What mountains?

Your latest *Caltech* magazine (Spring 2018) is really good.

My initial experience at Tech (1963, Fleming House) was roughly the same as Alvah Strickland's (MS '65). [See Strickland's Endnotes response about "discovering" a mountain in the backyard.] Nineteen sixty-three was at the height of the smog. I went out for freshman football (the coach then, Bert LaBrucherie, said he liked me because I was "small and slow," but that's another story). Coach said, during a workout, "Turn and face the mountains." Right, Coach. What mountains? We didn't know the San Gabriels were there!

Bob Parker (BS '67)

More Olympians

I enjoyed reading about Caltech's Olympians (magazine.caltech.edu/post/caltech-olympians). Another was Frank B. Jewett (BS '36), who finished ninth in sailing in the 1936 Games.

I had a close connection with two Caltech Olympians. Phil Conley (BS '56) was a teammate of mine in football, basketball, and track and field, and I can attest to his skills and competitiveness.

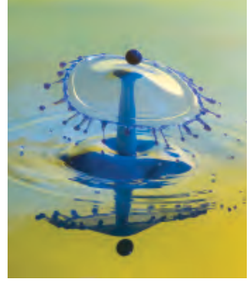
The other was Meredith Gourdine (PhD '60). In 1952, he won the silver medal in the long jump at the Summer Olympics in Helsinki. His lifetime best jump was 25' 9" at a time when the world record was Jesse Owens' 26' 8 1/4".

Meredith ("Flash") was a graduate student when I was an undergrad. He used to work out at the track at the same time as the track team, so I got to know him.

Dick Van Kirk (BS '58)

From the editors:

After receiving this letter, we added Meredith Gourdine to our lineup of Caltech Olympians on the magazine's website at magazine.caltech.edu/post/caltech-olympians.



Just a drop?

The photo on page 5 (SoCaltech opener, Spring 2018) is both beautiful and fascinating. But surely, we're not just looking at "a drop" of liquid. What, exactly, is happening in this photo? Please, add some explanation!

Peter Waser

From the editors:

Artist Ann Cutting offers this explanation: "The images are created by dropping timed and specifically sized drops into a shallow reservoir of water. The color is created with food dyes, and the viscosity is managed with guar gum added to the water. The camera shutter is open, and the drops are captured digitally by illuminating them with a synced high-speed strobe with a very short flash duration at low power to freeze the moment when drops collide. The second drop traveling downward collides with the first drop creating a Worthington jet heading upward."

Women in Sports

In the Spring 2018 edition of *Caltech*, the article "A season of firsts: Women's soccer takes the field at Caltech" states: "Fall 2017 marked the launch of Caltech's first-ever women's soccer program." This is an incorrect statement as in 1979-80 the first-ever Caltech women's soccer team [pictured at right] was formed.

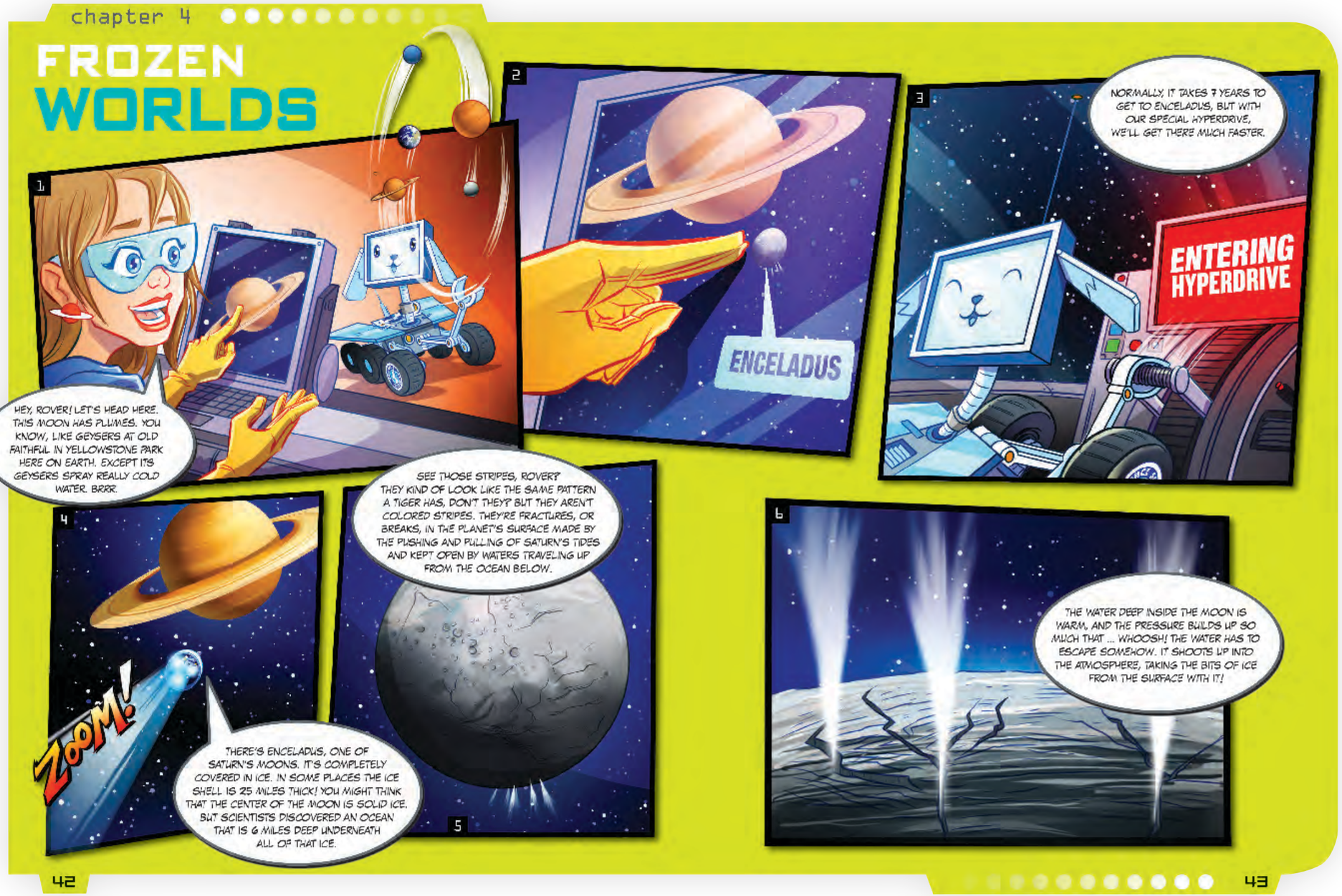
Gloria Badilla Jew (BS '83)
One of the original Caltech women's soccer players

From the editors:
To clarify, the article was referring to the first NCAA intercollegiate team. Caltech's athletics director, Betsy Mitchell, confirmed that the Institute has no records of intercollegiate play before the fall 2017 women's soccer team. Intercollegiate team play (AIAW or NCAA) requires the team members to be drawn only from registered undergraduate students.

Future Techer

From Twitter:

Justin Cohen (PhD '08)



SoCaltech

- Five Frankenstein facts
- What makes an animal?
- Cold War culture in Rome
- All signs point to the cosmos

Solar Science with Dr. E

Exploring Mars with rovers, designing better mission instruments, and researching asteroids keeps Bethany Ehlmann busy. Not too busy, though, to devote hundreds of evening and weekend hours to producing a children's book—*Dr. E's Super Stellar Solar System*—with National Geographic Children's Books.

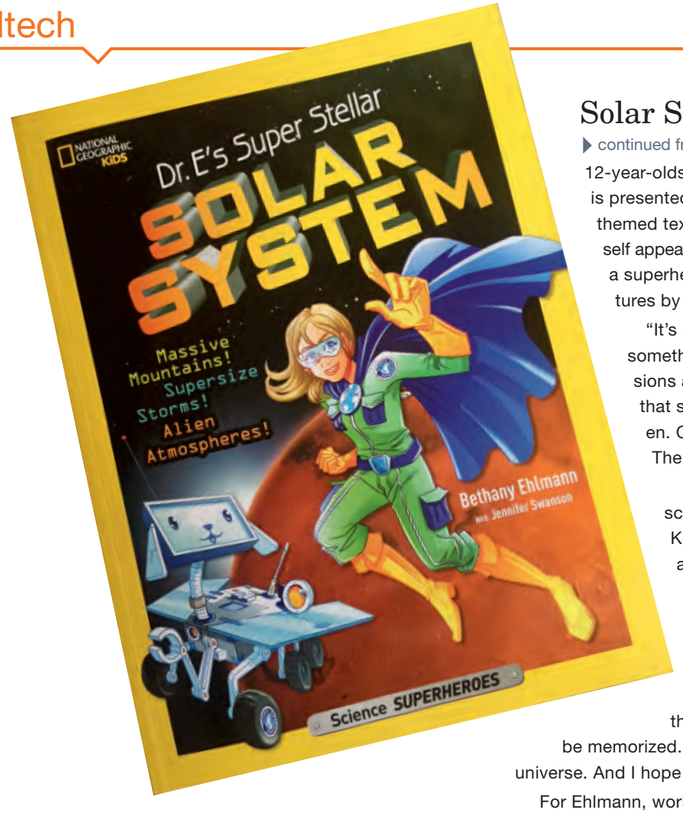
"Communicating what we do in planetary science is so important because it's some of the most inspiring scientific work there is," says Ehlmann, a professor of planetary science and a JPL research scientist. "We're pushing boundaries and learning things we never knew."

In the normal course of things, Ehlmann shares her knowledge of science through talks and lectures. The genesis of this recently published book came in 2013, when she was named an Emerging Explorer by the National Geographic Society, an accolade bestowed for outstanding work in the fields covered by the magazine.

Nat Geo asked Ehlmann to collaborate on a story-centered science book aimed at 8-to-

continued on page 6

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



Solar Science with Dr. E

continued from page 5

12-year-olds. To draw in its young audience, the content is presented in a variety of ways—through comic strips, themed text, activities, and scientist profiles. Ehlmann herself appears as "Dr. E," complete with infrared glasses and a superhero cape, and is accompanied on her adventures by a trusty robotic sidekick, Rover.

"It's not a single narrative," says Ehlmann. "It's something you can hop around in. Images from missions and infographics delve into all the processes that shape planets. Some parts are more story driven. Others offer activities that are more hands on. The idea is to appeal to different styles of learners."

For profiles, Ehlmann highlighted contemporary scientists—including Caltech's Mike Brown and Konstantin Batygin—rather than "the old tried and true" astronomers from the 1500s and 1600s like Copernicus and Galileo.

What does Ehlmann hope her young readers will take away? "A continued sense of curiosity and an awareness that it's in our power to learn still more about the mysteries out there. Science is not a collection of dry facts to be memorized. It's a dynamic means of understanding the universe. And I hope they learn that science is fun, too."

For Ehlmann, working on the publication has been eye-opening. "You can get really focused on being an expert on your own little part of the vast enterprise," she notes. "Sometimes you need to step back. There's nothing like having to explain to an 8-year-old to get you thinking of the big picture."

SURF's Up

Every summer, Caltech students have the opportunity to do research with experienced mentors working at the frontiers of their fields. This year, SURF (Summer Undergraduate Research Fellowships) participants are studying everything from **climate change** and **glacier dynamics in high-mountain Asia** to **the fabrication of flexible electrode arrays for artificial skin.**

SURFing this summer:

455 Student participants

197 Campus/JPL mentors

310 On-campus SURF projects

85 JPL-based projects

60 Off-campus SURF projects

Class Act:

The Human Animal

A new humanities class, offered this past winter at Caltech, took students on a literary, historical, and philosophical journey through ideas about what makes a human, what makes an animal, and what makes them different.

This 1853 engraving by French caricaturist J. J. Grandville depicts animals behaving as humans.

Required reading

Students enrolled in The Human Animal explored these questions through readings such as *The Dialogue of the Dogs*—a 17th-century novella from Spain in which two dogs converse about their masters, the ills of human society, and their own use of language—and fables by 17th-century French author Jean de La Fontaine, whose fictional creations include a community of frogs who, after begging the gods for a king, are cursed with a tyrannical and very hungry crane as a monarch.

Delving deeper

Topics for discussion included the question of animal "rationality"; early modern representations of the mentally and physically ill; and philosopher René Descartes' insistence that animals are little more than soulless machines.

Animal magnetism

"No one is neutral toward animals," says comparative-literature professor Jocelyn Holland, who conceived the idea for the class out of a desire to offer students a humanities course with broad appeal. "We have an affection for them, and we all have an idea of what they are like."

Holland also had her students read part of Jonathan Swift's *Gulliver's Travels,* in which Gulliver meets the Houyhnhnms, a race of intelligent horses with an advanced society, and the Yahoos, a race of human-like creatures with animalistic behaviors who are ruled by their Houyhnhnm overlords.

"We focus on a time period with big debates about the distinction between the human and the animal: whether they have souls, whether they can think and communicate, and whether we are responsible for treating them ethically," Holland says. "My goal is for the students to understand that an animal is a complex entity. There is nothing simple about the concept 'animal.'"

From the Caltech Archives Oral History Project

To date, the oral history project has published more than 160 interviews. Read them at **oralhistories.library.caltech.edu.**

"I was a nerd and studied physics and billiards—I did a lot of pool playing. I quit engineering as a goal, because I found out that physics majors and physicists could work on whatever they wanted."

– Jerry Pine, *Caltech professor of physics, emeritus (1928-2017)*

Six Questions for :

Melanie Masterton Sherazi

Melanie Masterton Sherazi has a fascination with Rome. Not the iconic Rome of the Trevi Fountain and the Colosseum. Rather, Sherazi's focus—and the theme of the book she is currently writing—is the literature, visual culture, and performance art produced by African Americans in Rome during the Cold War. Sherazi, the Howard E. and Susanne C. Jessen Postdoctoral Instructor in the Humanities at Caltech, became interested in this field of study through the work of the late African American expatriate author William Demby. Intrigued by Demby's work after reading his semiautobiographical experimental novel *The Catacombs* (1965), Sherazi went on to edit his final completed manuscript, *King Comus,* after his death in 2013. The novel was published by Ishmael Reed Publishing Company in 2017.

1. Why focus on Rome?

Though Paris and London are better known as magnets for American expatriates, my work argues for Rome's importance as an artistic hub where expat writers and artists collaborated with Italian artists and filmmakers, and were in direct conversation with the period's social movements.

2. What makes William Demby's work so important?

Demby innovated novelistic forms and styles, traveled internationally as a journalist in the postwar years to countries including Ethiopia and Japan, and collaborated in Rome with leading Italian filmmakers, including Rossellini and Fellini. Nevertheless, his groundbreaking work remains largely understudied in the United States, likely owing to his living abroad in Italy for more than 20 years.

3. How did you become interested in this field of study?

I had the pleasure of inventorying Demby's papers from Rome in his son's residence in Italy; this rich material opened onto a broader postwar cultural milieu that inspired my current book project.

4. You taught in the Los Angeles Unified School District for several years. What did you take away from that experience?

I had a wonderful experience teaching public high school English in LAUSD for eight years. My students brought a lot of humor and energy into the classroom, and I taught alongside many devoted colleagues who were passionate about public education. This experience gave me a long view of students' diverse learning styles and range of interests, which continues to inform my current approaches to teaching.

5. Why Caltech?

This postdoctoral instructorship gave me the opportunity to continue working on my current book and to design my own courses in a rigorous academic environment. I earned my degrees at the University of California, and Caltech is situated ideally in Southern California's vibrant research network.

6. What is it like to be at an institute primarily focused on science and technology?

I have found that the humanities are integrated seamlessly into Caltech's curriculum. My students have expanded my own ideas about literature with their original interpretations, driven by their interests and areas of expertise. For instance, a female student homed in on the fact that the young female protagonist of Carson McCullers' novel *The Member of the Wedding* (1946) planned to study radar in the future—a detail to which I had not paid particular attention. This student's insight guided our discussion in a new direction that complicated traditional readings of the novel's ending.

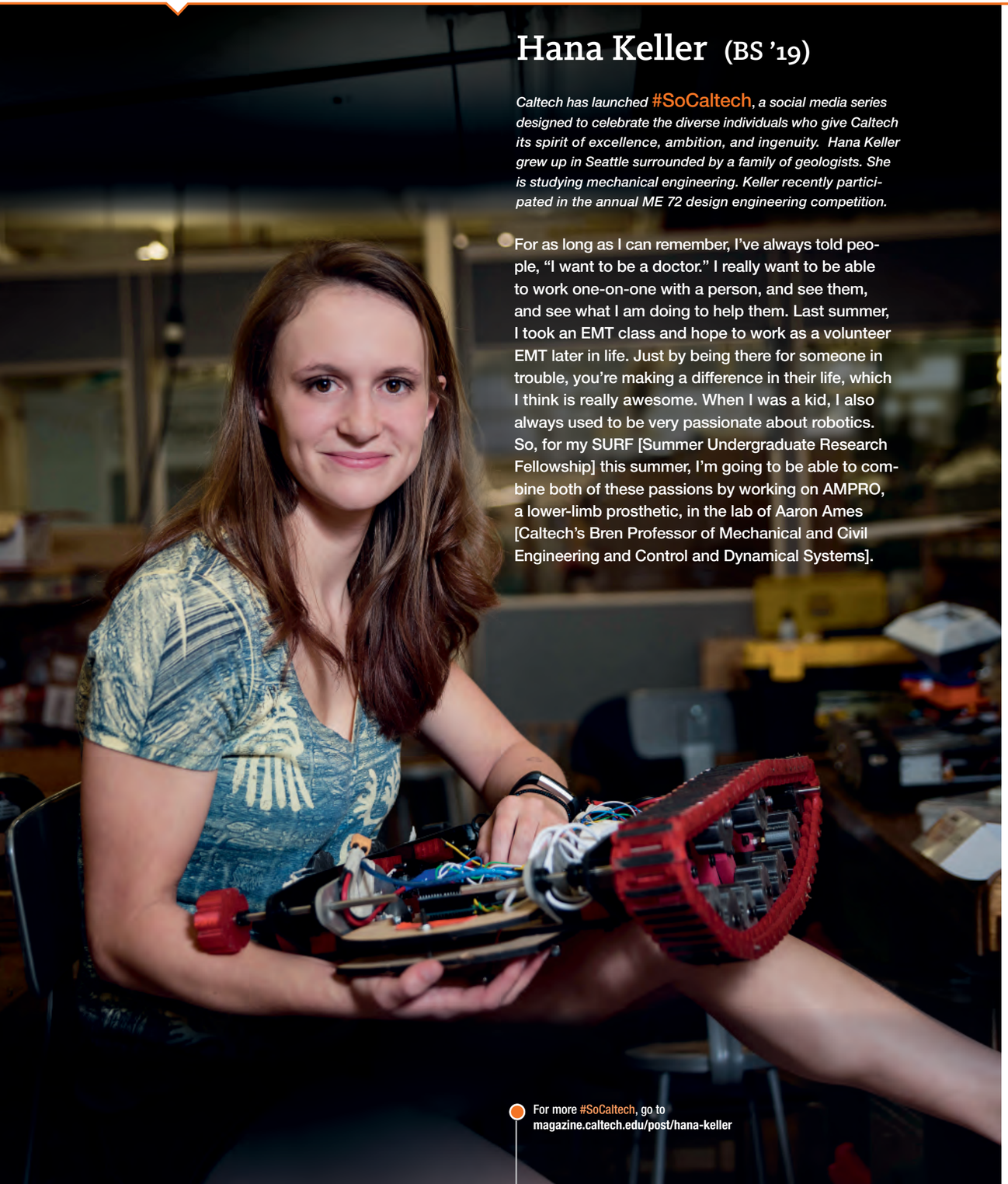
Object Lesson

Line of Sight

On a large and sprawling campus like JPL, signage is key to directing visitors from point A to point B. Hungry for lunch? Follow the signs to the Orbit Cafe. Interested in something a little more galactic? There's a sign for that, too.

Since December 2017, *Line of Sight*, a permanent art installation featuring three rotating signs erected on the JPL Mall, has oriented passersby to distant space missions' destinations, such as Uranus, Pluto, and Neptune.

Every 20 seconds, the signs' LED screens pivot in a new direction and change their displays as they receive real-time mission data on spacecraft and planet positions. A nearby sign reads: "Connect to the cosmos. Above your head, below your feet, and in any direction you point, lurks outer space. Hundreds of spacecraft orbit our tiny planet, and a few roam around other worlds." Lois Kim, the JPL visual strategist who created the concept for *Line of Sight,* worked with a team of engineers and data coders to translate her idea into reality. She says JPL employees are excited to see their missions on the signs, and she has added a few new ones at their request. For visitors, Kim hopes the signs will give a sense of the vast scope of the Lab's mission and work.



Hana Keller (BS '19)

Caltech has launched #SoCaltech, a social media series designed to celebrate the diverse individuals who give Caltech its spirit of excellence, ambition, and ingenuity. Hana Keller grew up in Seattle surrounded by a family of geologists. She is studying mechanical engineering. Keller recently participated in the annual ME 72 design engineering competition.

For as long as I can remember, I've always told people, "I want to be a doctor." I really want to be able to work one-on-one with a person, and see them, and see what I am doing to help them. Last summer, I took an EMT class and hope to work as a volunteer EMT later in life. Just by being there for someone in trouble, you're making a difference in their life, which I think is really awesome. When I was a kid, I also always used to be very passionate about robotics. So, for my SURF [Summer Undergraduate Research Fellowship] this summer, I'm going to be able to combine both of these passions by working on AMPRO, a lower-limb prosthetic, in the lab of Aaron Ames [Caltech's Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems].

For more #SoCaltech, go to magazine.caltech.edu/post/hana-keller

Five Facts About ...

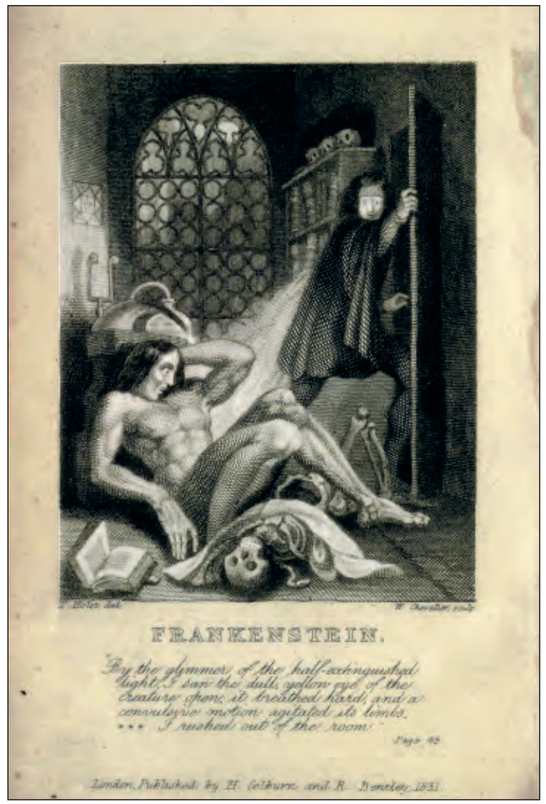
FRANKENSTEIN

With its themes of scientific ambition—and the moral questions it raises about scientific progress—*Frankenstein* is a quintessentially Caltech novel, says Kevin Gilmartin, dean of undergraduate students and professor of English.

"Caltech students do come to it as a novel that is very much about science and, in many ways, it is," Gilmartin says, "but it's also about a lot of other things, and it's always very exciting to present those other dimensions."

To mark the 200th anniversary of Mary Shelley's novel, Gilmartin joined scholars from the Keats-Shelley Association and the Byron Society of America in organizing "Frankenstein Then and Now, 1818-2018," a two-day conference held in May at The Huntington Library, Art Collections and Botanical Gardens. Supported in part by the Division of the Humanities and Social Sciences' Anne Rothenberg Fund for the Humanities, the conference explored *Frankenstein*'s enduring influence on art and culture.

"Mary Shelley's *Frankenstein* was engaged with developments in science and medicine," Gilmartin notes. "I find very intriguing the ways in which this novel continues to resonate with our own anxieties around the life sciences."



Above: promotional photo of Boris Karloff from *The Bride of Frankenstein*. Below left: inside cover art from the 1831 edition of *Frankenstein*.

FRANKEN FACTS

1. Mary Godwin Shelley, the daughter of feminist writer Mary Wollstonecraft and philosopher William Godwin, began writing *Frankenstein* in 1816, when she was **18 years old.** She and her future husband, the poet Percy Bysshe Shelley, were visiting Lord Byron at his villa on Lake Geneva in Switzerland when bad weather forced the party indoors and Byron proposed they each write a ghost story. *Frankenstein* was Mary Shelley's submission.

2. The first edition of the novel was **published anonymously.** Shelley's name was added to the second edition of the book, published in 1831, after she had revised it.

3. While the novel has inspired dozens of film adaptations, it is 1931's *Frankenstein*, directed by James Whale, that is responsible for perhaps the most abiding image of Frankenstein's monster: a **square-headed creature** with heavy eyelids and bolts in his neck.

4. The full title of Shelley's work is *Frankenstein; or, The Modern Prometheus,* and it is widely considered to be the **first science-fiction novel.**

5. The Huntington holds a **significant collection** of materials related to Mary and Percy Shelley, including notebooks and letters.

Commencement 2018:

Civil Rights Leader John Lewis to Speak

Those attending this spring's Commencement ceremony at Caltech will share Beckman Mall with a true hero of the civil rights movement. U.S. congressman John Lewis, who is slated to be the speaker at the June 15 event, is known as "the conscience of Congress" and has dedicated his life to protecting human rights and securing civil liberties, both through social movements and as an elected official.

He was the youngest of the Big Six leaders behind the 1963 March on Washington, the occasion of Martin Luther King Jr.'s "I Have a Dream" speech, and, two years later, at age 25, led more than 600 peaceful protestors across the Edmund Pettus Bridge in Selma, Alabama. State troopers attacked the demonstrators, a brutal confrontation that would later be recognized as a turning point in the movement and in American history.

"His example of intellectual courage matched by moral fortitude should inspire the class of 2018 as they take their next steps forward in life," Caltech president Thomas F. Rosenbaum said, noting that Lewis's visit comes in the same year in which Caltech observes the 60th anniversary of King's 1958 visit to campus. For more commencement coverage, visit commencement.caltech.edu.

"Los Angeles owes its existence to earthquakes. Its location, in the arid Southwest, could have left it an uninhabitable desert had it not been for the mountains that surround it, pushed up by active faults, capturing moisture from the clouds that come off the ocean. ... Faults may have made Los Angeles a viable city, but they are a precarious asset, and the risk of earthquakes is ever present."

—Seismologist Lucy Jones, research associate at Caltech

from The Big Ones: How Natural Disasters Have Shaped Us (and What We Can Do About Them)
Doubleday, 2018

When Aaron Ames, Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems, and Grecia Lopez, assistant research scientist in the Division of Geological and Planetary Sciences, tied the knot recently at the Athenaeum, they enlisted the help of one of Ames's colleagues—Cassie the bipedal robot—to serve the role of ringbearer. She didn't miss a step.

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In the Community

Sharing Science: Seismology, Solar Cells, and Space-Time

More than 2,000 science enthusiasts flocked to campus on Saturday, March 31, for the first Science for March, a celebration of science held on Beckman Mall and featuring more than 50 science activities, TED-style talks, and lectures.

Sponsored by the Caltech Postdoctoral Association; the Graduate Student Council; the Center for Teaching, Learning, & Outreach; and other campus affiliates, the inaugural event aimed to make science more accessible to the local community, especially students in grades K–12.

Dozens of booths offered visitors the chance to explore areas of science including seismology, microscopy, space exploration, and antibiotic resistance. At the CCI Solar (Center for Chemical Innovation in Solar Fuels) booth, kids and adults lined up to make solar cells using blackberry juice and other household materials. At another booth, LIGO staffers demonstrated a "fabric universe"—a spandex sheet stretched over a Hula-Hoop—to show how weighted balls placed on top stretch and deform spandex in the same way the gravity of massive objects warps space-time.

Tara Mastro, a postdoctoral scholar in biology and biological engineering and co-organizer of the event, says the day accomplished the goal of engaging the curiosity of visitors, adding that it was especially rewarding to hear "people in the community asking meaningful questions about the concepts we were presenting."

Science for March will be back next year, Mastro says, with "more talks and more booths."

—Jon Nalick

Origins

Subterranean Sci-Fi

The first time Walker Melton (BS '19) went looking for Caltech's science-fiction library, he found himself lost in the maze of underground corridors beneath Fleming House. Finally, he happened upon a nondescript gray door with a strip of paper tacked up that read "SPECTRE." Melton, a junior majoring in physics and the brand-new leader of Caltech's science-fiction club, opened the door onto a treasure trove he had heard about before even applying to Caltech and was now charged with bringing back to life.

Back in the '90s, this subterranean room—filled with around 12,000 volumes lined up on 52 blond wood bookshelves in a snug, windowless space furnished with a couch, a trio of armchairs, and a round "wizard" table—was a popular destination for the student population. From 1987 until 2002, a student club called SPECTRE ran the operation from a room in the Student Activities Center, loaning out books and playing movies in the screening room next door.

As far as Melton knows, SPECTRE owes its name to the organization that was James Bond's ultimate nemesis, but he says others believe it may have stood for "speculative treasures." As he and club co-leader Rita Aksenfeld (BS '20) begin the task of resurrecting the club, they have opted to clarify matters, calling it simply the Science Fiction and Fantasy Club. They were encouraged to tackle the rebuilding of the library by administrators in Parsons-Gates who lamented the demise of the original club. The students' goals for the library, Melton says, are to revamp the cataloguing system, make the space a fully functioning library once more, and start acquiring new books.

"It would be fun to work on expanding the collection," he says, "since a lot of good sci-fi books have come out in the last three to 10 years. It's generally a pretty good collection, but there's still room for more."

Highlights of the current collection include signed editions of George R. R. Martin's *A Song of Ice and Fire* (later immortalized on- screen as *Game of Thrones*) and Robert Zubrin's *The Case for Mars: The Plan to Settle the Red Planet and Why We Must* (inscribed "Let's make this happen!"); an event flyer for a talk by the late science- fiction writer and Pasadena resident Octavia Butler; impressive collections of Isaac Asimov and Arthur C. Clarke; many of Robert Heinlein's works, including *Stranger in a Strange Land;* and Star Trek figurines by the dozens. The library also houses filing cabinets and shelves filled to capacity with short stories, comic books, and magazines.

Melton and Aksenfeld, with the help of Caltech's Information Management Systems & Services, hope to have the collection fully catalogued by late spring.

"SPECTRE is a remarkable example of undergraduate book collecting," says Vice President for Strategy Implementation Diana Jergovic. "It was a pleasure for our group to help reinstate this vibrant legacy assembled by past generations. Our hope is that students once again enjoy the books, movies, and special gathering space."

A May 19 open house during Reunion Weekend celebrated the relaunch of the science-fiction library.

—Judy Hill

Take a video tour of the library at **magazine.caltech.edu/post/sci-fi**

Feynman at 100

In his years at Caltech, Richard Feynman—theoretical physicist, Nobel laureate, famed lecturer, bongo player—made an outsized impression on all who came into contact with him. Here, a hundred years after his birth, is a selection of reflections on the multifaceted scientific genius from his Institute colleagues and friends, many drawn from the Caltech Archives Oral History Project.

Feynman *the thinker*

Feynman played a very key role [in understanding the collapse of supermassive stellar objects]. He bumped into me one day, and he says, "Willy, you know those supermassive objects that you and Fred have been working on are unstable. They'll collapse, due to general relativity." ... So, he actually then gave a lecture in one of his classes and Icko Iben, who was a postdoc with me at the time, was attending Dick's classes. Icko immediately began making numerical solutions of the problems, using the Caltech computer, and convinced me that Dick was right. I began to put general relativity in, but only in terms of the next approximation after Newton, and found right away that Dick was right, that the damn things would collapse.

William A. Fowler (1911-1995), Professor of Physics; Nobel Laureate

You know how Richard Feynman was once recruited by the University of Chicago, which offered to double his salary or something like that. He was asked, "Why wouldn't you leave Caltech and take this offer?" and I think—to paraphrase—he said, "At Caltech, if I moved a meter or two, I would be in collision with somebody who will excite my interest."

Ahmed Zewail (1946-2016), Linus Pauling Professor of Chemistry and Professor of Physics; Nobel Laureate

In his own words

The first principle is that you must not fool yourself—and you are the easiest person to fool. So, you have to be very careful about that. After you've not fooled yourself, it's easy not to fool other scientists. You just have to be honest in a conventional way after that.

Richard Feynman, 1974 Caltech Commencement Address

Feynman *the teacher*

He showed up in his informal outfit, and I remember that 3,000 kids sat outside on this big grassy knoll around the science center. ... He talked for about 40 minutes, and they were fascinated. They didn't move. They were all looking at him. Gee, whiz. He had a way.

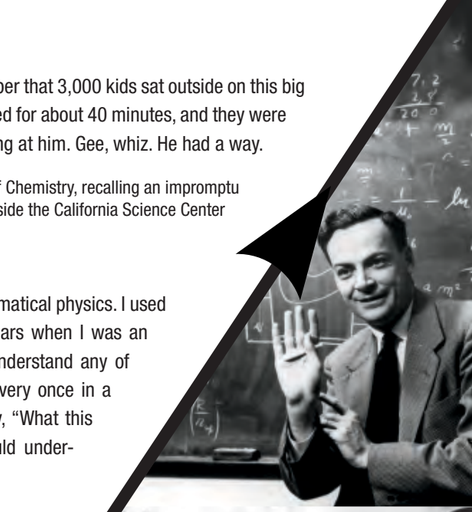
Harry Gray, Arnold O. Beckman Professor of Chemistry, recalling an impromptu talk by Feynman outside the California Science Center

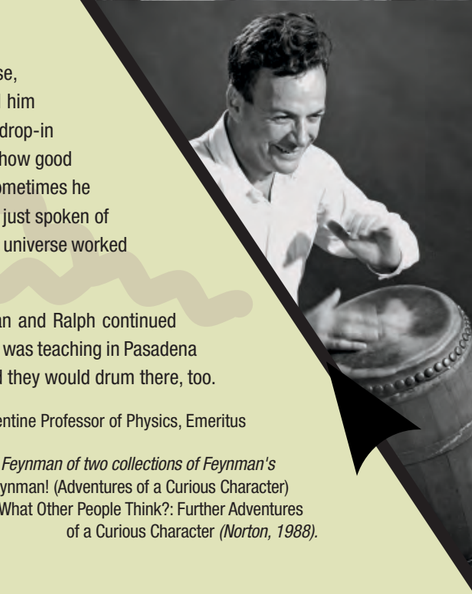
Once I asked him to explain to me, so that I could understand it, why spin-1/2 particles obey Fermi-Dirac statistics. Gauging his audience perfectly, he said, "I'll prepare a freshman lecture on it." But a few days later he came to me and said: "You know, I couldn't do it. I couldn't reduce it to the freshman level. That means we really don't understand it."

David L. Goodstein, Frank J. Gilloon Distinguished Teaching and Service Professor, Emeritus; Professor of Physics and Applied Physics, Emeritus; *Physics Today,* February 1989

I had Dick Feynman for mathematical physics. I used to go around to all his seminars when I was an undergrad, even. I couldn't understand any of the mathematics at all, but every once in a while, he'd stop and he'd say, "What this really means is...," and I could understand that.

Carver Mead, Gordon and Betty Moore Professor of Engineering and Applied Science, Emeritus





Feynman *the percussionist*

Feynman heard [my son] Ralph and his friends drumming at the other end of the house and, of course, he went in—he was more comfortable with kids anyway. He introduced himself and they invited him in to drum. And that led to rather regular drumming by Feynman, my son, and a couple of other drop-in friends. I myself was curious about Feynman's drumming ability, so I asked Ralph one time, "Well, how good a drummer is Feynman?" He said, "Well, he picks up the rhythms all right, and he's very fast but sometimes he has a hard time getting started. But for an old guy, he's pretty good." I informed Ralph that he had just spoken of the capabilities of possibly the one person in the world who knew more about how everything in the universe worked than anyone else on Earth at that moment.

Anyway, Ralph's other musical friends gradually went off to college here and there, but Feynman and Ralph continued drumming together. The Feynmans would invite Ralph over to their home in Altadena quite often. He was teaching in Pasadena schools at the time. Sometime during this period the Feynmans bought a beach house in Baja, and they would drum there, too.

Robert Leighton (1919-1977), William L. Valentine Professor of Physics, Emeritus

Ralph Leighton is the co-author with Feynman of two collections of Feynman's reminiscences: Surely You're Joking, Mr. Feynman! (Adventures of a Curious Character) *(Norton, 1985), and* What Do You Care What Other People Think?: Further Adventures of a Curious Character *(Norton, 1988).*

Read more Feynman reminiscences at **magazine.caltech.edu/post/feynman-at-100**

Bacterial BUILDERS

Frances Arnold is directing bacteria to build molecules never before assembled in nature.

by Emily Velasco

Chemistry is on the verge of a bacterial revolution. Fast-forward into the future, and you might find that the polyester in a Hawaiian shirt, the rubber in a new set of tires, or even Grandma's blood pressure medication was made in much the same way beer is brewed: by harnessing the powers of the tiny unicellular organisms that are ubiquitous in our world.

Sound far-fetched? The yeast that have been used to make beer for hundreds of thousands of years, as well as some even smaller bacteria, are already being co-opted to create materials like spider silk, biodegradable plastics, vitamins, insulin, and human growth hormone. Scientists perform such transformations by pulling the genetic material out of another organism—a spider, for example—and inserting it, with a few edits and additions, into a microorganism. When the modified organisms return to their normal microbial business, they will also churn out what their new DNA tells them.

While effective, the method works only if a living creature already exists with DNA encoded for the desired product and if the DNA can be appropriately modified to be read by the microbes. But what are scientists to do if they want bacteria to make something that is not already a natural, organic, preexisting compound?

They give evolution a little nudge.

One way to do that is through a process familiar to breeders of all sorts of domesticated animals. When ancient humans wanted wolves as hunting companions, for instance, they picked the friendliest wolf cubs and kept breeding them and their friendliest offspring until they arrived at man's best friend, in all its different forms.

The difference is that today when researchers want new breeds of bacteria, they can deliberately tweak the genes directly instead of just waiting for useful mutations to arrive by accident. It is a process known as directed evolution, first developed by Caltech chemical engineer Frances Arnold in the early 1990s. In the years since, she and her colleagues have created genes that encode not just better versions of enzymes that already exist but genes that compel the organisms to perform a variety of chemical feats never before seen in nature.

"You mutate a gene, see which progeny have the properties that you want, pick the one or ones that you like, and repeat the process," says Arnold. "You keep doing it over and over again until they do what you want them to. The great thing about bacteria is that you can do this very quickly because bacteria reproduce rapidly. A generation can be as short as a few days, sometimes even shorter."

In 2016, Arnold and her group announced that they had used directed evolution to create enzymes that enable bacteria to bond silicon atoms to carbon atoms. Though silicon-carbon bonds are common in synthetic materials (think silicone caulk), such bonds in organic materials had previously only been created by chemists.

"No living organism is known to put silicon-carbon bonds together, even though silicon is so abundant, all around us, in rocks and all over the beach," says Jennifer Kan, a postdoctoral scholar in Arnold's lab and the lead author on the paper describing the advance.

To create this new capability, they started with a gene from a bacterium that lives in Icelandic hot springs; Kan discovered that this bacterium already produced a protein that could bond silicon to carbon under certain laboratory conditions, albeit not particularly well. Their new enzyme—a common protein called cytochrome c—was then shaped by the researchers through directed evolution to produce an efficient enzyme dedicated to making new silicon-carbon bonds. Within three generations, they had a bacterial enzyme that was 15 times more efficient at combining silicon and carbon than the very best chemist-created catalysts for the same reaction.

"This iron-based, genetically encoded catalyst is nontoxic, cheaper, and easier to modify compared to other catalysts used in chemical synthesis," says Kan. "The new reaction can also be done at room temperature and in water."

A year later, Arnold's team announced another creation: bacteria that could form carbon-boron bonds. This, too, was a first for a living creature; no organism in its native state is known to make bonds between boron and carbon. They started with the same gene for cytochrome c from the Icelandic bacteria they had used before but pushed it in a different direction. This time, the enzyme they created was 400 times more efficient than comparable human-made catalysts. The group's paper describing the boron-carbon bonds was published in October of last year in the journal *Nature*.

"We have given life a whole new building block that it did not have before," says Arnold. "This is just the beginning. We've opened a new space for biology to explore, a space that includes useful products invented by humans."

Her group's discoveries and creations piled up. Arnold and her colleagues have evolved bacterial enzymes that can create amino acids that do not exist in nature—amino acids that may become the basis of future pharmaceuticals. They have evolved bacteria that create a red fluorescent protein that can be used for imaging other cells under a microscope. And, in April of this year, they announced that they had evolved an enzyme that enables a common strain of *Escherichia coli* to make tiny, energy-packed carbon rings that are rarely found in nature.

These rings, called bicyclobutanes, contain four carbon atoms arranged to form two triangles that share a side. Bicyclobutanes are difficult to make because the bonds between the carbon atoms are bent at angles that put them under a great deal of strain; bending these bonds away from their natural angle takes energy. It is that strain that makes bicyclobutanes valuable, however, since the bent bonds pack energy that can drive chemical reactions, making bicyclobutanes useful precursors to various types of materials, pharmaceuticals, and agrochemicals.

"I have to say we are flabbergasted at the sorts of things that we can make and how inventive evolution can be," Arnold says. She points out that, even without human help, bacteria are adept at developing biological solutions to chemistry problems, like breaking down antibiotics so they can thrive where humans do not want them to grow. It seems reasonable, then, to use those powers to create manufacturing processes that are both more environmentally friendly and potentially less expensive than traditional chemical processes.

"I have to say we are flabbergasted at the sorts of things that we can make and how inventive evolution can be."

In recognition of "her discoveries that launched the field of 'directed evolution,'" Arnold was awarded the Millennium Technology Prize in 2016. The prize, worth 1 million euros, is considered one of the most prestigious awards for technological innovations.

"The big question is how I best use biology's inventive capabilities to create new chemistry that would be useful not to a bacterium but to me," Arnold says. "Can I use these remarkable evolutionary mechanisms to innovate in real time and program microorganisms to do what human chemists struggle with?"

Today, the answer, it seems, is yes. As the technology Arnold invented 25 years ago has matured, it has become more accessible: high school students are conducting experiments in which they direct new genes to evolve, for instance, and amateur biologists across the country have organized themselves under a banner called DIYBio that conducts, among other things, directed evolution experiments. One DIYBio group in the San Francisco Bay Area used directed evolution to breed bacteria that can produce sunblock.

Arnold predicts that in the decades to come directed evolution will tackle problems of growing complexity, such as evolving multiple genes at once, and will be aided by emerging technologies like machine learning and ever-faster methods of test-tube evolution. Her goal, however, will remain the same.

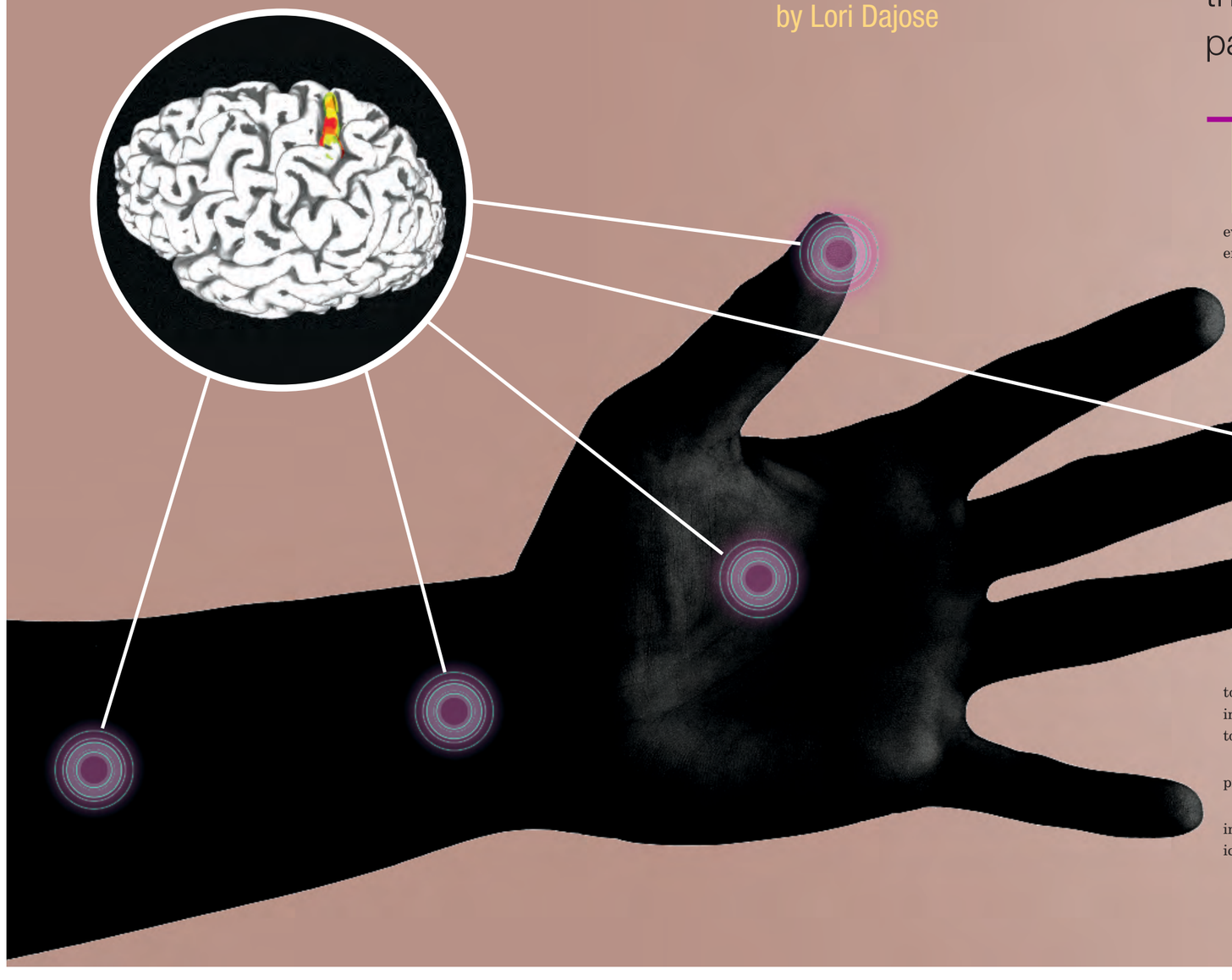
"We would like to be able to program sustainable, self-replicating microorganisms to make catalysts for the cost of the sugar to feed them," Arnold says. "We would like for them to produce many of the materials, chemicals, pharmaceuticals, and even fuels we use in our daily lives and do so cleanly and efficiently, using renewable resources."

Frances Arnold is the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry and director of the Donna and Benjamin M. Rosen Bioengineering Center. Her work on directed evolution is supported by the National Science Foundation, the National Institutes of Health, the Jacobs Institute for Molecular Engineering for Medicine, the Army Research Office, and the Rothenberg Innovation Institute.

Frances Arnold pioneered directed evolution and has been a driving force for its development. The technology is increasingly being used to create synthetic materials using biological means.

To Feel Again

by Lori Dajose



A tiny brain implant developed at Caltech returns the sensations of touch and movement to a paralyzed man's arms and hands.

Three years ago, a man became paralyzed from the shoulders down after a spinal cord injury; since that time, he had been unable to move or even feel his limbs. Now, however, he is able to experience sensations of touch and movement in his hands and arms when two tiny electrode arrays activate particular neurons. Developed in the laboratory of Caltech neuroscientist Richard Andersen, the electrodes were implanted in the somatosensory cortex of the man's brain.

The somatosensory cortex is a strip of brain tissue that governs the body's proprioceptive sensations (sensations of movement or the body's position in space) and cutaneous sensations (those of pressure, vibration, touch, and the like).

Although previous work by other groups has been able to produce tingling or buzzing sensations in patients' hands, the Andersen lab's implants were the first to create more natural sensations with very small pulses of electricity within the brain's cortex. According to Andersen's patient, the sensations varied in type, intensity, and location, and they felt more closely akin to those he had experienced prior to his injury.

"It was quite interesting," he says. "It was a lot of pinching, squeezing movements, things like that."

In 2015, the Andersen lab developed brain-machine interfaces (also known as BMIs) to connect a prosthetic robotic arm to electrodes implanted in the region of the brain that governs intentions. In this way, a different paralyzed man was able to reach out with a prosthetic arm, grasp a cup, and bring it to his mouth to take a drink. What was missing, however, was the ability to actually *feel* the cup in the prosthetic hand; this new implant could create a bidirectional interface that would make that sort of sensation possible.

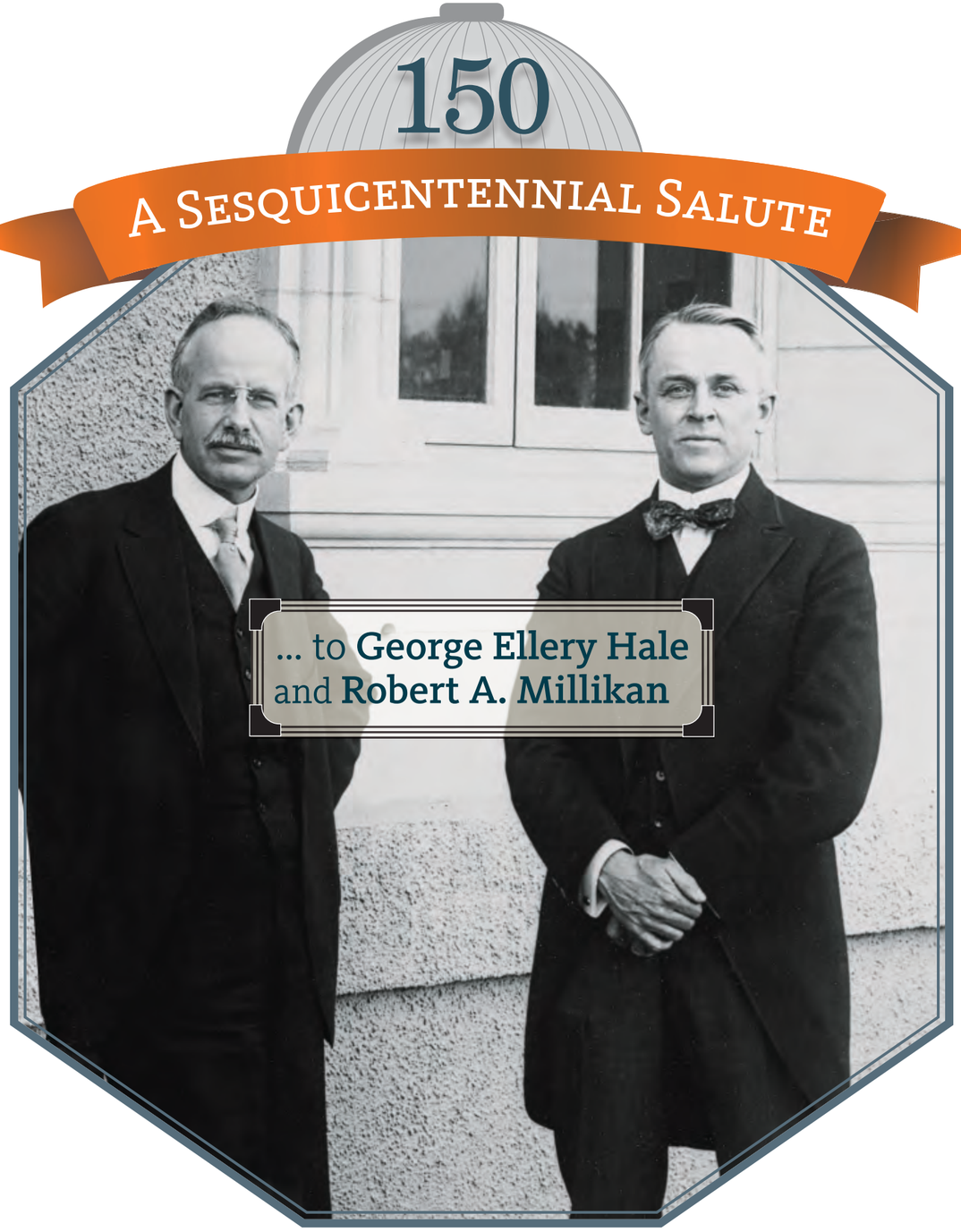
"Currently the only feedback that is available for neural prosthetics is visual, meaning that participants can watch the brain-controlled operation of robotic limbs to make corrections," says Andersen. "However, once an object is grasped, it is essential to also have somatosensory information to dexterously manipulate the object. Stimulation-induced somatosensory sensations have the potential added advantage of producing a sense of embodiment; for example, a participant may feel over time that the robotic limb is a part of their body."

A paper describing this work appeared in the April 10 issue of the journal *eLife* and included authors from Caltech, the Keck School of Medicine at USC, and the Rancho Los Amigos National Rehabilitation Center.

Richard Andersen is the James G. Boswell Professor of Neuroscience, T&C Chen Brain-Machine Interface Center Leadership Chair, and director of the T&C Chen Brain-Machine Interface Center. Funding for this research was provided by the U.S. Department of Health and Human Services, the National Institutes of Health, the National Institute of Neurological Disorders and Stroke, the T&C Chen Brain-Machine Interface Center, the Della Martin Foundation, the Boswell Foundation, the National Science Foundation, and the David Geffen Medical Scholarship.

150

A Sesquicentennial Salute



… to George Ellery Hale and Robert A. Millikan

This spring marks the 150th anniversary of the births of two of the Institute's founders, George Ellery Hale and Robert Andrews Millikan. In their honor—and also to acknowledge Caltech's third founder, Arthur Amos Noyes, who would have turned 150 years old in 2016—we remember their critical roles in establishing the Institute and their remarkable scientific achievements.

In this article excerpt, Judith Goodstein, Caltech's archivist for 41 years, tells the story of the early years of the Institute, when this troika of visionaries set the stage for a future of innovation and ambition on California Boulevard.

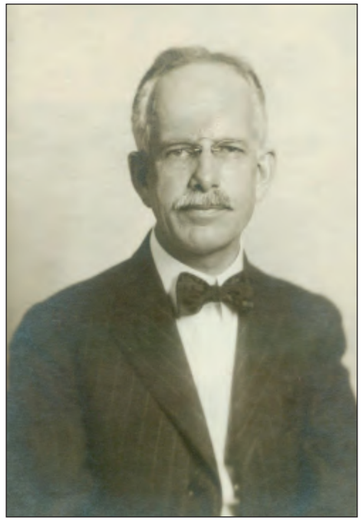
Caltech's beginnings are rooted in a modest little college founded in Pasadena in 1891 by wealthy former abolitionist and Chicago politician Amos Throop. Initially named Throop University, the school changed its name to Throop Polytechnic Institute in 1893. In its first 15 years, Throop served the local community, teaching a great variety of subjects, from arts and crafts to zoology, with considerable emphasis on vocational training. By 1906, Throop needed a fresh sense of purpose. The American astronomer **George Ellery Hale,** the first director of the nearby Mount Wilson Observatory and a newcomer to Pasadena, would provide it.

A scientist bubbling over with educational, architectural, and civic ideas, Hale was elected to the school's board of trustees in 1907 and promptly set about to transform it. He persuaded school officials to abandon Throop's high school and other programs and concentrate on expanding and developing the college along engineering lines; recruited James A. B. Scherer, who served as Throop's president between 1908 and 1920; and enticed Arthur A. Noyes, former president of MIT and the nation's leading physical chemist, to join him in Pasadena. In Noyes, Hale saw not only an opportunity to bring chemistry at Throop College (Throop officially changed its name to Throop College of Technology in 1913) up to a level with that at MIT but also to put Throop itself in the national limelight. The third member of Hale's scientific troika was the physicist **Robert A. Millikan,** who began, in 1917, to spend several months a year at Throop as director of physical research.

The three of them spent the World War I years in Washington, organizing and recruiting scientists to work on military problems, but also building a superb network of contacts that would later serve the school well. Collectively ambitious for American science, eager to see their country play a larger role on the world's scientific stage, and determined to put Throop on the map, Hale, Millikan, and Noyes had become a formidable scientific triumvirate by 1918. By Armistice Day, they had set the stage to transform the engineering school into an institution that put pure science first.

Between 1919 and 1921, the school obtained a handsome endowment, drafted a new educational philosophy, took its present name, and selected a new man to guide its destiny for the next 25 years. Hale and Noyes wanted to use Caltech to reshape the education of scientists. Millikan wanted to make Caltech one of the physics capitals of the world. To do that, he needed research funds. The three men came to an agreement. Hale and Noyes promised Millikan the lion's share of the school's financial resources and minimal administrative duties as head of the Institute. In return, Millikan agreed to come as director of the Norman Bridge Laboratory of Physics and administrative head of the Institute. By then, Noyes had resigned from MIT and accepted a full-time appointment as director of chemical research in Pasadena.

"The History of Caltech" was first published on the Nobel Prize website, nobelprize.org.



George Ellery Hale

Invented the spectroheliograph, an instrument for taking pictures of gaseous eruptions on the sun. The instrument was housed at an observatory built for him by his father near their home.

Founded *The Astrophysical Journal* in 1894—today's premier publication for astronomy research.

Built the world's largest telescope at the time, a 40-inch refractor telescope in Wisconsin, operated by the University of Chicago. Along with the telescope, which opened in 1897, he built the attached Yerkes Observatory, a laboratory space for other related research.

Helped establish the American Astronomical Society in 1899.

Climbed Mount Wilson in 1903 with two other astronomers, realizing its potential to revolutionize our views of the universe.

For a second time, built the world's largest telescope, a 60-inch reflector lens at Mount Wilson, which opened in 1908.

Seeing the Future

"Like buried treasures, the outposts of the Universe have beckoned to the adventurous from immemorial times. Princes and potentates, political or industrial, equally with men of science, have felt the lure of the uncharted seas of space, and through their provision of instrumental means the sphere of exploration has rapidly widened. ... Each expedition into remoter space has made new discoveries and brought back permanent additions to our knowledge of the heavens."

—**George Ellery Hale,** *Harper's Magazine,* 1928

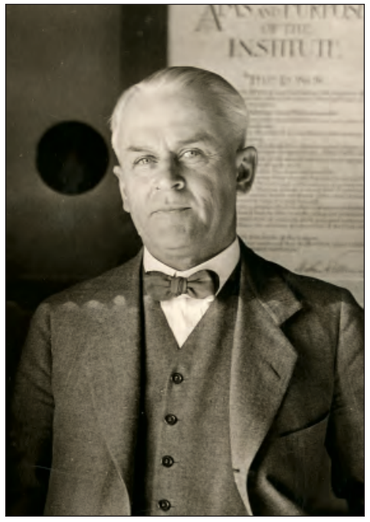
For a third time, built the world's largest telescope—the 100-inch Hooker Telescope at Mount Wilson—which, delayed by World War I, finally became operational in 1918.

For a fourth time, orchestrated the building of the world's largest telescope, a 200-inch mirror at the Palomar Observatory. It saw "first light" in 1949, 11 years after Hale died. It remained the world's largest telescope until 1975, when the Russian BTA-6 saw first light..

"Hale helped turn Pasadena from a sleepy town best known for its orange groves and as a place of winter residence into the thriving scientific and cultural center it is today. He had a remarkable ability to get funding for projects and keep them on budget. It's hard to fathom how much he did in his lifetime."

–**Shrinivas (Shri) Kulkarni**, the first George Ellery Hale Professor of Astronomy and Planetary Science; Director, Caltech Optical Observatories

Worked with Henry E. Huntington, a railcar magnate who had a collection of rare books and paintings, to create The Huntington Library, Art Collections and Botanical Gardens.



Robert Andrews Millikan

A fine athlete and talented boxer, Millikan considered a career in physical education while at Oberlin College.

Became the first student, in 1895, to receive a PhD from the physics department at Columbia University.

Started, in 1907, the first of two experiments to measure the charge of the electron by balancing the gravitational and electrical forces acting on charged water droplets.

Demonstrated that an electric charge always occurs as an integer multiple of a basic unit (the electron charge), which he measured accurately.

Published his results in 1910, which were contested by Austrian physicist Felix Ehrenhaft. In 1913, Millikan settled the issue, publishing accurate results from a greatly improved experiment where he replaced water (which evaporated too quickly) with oil.

Beginning in 1915, worked to verify Einstein's theory of the photoelectric effect (the emission of electrons by a conductor struck by light), by which the maximum energy of ejected electrons is proportional to the individual energy of incident photons, a manifestation of the particle-like nature of light.

Awarded the 1923 Nobel Prize "for his work on the elementary charge of electricity and on the photoelectric effect."

Drop by Drop

I suspect that the changes that have taken place during the last century in the average man's fundamental beliefs, in his philosophy, in his concept of religion, in his whole world outlook, are greater than the changes that occurred during the preceding four thousand years all put together. ... [S]cience and its applications to human life ... have bloomed in my time as no one in history had ever dreamed could be possible.

—**Robert Andrews Millikan,** *The Autobiography of Robert A. Millikan* (1951)

"I think that Millikan was an extraordinarily great person in so many different ways: As a physicist, doing physics; as an administrator, doing more than ordinary administration—actually building a new institution from essentially nothing, which meant getting money, for one thing, and getting people; and being a good enough promoter, or advertising agent if you like, to put Caltech on the map."

–**Carl Anderson,** Professor of Physics, Emeritus (1905–1991), Caltech Archives Oral History Project

At Caltech, undertook a major study of radiation from outer space. Millikan proved that this radiation is indeed of extraterrestrial origin, and he named it "cosmic rays."

Served as vice chairman of the National Research Council and helped to develop anti-submarine and meteorological devices during World War I.

Fictional Caltech

BY LORI OLIWENSTEIN

Caltech's intellectual gravitas and uninhibited innovativeness are traits that have attracted the attention of a number of novelists over the years. In this sampling of fictional works featuring campus and JPL—with stories that range from space adventures to police procedurals to young adult romances—authors have name-dropped Caltech whenever they want to prove a character's brainpower, add a dash of scientific weightiness, or suggest a driven curiosity.

In some of these books, actual facilities on campus or at JPL are described in detail to provide a backdrop for high-stakes, cutting-edge, or downright futuristic research that propels a plot forward. Characters have drinks at the Ath, spend long days and nights in JPL's spacecraft assembly room, and walk past the Institute's "tile roofs and Moorish arches." One novel sets up a meeting between two characters in front of the long-demolished Throop Hall, "an imposing domed administrative building in the local Spanish Colonial style."

The sometimes-implausible scientific scenarios many of these novels create begin to seem entirely possible when set at the Institute, given the intrepid spirit of researchers on campus and at JPL.

The Unseen World
Liz Moore

(W.W. Norton & Company, 2016)

IN BRIEF:

Liz Moore's 12-year-old protagonist is forced to cope with the suddenly declining mental status of her brilliant single-parent father, David—a leading authority in computer science and language processing as well as a Caltech alum. Or is he?

To say more would be to spoil this novel about family and intelligence, both human and artificial.

ON THE PAGE:

...At some point, a missing-person report had been filed for David by his own family. This was enough to trigger further investigation into his past—which, in turn, had led to the further revelation that Caltech—the institution that David had always cited as his undergraduate alma mater—had no record of his name.

Tiger Eyes
Judy Blume

(Bradbury Press, 1981)

IN BRIEF:

Renowned author Judy Blume looked to Caltech to establish the scholarly bona fides of the love interest of her main character in *Tiger Eyes*. In this young adult novel, Davey moves to Los Alamos after her father dies; there, she meets a young man taking a semester off from Caltech to be with his father, who is dying of cancer.

ON THE PAGE:

"He doesn't like to talk about himself," Mr. Ortiz says.

As if I don't already know.

"And now he's got a full scholarship to Cal Tech,[*]" Mr. Ortiz continues. "He's a junior and he's going to be a brilliant physicist."

"Hey, Dad..." Wolf says, "give me a break."

Contact
Carl Sagan

(Simon & Schuster, 1985)

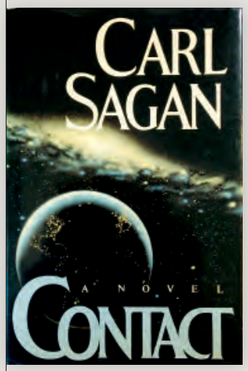
IN BRIEF:

In Carl Sagan's *Contact,* Earth's humans encounter other intelligent beings for the first time. Radio astronomer Eleanor Arroway leads the project to decode and respond to "the Message" received from 26 light-years away ... armed with a PhD from Caltech.

ON THE PAGE:

As a topic for her doctoral thesis, Ellie chose, with the concurrence of the faculty, the development of an improvement in the sensitive receivers employed on radio telescopes. ...

She then installed her new instrument on one of Cal Tech's[*] radio telescopes in Owens Valley and detected, at entirely new frequencies, what astronomers call the three-degree black-body background radiation—the remnant in the radio spectrum of the immense explosion that began this universe, the Big Bang.



The Teleportation Accident
Ned Beauman

(Sceptre, 2012)

IN BRIEF:

In the midst of his sometimes raunchy, sometimes time-bending adventures, protagonist Egon Loeser runs into a Professor Bailey at Caltech in the mid-1930s. Bailey, it turns out, is trying to build a teleportation device very much like the one Loeser had been building as a theatrical set piece back in Germany.

ON THE PAGE:

Several of the characters are discussing Albert Einstein's visits to Caltech's campus; one asks whether Professor Bailey ever met with Einstein:

"They did, yes. Which is unusual. Professor Bailey is normally quite secretive about his work."

"Why would a CalTech[*] physicist need to be secretive?" said Plumridge. "He's juggling atoms, not patenting a toaster."

The Hunt for Red October
Tom Clancy

(Naval Institute Press, 1984)

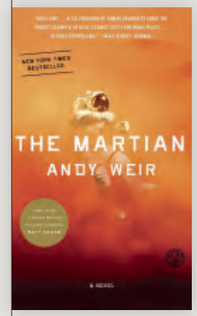
IN BRIEF:

This is the novel with which Tom Clancy launched his literary career, the thriller that introduced his most enduring protagonist, Jack Ryan. Also among the cast of characters chasing down the Red October—a Russian nuclear submarine that is heading toward the United States—is naval-sonar specialist Ron Jones, a former Caltech undergrad. Jonesy, as he is known through much of the book, is the one who notices the almost-undetectable signals coming from the top secret and highly advanced sub whose captain, it turns out, is trying to defect. And with that, the high-stakes pursuit is on.

ON THE PAGE:

Three years earlier, Jones had been asked to leave the California Institute of Technology in the middle of his junior year. He had pulled one of the ingenious pranks for which Cal Tech[*] students were justly famous, only it hadn't worked. Now he was serving his time in the navy to finance his return.

[*] The Institute's name has been rendered in different ways over its history; some of those are reflected in the excerpts above.



The Martian
Andy Weir

(Crown Publishers, 2014)

IN BRIEF:

JPL and its rocket scientists are front and center in the efforts to rescue astronaut Mark Watney from the surface of the Red Planet in Andy Weir's recent novel-turned-blockbuster-movie, *The Martian*. Indeed, when the movie version was released, JPL's news office released an article with the title "JPL's Role in Making 'The Martian' a Reality."

"Acclaimed for its attention to scientific and technical detail, 'The Martian' is steeped in decades of real-life Mars exploration that JPL has led for NASA," JPL noted. For instance, JPL designed, built, and operated the Mars Pathfinder lander that "figures prominently into Watney's ability to communicate with Earth and survive his long ordeal."

Throughout both versions of the story, JPL's engineers are portrayed as innovative and focused, willing—and able—to conquer almost any challenge. And (spoiler alert) they do, although not always on their first try.

ON THE PAGE:

Every system and subsystem was working correctly. JPL did a damn good job making these rovers. If I get back to Earth, I'm buying Bruce Ng a beer. Though I guess I should buy all the JPL guys a beer.

Beers for everyone if I get back to Earth.

The Delta Star

Joseph Wambaugh

(William Morrow and Company, 1983)

IN BRIEF:

The Delta Star has been described as a book that "mixes the think-tank world of Nobel Prize chemistry with the underworld of cops and killers." What is behind that successful mix? Caltech. Not only is one of the shady characters in this whodunnit a scientific "groupie," as Wambaugh dubs him, but the book's acknowledgments include "many thanks to the faculty, students, and staff of the California Institute of Technology, especially to Professor Harry B. Gray, chairman of the division of chemistry and chemical engineering [CCE], for the generous help, considerable enlightenment, and great kindness."

If that were not enough, Gray has a not-so-cameo role in the plot, even briefly drawing the attention of the detectives behind the murder investigation. JPL, CCE, and the Caltech Associates receive mentions, and Wambaugh spouts impressive stats about the Institute, its faculty members, and their award-winning scientific efforts.

ON THE PAGE:

> Mario Villalobos had known about as much as the average citizen knows about the handful of first-rate scientific institutes in America. That is, he had known next to nothing. ... He learned that an extraordinary number of Nobel Prizes had been awarded to Caltech alumni and faculty, and that this small faculty had a higher percentage of members elected to the National Academy of Sciences and National Academy of Engineering than any educational institution in America. There were always Nobel laureates among the active faculty and in such a place it was to be expected that there were many more who had hopes and dreams of becoming one.

Deceptive connections?

In **Deception Point** (Pocket Books, 2001), Dan Brown brings to life the powerful William Pickering, director of the so-called National Reconnaissance Office. Some *Caltech* magazine readers believe this name is a reference to JPL's fourth and longest-serving director, Bill Pickering (BS '32, MS '33, PhD '36); after all, it is a beleaguered NASA that discovers the unusual meteorite that drives the story's plot. But if it is, Brown has left few hints or breadcrumbs to back up that supposition.

If those hints—or actual proof—exist, the readers of *Caltech* magazine will find it. Send an email to **magazine@caltech.edu** with evidence from the book or outside sources, and check **magazine.caltech.edu/post/your-caltech-novel** for updates.

Seveneves

Neal Stephenson

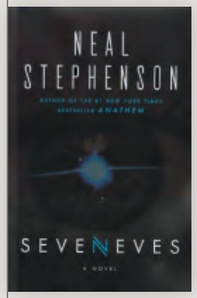
(William Morrow and Company, 2015)

IN BRIEF:

Neal Stephenson's novel tells the story of efforts to save the human species over five millennia after the moon suddenly and inexplicably disintegrates. In the book's earliest pages, this event is described by a number of characters, including Dubois Jerome Xavier Harris, PhD, an astronomer and TV personality who just happens to be in a familiar setting when the lunar lunacy begins.

ON THE PAGE:

> The moon blew up while [Dr. Harris] was attending a fund-raising reception in the courtyard of the Caltech Athenaeum.



Saturn Run

John Sandford and Ctein

(G.P. Putnam's Sons, 2015)

IN BRIEF:

It is a Caltech intern who, in the year 2066, notices what seems to be a spacecraft decelerating toward Saturn in this science-fiction thriller. The race is soon on between the United States and China to investigate and bring back this ship, which hails from a planet thought to be at least a century ahead of Earth in its technology. Caltech plays a big role here, as does the not-necessarily-qualified intern who nonetheless discovers the original Saturn-bound spacecraft. There is also his boss, astrophysicist Ed Fletcher of the "Caltech Astrophysics Working Group," and there is JPL, which becomes involved in the efforts to build a spacecraft that can arrive at Saturn before anything launched by China.

Caltech is also the alma mater of Ctein (BS '71)—Sandford's writing partner on this project—who double majored in English and physics.

ON THE PAGE:

On the ill-qualified intern:

> As one of the Real Scientists put it, "He couldn't change a [expletive] tire," which, in Caltech terms, didn't literally mean he couldn't change a tire, it simply meant he couldn't reliably explain the difference between a Schwarzschild radius and Schrödinger's cat.

* The Institute's name has been rendered in different ways over its history; some of those are reflected in the excerpts above.

Lucifer's Hammer

Larry Niven and Jerry Pournelle

(Playboy Press, 1977)

IN BRIEF:

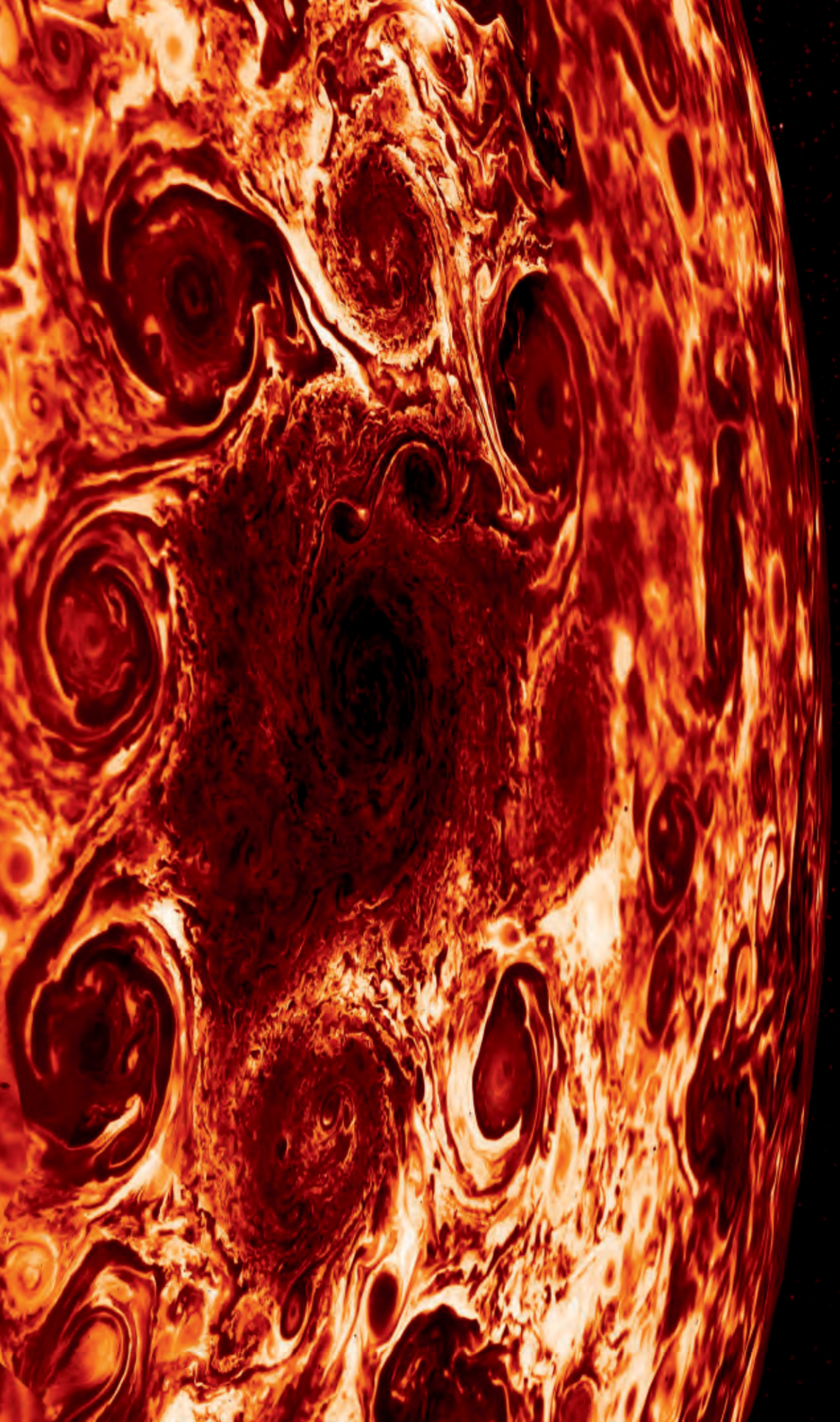
In *Lucifer's Hammer,* there is a newly discovered comet about to wreak havoc on planet Earth. A California senator organizes a joint U.S./Russia space mission to study the comet, looking to campus and JPL to play a role in protecting the planet ... a role that is doomed to failure.

ON THE PAGE:

In one early scene, a TV crew heads to JPL to do an interview about comets. Charlie, a cameraman on the crew, remarks to a production assistant named Mark:

> "Sure put it the hell far from Pasadena."
>
> "Used to test jet engines there," Mark said. "JPL. Jet Propulsion Laboratories, right? Everybody thought they'd blow up, so they made Cal Tech* put the labs out in the Arroyo." He waved to indicate the houses outside. "Then they built the most expensive suburb in this end of L.A. just around it."

This is by no means a comprehensive roundup of all fictional representations of the Institute. If this article leaves out a favorite, send a note to magazine@caltech.edu.



Jupiter's Unearthly Jet Streams

The Jet Propulsion Laboratory announced in March that the Juno mission to Jupiter—a mission operated by JPL on behalf of NASA—has collected data indicating that the atmospheric winds of the gas-giant planet run deep into its atmosphere and last longer than similar atmospheric processes found on Earth. The findings were part of a four-article series on Juno that was published in the journal *Nature* in March; scientists say these findings will improve understanding of Jupiter's interior structure, core mass, and, eventually, its origin.

The *Nature* articles also include Juno science results showing that the massive cyclones surrounding Jupiter's north and south poles are enduring atmospheric features and unlike anything encountered in our solar system.

"The depth of the winds on Jupiter has been debated for half a century," says David Stevenson, the Marvin L. Goldberger Professor of Planetary Science at Caltech, leader of the Interiors Working Group of Juno, and a co-author of the *Nature* papers. "It matters because it helps us understand how the planet works."

The depth to which the roots of Jupiter's famous zones and belts extend has been a mystery for decades. Gravity measurements collected by Juno during its close flybys of the planet have now provided an answer.

"Juno's measurement of Jupiter's gravity field indicates a north-south asymmetry, similar to the asymmetry observed in its zones and belts," said Luciano Iess, Juno co-investigator from Sapienza University of Rome and lead author on a *Nature* paper on Jupiter's gravity field.

On a gas planet, such an asymmetry can come only from flows deep within the planet; and on Jupiter, the visible eastward and westward jet streams are likewise asymmetric north and south. The deeper the jets, the more mass they contain, leading to a stronger signal expressed in the gravity field. Thus, the magnitude of the asymmetry in gravity determines how deep the jet streams extend.

"Galileo viewed the stripes on Jupiter more than 400 years ago," says Yohai Kaspi, Juno co-investigator from the Weizmann Institute of Science in Rehovot, Israel, and lead author of a *Nature* paper on Jupiter's deep weather layer. "Until now, we only had a superficial understanding of them and have been able to relate these stripes to cloud features along Jupiter's jets. Now, following the Juno gravity measurements, we know how deep the jets extend and what their structure is beneath the visible clouds. It's like going from a 2-D picture to a 3-D version in high definition."

The result was a surprise for the Juno science team because it indicated that the weather layer of Jupiter was more massive, extending much deeper than previously expected. The Jovian weather layer, from its very top to a depth of 1,900 miles (3,000 kilometers), contains about 1 percent of Jupiter's mass (about three Earth masses).

"By contrast, Earth's atmosphere is less than one-millionth of the total mass of Earth," says Kaspi. "The fact that Jupiter has such a massive region rotating in separate east-west bands is definitely a surprise."

The finding is important for understanding the nature and possible mechanisms driving these strong jet streams. In addition, the gravity signature of the jets is entangled with the gravity signal of Jupiter's core.

by Judy Hill

First Flight

A Caltech alumna overcomes her fears and takes to the skies.

She is a pilot and a professor. She is a computer scientist and an aerobatic expert. In fact, she is the first Latina to secure a place on the United States' World Aerobatic Championship team. Cecilia Rodriguez Aragon (BS '82) has jumped out of airplanes; performed loops, spins, and rolls at air shows; worked as a test pilot; and contributed to the design of experimental airplanes.

Currently a professor in the College of Engineering at the University of Washington, Aragon has worked with Nobel laureates and taught astronauts to fly. President Obama recognized her work with a prestigious Presidential Early Career Award for Scientists and Engineers.

For the first three decades of her life, however, Aragon says she was beset by fear and anxiety.

Growing up in Indiana as the daughter of immigrants, she recalls becoming accustomed to strangers thinking less of her and always feeling as if she were "on the outside." Becoming a Caltech undergraduate, she says, felt like coming home.

"It had never occurred to me that there were so many other people who would accept me for my love of math and science," she notes. "It didn't matter that I was Hispanic, female ... all those things that had been strikes against me were like nothing. What mattered in terms of belonging was your knowledge and your ability, not your skin color or gender. Caltech opened my eyes to the idea that being a part of a community was possible. It was pure joy. It was liberating. For me, it meant if I worked hard and studied I could become a member of a community."

But once she entered UC Berkeley's computer science PhD program—as she recounts in her unpublished memoir *Flying Free: How I Used Math to Overcome Fear and Achieve My Wildest Dreams*—Aragon again felt like an imposter, and the "terrified child" woke up once more.

> In 1985, I was twenty-five years old and scared of elevators. My graduate school administrator once found me crying in the ninth-floor women's restroom, after I'd climbed eight flights of stairs, too frightened to jump past the elevator doors. My fears immobilized me even in situations that didn't seem to bother anyone else. My muscles stiffened whenever I climbed a ladder, shook hands with a stranger, or talked on the telephone. This physical reaction bewildered me, but I had no idea how to avoid it. It seemed that whenever I had to perform, my brain circuits got jammed by fear, and I froze. I was afraid to study for exams, scared to imagine writing a thesis, terrified that people would find out the truth: I was a Failure with a capital 'F.' Overcoming my fears seemed impossible.

When Aragon was hired as a software developer at Digital Equipment Corporation's research lab in Palo Alto in 1985, she had recently dropped out of graduate school, having convinced herself she could never complete the required dissertation.

One day, her new colleague, Carlos, a private pilot, invited her to go flying. "I froze," writes Aragon, "and once again the circuits of my brain jammed with fear." Still, she realized she was being offered a valuable opportunity to face her fears, take a risk, and break out of what had become an increasingly narrow and fettered life. She said yes.

Aragon recalls that first heady small-plane flight above the waters of San Francisco Bay.

> We taxied out. Carlos gave me a thumbs up, and I nodded weakly. He advanced the throttle, the engine roared, and we accelerated along the runway. Beyond the metal cowling, a view of the wide world opened out in front of me. Then the plane lifted its nose, and we were airborne.
>
> There was nothing to do but hold on.
>
> The earth dropped away from us.
>
> We were flying.
>
> And my heart lifted.
>
> Then I remembered: As a child, my single greatest wish was to be able to fly. Not in a plane, but to levitate into the air the way fantastical creatures in books did, to play hide and seek among the branches of trees and rise above the ground, to be free of my ordinary life crowded with scary things and intimidating people.
>
> Carlos pointed the plane toward the Golden Gate Bridge, a shimmering arc across the sea and sky. I wanted to laugh. I smiled so hard the muscles of my face ached.

There is a principle in mathematics called mathematical induction, a two-step concept that says if a property or theory can be shown to be true for one natural number (n) and then shown to be true for n+1, it will be true for all natural numbers. Aragon says that, for her, touching down from that first flight animated that idea.

"I realized I could apply it to my own life," she says. "The first time I faced my fear it was terrifying and made my heart pound, but after I got through it once, I knew I could do it again. And again. It was completely astonishing and magical to me."

> Flying became my art, my science, and my passion. In a span of just six years, I taught myself to overcome my self-doubt,

shyness, and deep-seated fear of heights to become one of the best aerobatic pilots in the world.

But flying, it turned out, was just the beginning.

After my stint on the US Aerobatic Team, I applied the strategies I'd used to teach myself to fly to go after the dreams I'd deferred. In 2003, I went back to complete my PhD in computer science, the program I'd quit because I thought I wasn't smart enough. I worked with astronomers to solve the greatest mysteries of the universe. Then I applied for my dream job, a career I'd all but given up on because the odds against it were so great. I received six offers and landed what seemed to me to be the best job on the planet—Professor in the College of Engineering at the University of Washington.

I've lived the kind of life I never would have dreamed of as a shy awkward child in Indiana, a child no one expected much of. ... [And] I did it through a series of simple and rather ordinary steps, by combining math and logic with passion in an unexpected way.

Cecilia Aragon is the director of the Human-Centered Data Science Lab at the University of Washington. She and her team use both quantitative and qualitative methods to study how people make sense out of very large data sets. She was awarded a 2017–18 Fulbright Fellowship to conduct research in human-centered data science and teach visual analytics in Chile.

In Memoriam

Stephen Hawking

1942–2018

Theoretical physicist Stephen Hawking died on March 14, 2018, at age 76 from complications of amyotrophic lateral sclerosis (ALS). Famous for his mind-bending theories of black holes and his popular book, *A Brief History of Time: From the Big Bang to Black Holes,* Hawking was a frequent visitor to Caltech. He did much of his seminal research on black holes during a yearlong visit to Caltech from 1974–75. Over the next four decades, Hawking, a professor at the University of Cambridge and a Sherman Fairchild Distinguished Scholar at Caltech, returned to the Institute often to conduct research and exchange ideas with faculty, postdoctoral scholars, and graduate students.

"Stephen was not only one of the greatest scientists of our era; he was also a wonderful friend, and an inspiration to me, both personally and scientifically," says Kip S. Thorne (BS '62), Richard P. Feynman Professor of Theoretical Physics, Emeritus. "He lived life to the full. He took me to Antarctica in the depths of the Antarctic winter! His sense of humor was legendary. When he started a sentence, laboriously on his computer, I never knew whether it would end in a deep pearl of wisdom or an off-the-wall joke. His insights into our universe have inspired generations of physicists who follow in his wake, and will continue to inspire for decades to come. I miss him terribly, already."

"Stephen Hawking was one of the world's greatest physicists, and his death is an enormous loss," says Sean Carroll, a colleague of Hawking's and a research professor of physics at Caltech. "He did more to advance our understanding of gravity than anyone since Albert Einstein. Stephen was also an irrepressible character who persevered in the face of overwhelming adversity. He traveled frequently, and could have gone anywhere; we were fortunate that he chose to frequently come to Caltech."

Hawking was known for his scientific wagers, including a bet with Thorne and John P. Preskill, Richard P. Feynman Professor of Theoretical Physics at Caltech, regarding his declaration that information that fell into a black hole would be lost forever. He eventually conceded that he had been wrong.

Preskill recalls, "What I'll remember best about my time with Stephen is that we could make each other laugh. I sensed when we first met that he would enjoy being treated irreverently. So, in the middle of a scientific discussion I could interject, 'And what makes you so sure of that, Mr. Know-It-All?' knowing that Stephen would respond with his eyes twinkling, 'Wanna bet?'"

Read more about Hawking's life at **magazine.caltech.edu/post/in-memoriam**

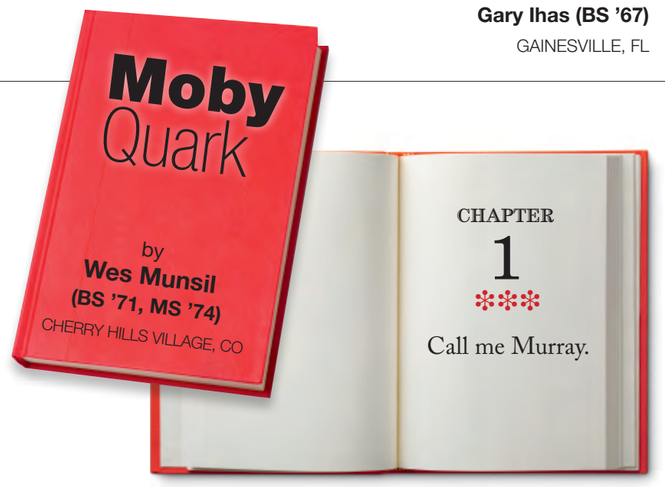
Endnotes

What is the title and first line of your Caltech novel?

Taking the World by Storm

Driving along California Blvd. on a sunny afternoon, Norbert had no inkling of what was going on behind the seemingly placid Spanish architecture walls to his left.

Gary Ihas (BS ’67)
GAINESVILLE, FL



The White Arches

He walked carefully along the smooth reddish tiles toward Arms Laboratory, clutching the thick stack of typing paper under his arm. Finished! His thesis at last done, freshly returned to him by the typist, with her fervent wishes for his success.

Henry Schwarcz (PhD ’60)
DUNDAS, ONTARIO, CANADA

A Tale of Two Extrema

It was the maximum of times, it was the minimum of times.

Brett Bochner (BS ’91)
BABYLON, NY

An Apprentice Scientist

I stood at the window overlooking a run of olive trees and wondered what I was about to become.

Charles Goebel (BS ’57)
READING, PA

Countdown P.A.G.E.

The chalk dust had barely settled from the umpteenth blackboard of scribblings when it struck me. The eraser. My thermo prof had a good arm.

Michael Wong (BS ’94)
HOUSTON, TX

Revenge of the Valkyries

Holding his wire cutters, this time he was fully ready for finals week.

Larry Oliver (BS ’65)
BLACK MOUNTAIN, NC

The Big Orange Brain Trust

As Dean Huntley smashed his right fist into his left palm, he cautioned: “We MOLD our students into research scientists.”

John Louie (PhD ’87)
RENO, NV

I didn’t think it rained in SoCal, Jonathan thought, as he woke in the shower following a long night and morning of Phys 125.

Breaking Brainy

“You should always let men do better than you in class,” advised Aunt Skyler. “Smart girls aren’t sexy.” But within weeks of arriving at Caltech and getting intimate with Cr(acac)3 in Noyes Lab, I’d ditched all my aunt’s principles and was regularly nailing the top Chem 1 score in the entire freshman class. It only got worse from there.

Cecilia Aragon (BS ’82)
SEATTLE, WA

For more Endnotes responses, go to
magazine.caltech.edu/post/endnotes-novel

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And remember to get social:

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Erasable MRIs: Mikhail Shapiro, assistant professor of chemical engineering, and his colleagues have developed "erasable" MRI contrast agents that, on command, can blink off. The contrast agents—air-filled protein structures called gas vesicles—emit magnetic signals that collapse when hit with waves of sound, causing them to disappear and making it easier for researchers to interpret the MRI scans. "It's the same principle behind blinking bicycle lights," says Shapiro. "Having the lights turn on and off makes them easier to see, but in our case we just blink off the contrast agent once."

Find out more at
magazine.caltech.edu/post/mri-scans