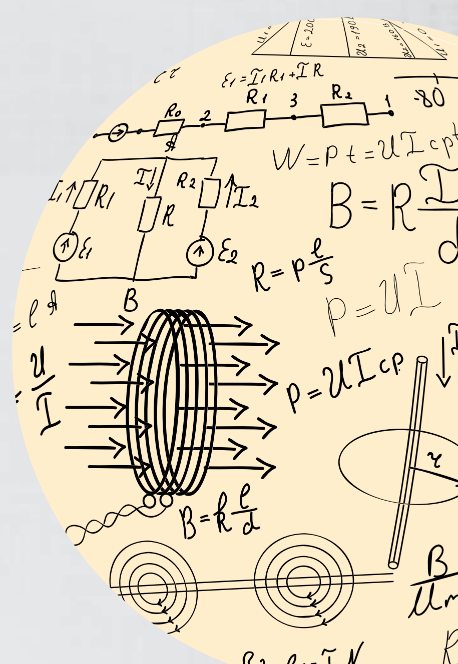
e&S
Engineering & Science

Caltech

VOLUME LXXIX, NUMBER 1, SPRING 2016

e&S
Engineering & Science
VOLUME LXXIX, NUMBER 1, SPRING 2016



Caltech on Social Media

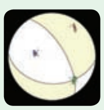
Follow us, retweet us, regram us, and let us know you're talking about us by including @Caltech in your tweets and @caltechedu in your Instagram posts.

@ggainford Dancing, singing, Keanu, Hawking, Antman. That's science @Caltech Entangled Evening.

@nisbjorn To be honest @plutokiller kind of owed us a new planet #Planet9

@tech_grrrl OH @ caltech: "I just watched a girl put Fanta in her ice cream cone instead of her glass. And it's not even finals week."

@roybotzroybotz @Caltech winning at basketball? I would check – they may be robots…#robotics #robots #humor #art #whhiirrrr-beep



@CPPGeophysics Typical Caltech Seismo coffee break: "yes, quake could have occurred on Banning fault. Did I ever tell you story of how I named that fault?"

@TableTopGeneral Daughter just told me her @Lammily doll is "a professor at @Caltech, and she rides her horse to work"

@caltechswimdive Pretty nice view from last night's recovery practice #gobeavers

Tweets and Instagram comments may have been edited for spelling and grammar.

Caltech Engineering & Science

VOLUME LXXIX, NUMBER 1, SPRING 2016

EDITOR IN CHIEF
Lori Oliwenstein

MANAGING EDITOR
Doreese Norman

SENIOR EDITOR
Katie Neith

CONTRIBUTING WRITERS
Andrew Allan, Lori Dajose, Kimm Fesenmaier, Katie Neith, Lori Oliwenstein, Nehaly Shah, Ker Than, Marcus Woo, Dave Zobel

COPY EDITORS
Michael Farquhar, Sharon Kaplan

ART DIRECTOR
Jenny K. Somerville

DESIGN AND LAYOUT
Keith & Co.

THE CALIFORNIA INSTITUTE OF TECHNOLOGY
Farnaz Khadem, *Chief Communications Officer*
Diana Jergovic, *Vice President for Strategy Implementation*

THE CALTECH ALUMNI ASSOCIATION
Lee Fisher, *President*

Read *E&S* on the go at EandS.caltech.edu

Contact *E&S* at lorio@caltech.edu

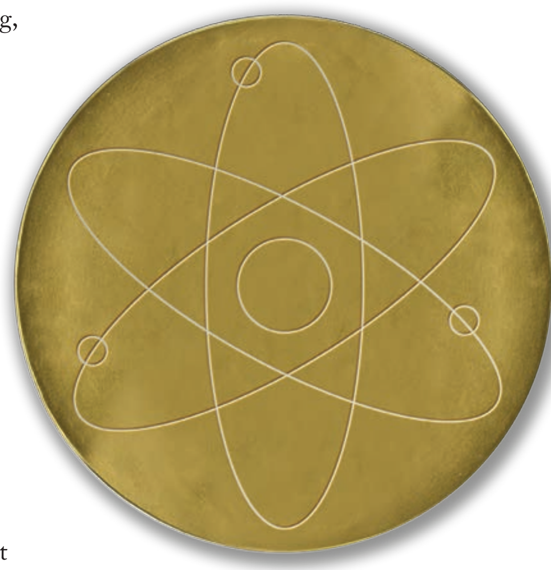
Engineering & Science (ISSN 0013-7812) is published quarterly at Caltech, 1200 East California Boulevard, Pasadena, CA 91125. Annual subscription $20.00 domestic, $30.00 foreign air mail; single copies $5.00. Send subscriptions to *Engineering & Science*, Caltech Mail Code 12-71, Pasadena, CA 91125. Third-class postage paid at Pasadena, CA. Published by Caltech and the Alumni Association.

Printed by Navigator Cross-Media, Inc., Glendale, California.

PICTURE CREDITS
Cover: (left circle) Keith & Co.; (middle circle) grebcha/shutterstock.com; (right circle: middle) Keith & Co.; (right circle: lower left) Jbourjai/Wikimedia.org; (right circle: upper left) Science Photo/shutterstock.com; TOC: (left circle: basketball) irin-k/ shutterstock.com; (left circle: petri dish) Satirus/iStock.com; (left circle: chalk board) Lance Hayashida; (lower left circle: magnifying glass) Rtimages/shutterstock.com; (lower left circle: rock) Albert Russ/shutterstock.com; (middle circle) Vladimir Popovi/iStock.com; (lower middle right circle) Believe_In_Me/iStock.com; (lower right circle) Juliann/shutterstock.com; (upper right circle) Karramba Production/shutterstock.com; 3: Keith & Co.; 4–5: Tania Darnton; 6: (left) Stephen Voss; 6: (right) Moesta et al./Nature; 7: Jenny K. Somerville; 8: (top) Haowen Ruan Mooseok Jang and Changhuei Yang of Caltech; 8: (bottom) Katie Neith; 9: Lance Hayashida; 10: (top) courtesy of the Caltech Archives; 10: (bottom) Lance Hayashida; 11: courtesy of the Caltech Archives; 13–17: (Robert A. Millikan, Carl David Anderson, Richard P. Feynman, Max Delbrück, William Alfred Fowler, Ahmed H. Zewail) courtesy of the Caltech Archives; 15: (David Baltimore) Lance Hayashida; 16: (Rudolph A. Marcus) Lance Hayashida; 17: (Robert H. Grubbs) Lance Hayashida; 17: (Eric Betzig) Matt Staley/HHMI; 18: courtesy of the Caltech Sports Information Office; 20: Mark McGinnis; 22: Seth Hansen; 24: Joey Guidone @SalzmanArt; 26: Breakthrough Prize; 28: Dustin Snipes; 30: courtesy of Cindy Ko; 31: courtesy of Peter Buhler; 32: courtesy of Todd Gingrich; 33: courtesy of Emma Schmidgall; 35: Lance Hayashida; 36: (top) courtesy of the Caltech Archives; 36: (middle) Lance Hayashida; 36: (below) xingmin07

After the Prize

I often talk about Caltech as being my personal Disneyland, a place full of wonders and attractions for the science geek. Or sometimes I'll describe the people here as my celebrities. In fact, what I knew of Caltech before I came here in late 2008 were the names of its science "stars": Linus Pauling, Richard Feynman, David Baltimore, to name only a few.



Unlike the Kardashians, this cult of personality revolves around achievement not notoriety. These are people whose work has led to a Nobel (35 awards given to 34 Caltech-connected scientists, with five of those in residence and seven named in within the past 15 years) or a MacArthur grant (17 faculty members) or a National Medal of Science (58 faculty and alumni), or any of the many other honors out there.

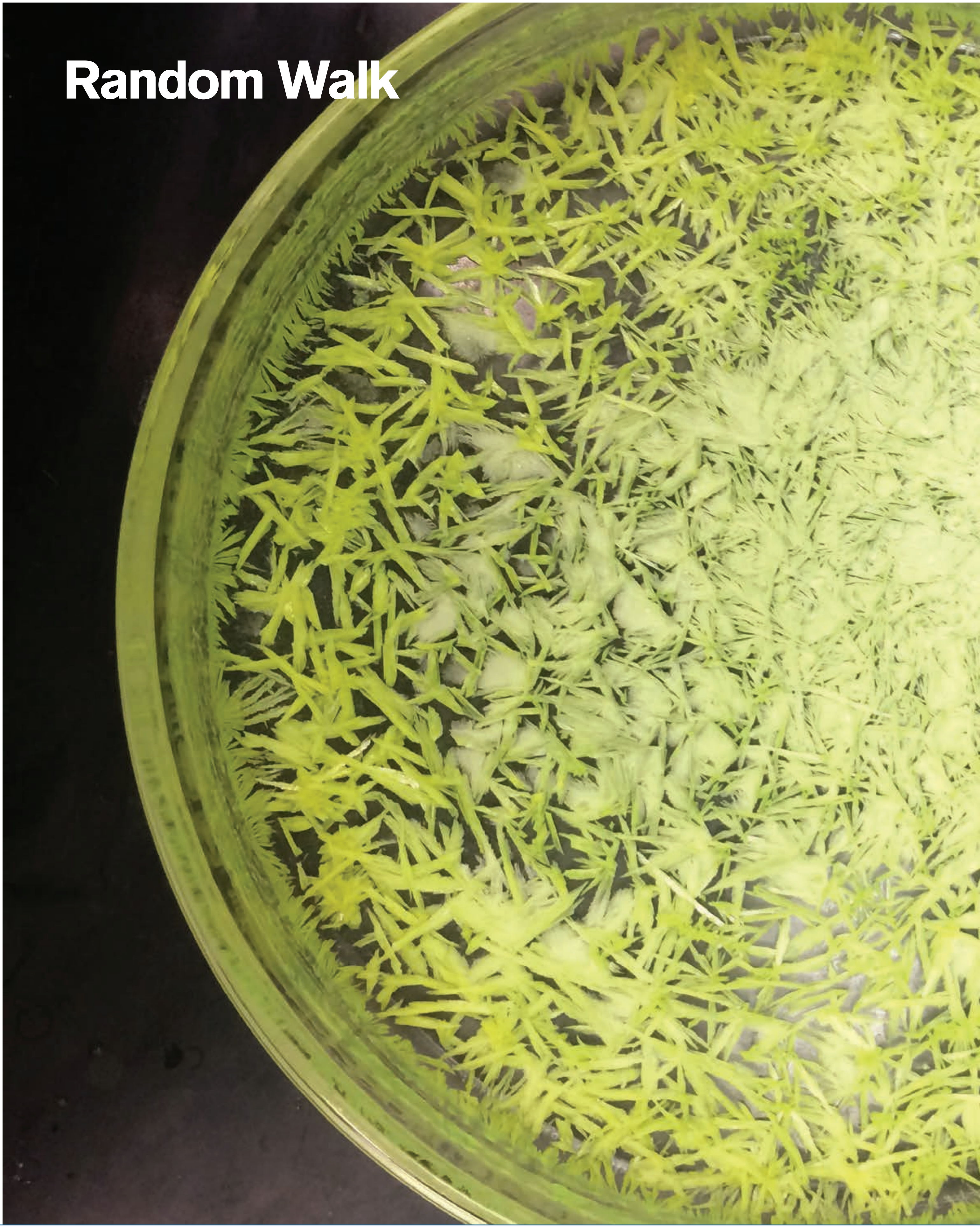
Scientists are generally uncomfortable talking about prizes and accolades; they are, instead, focused on the work. But if you look at the careers of those who have been recognized for their scientific or other efforts, it becomes clear that recognition has some kind of effect: it opens doors and possibilities, and sometimes even changes paths. (See "Life of a Laureate," page 12.) You could argue that that's just the way these scientists are built, that they would have done amazing things anyway. But since I can't figure out how to do that controlled study, I'm comfortable positing that—whatever the reason—the after-the-prize lives of Caltech scientists are rich, productive, and fascinating.

That's why we've spent this issue looking at the work that comes after the accolades. For instance, in "A Feeling Touch" (page 20), Katie Neith considers the effect two BRAIN Initiative grants have had on biologist Richard Andersen's robotic limb research. Marcus Woo looks at how and whether the relatively new —and extremely well-funded—Breakthrough Prize in Fundamental Physics is creating celebrities out of quantum computing and superstring experts in "Glitz and Qubits" (page 24). And recent alum Lori Dajose (BS '15) talks with other Caltech alums given scholarships and fellowships that have taken them "Beyond the Beaten Path" (page 28).

For all of these remarkable scientists, no matter the stage of their career, the best may very well be yet to come. I can't wait to read the next chapters of their stories—and of those who will undoubtedly come after them.

—Lori Oliwenstein, Editor in Chief

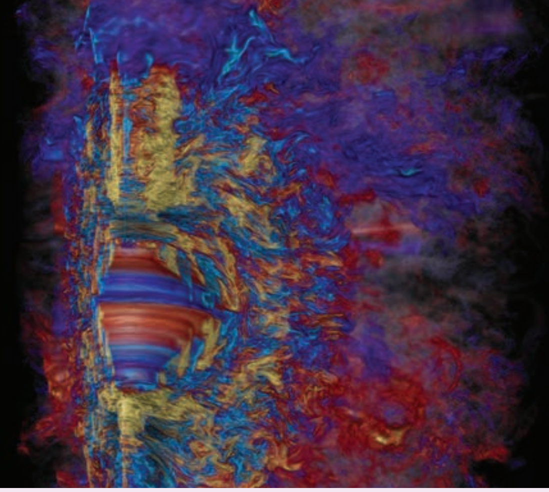
Random Walk



GOOD LUCK GREEN

These glowing crystals generated by Tania Darnton, a Caltech graduate student in the lab of chemist Harry Gray, are composed of the tetraphenylphosphonium (Ph_4P^+) salt of the compound tetrakis(diphosphonato) diplatinate(II), commonly known as Pt(POP) due to its phosphorus-oxygen-phosphorus bridges. This compound is a precursor to another molecule Darnton is studying for her thesis, which is a highly luminescent derivative of Pt(POP) with possible applications in oxygen-sensing thin films and catalytic electron-transfer reactions. According to Darnton, the crystals were created via the slow evaporation of a methanol solution of the compound—quite by accident, in fact. She hadn't synthesized the Ph_4P^+ salt before, and after several frustrating hours of trying unsuccessfully to isolate the compound she decided to just leave the solution out and try again in the morning. When she returned the following day, she was greeted with bright green crystals, which she called a "wonderful reward" after the disappointment of the night before. Such compounds could be used in building detectors for laboratories to ensure proper atmospheric conditions for sensitive chemical reactions.

Building Powerful Magnetic Fields



A visualization of the strong, ordered magnetic field built up by dynamo action in the core of a rapidly rotating, collapsed star.

When certain massive stars use up all of their fuel and collapse onto their cores, explosions 10 to 100 times brighter than the average supernova occur. Astrophysicists from Caltech, UC Berkeley, the Albert Einstein Institute, and the Perimeter Institute for Theoretical Physics have used the National Science Foundation's Blue Waters supercomputer to perform three-dimensional computer simulations to fill in an important missing piece of our understanding of what drives these blasts.

In the past, scientists have simulated the evolution of massive stars from their collapse to jet-driven explosions by factoring unrealistically large magnetic fields into their models—without explaining how they could be generated in the first place.

"That's what we were trying to understand with this study," says Luke Roberts, a NASA Einstein Fellow at Caltech and a coauthor on a paper reporting the team's findings in the journal *Nature*. "How can you start with the magnetic field you might expect in a massive star that is about to collapse—or at least an initial magnetic field that is much weaker than the field required to power these explosions—and build it up to the strength that you need to collimate a jet and drive a jet-driven supernova?"

For more than 20 years, theory has suggested that the magnetic field of the innermost regions of a massive star that has collapsed, also known as a proto-neutron star, could be amplified by an instability in the flow of its plasma if the core is rapidly rotating, causing its outer edge to rotate faster than its center. However, no previous models could prove this process could strengthen a magnetic field to the extent needed to collimate a jet, largely because these simulations lacked the resolution to resolve where the flow becomes unstable.

Lead author on the paper Philipp Mösta—who started the work while a postdoctoral scholar at Caltech and is now a NASA Einstein Fellow at UC Berkeley—and his colleagues developed a simulation of a rapidly rotating collapsed stellar core and scaled it so that it could run on the Blue Waters supercomputer, known for its ability to provide sustained high-performance computing for problems that produce large amounts of information. The team's highest-resolution simulation took 18 days of around-the-clock computing by about 130,000 computer processors to simulate just 10 milliseconds of the core's evolution.

In the end, the researchers were able to simulate the so-called magnetorotational instability responsible for the amplification of the magnetic field. As theory predicted, they saw that the instability creates small patches of an intense magnetic field distributed throughout the core of the collapsed star. They found that a dynamo process connects those patches and generates currents that amplify the magnetic fields, turning them into the kind needed to power jets. —*KF*

"I'm always surprised and delighted by the ways in which we expand our understanding.

Whether we're contemplating the first moments of the universe, the fundamentals of life here on Earth, personalized medicine, or the capability of the phone in your pocket—science continues to transform our lives on a daily basis."

—France A. Córdova (PhD '79), director of the National Science Foundation, in an interview with Ben Tomlin of the Caltech Alumni Association.

TRACKING DOWN THE "MISSING" CARBON FROM THE MARTIAN ATMOSPHERE

Mars is blanketed by a mostly carbon dioxide atmosphere—one that is far too thin to prevent large amounts of water on the surface of the planet from subliming or evaporating. But many researchers have suggested that the planet was once shrouded in an atmosphere many times thicker than Earth's. For decades that left the question, "Where did all the carbon go?"

Now scientists from Caltech and JPL think they have a possible answer. The team suggests that 3.8 billion years ago, Mars might have had only a moderately dense atmosphere. The researchers have identified a photochemical process that could have helped such an early atmosphere evolve into the current thin one without creating the problem of "missing" carbon.

"With this new mechanism, everything that we know about the martian atmosphere can now be pieced together into a consistent picture of its evolution," says Renyu Hu, a postdoctoral scholar at JPL, a visitor in planetary science at Caltech, and lead author on the paper that appeared in *Nature Communications*.

When considering how the early atmosphere might have transitioned to its current state, there are two possible mechanisms for the removal of excess carbon dioxide (CO_2). Either the CO_2 was incorporated into minerals in rocks called carbonates or it was lost to space.

A separate study coauthored by Bethany Ehlmann, assistant professor of planetary science at Caltech, used data from several Mars-orbiting satellites to inventory carbonate rocks, showing that there are not enough carbonates in the upper crust to contain the missing carbon from a very thick early atmosphere.

To study the escape-to-space scenario, scientists examined the ratio of carbon-12 and carbon-13, two stable isotopes of the element carbon that have the same number of protons in their nuclei but different numbers of neutrons, and thus different masses. Comparing measurements from martian meteorites to those recently collected by NASA's Curiosity rover, they found that the atmosphere is unusually enriched in carbon-13. To explain that, they describe a mechanism involving a photochemical cascade that produces carbon atoms that have enough energy to escape the atmosphere, and they show that carbon-12 is far more likely to escape than carbon-13.

"With this mechanism, we can describe an evolutionary scenario for Mars that makes sense of the apparent carbon budget, with no missing processes or reservoirs," says Ehlmann, who is also a coauthor on the Hu study. —*KF*

TRIPLE THREAT

The public high school in Blue Springs, Missouri, just outside Kansas City, graduates more than 500 seniors each year. Remarkably, the valedictorian in 2015 was the younger sister of the valedictorian in 2014—who was the younger sister of the valedictorian in 2013.

And all three are now Caltech undergraduates.

These are the Butkovich sisters: junior Slava and sophomore Nina, both majoring in chemical engineering, and freshman Lazarina ("Laza"), currently deciding between chemical engineering and chemistry.

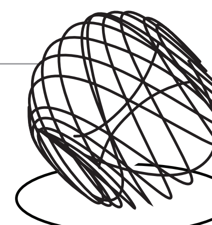
The sisters represent "a three-peat," says Caltech admissions director Jarrid Whitney, not a package deal. "All our applicants are reviewed independently and without regard to siblings, parents, or other legacies. For three family members to receive consecutive offers of admission indicates how tremendously talented all three of them must be."

For their part, Slava, Nina, and Laza (pictured right to left, below) find their own nearly identical trajectories unsurprising. "We were taught at a young age that science majors can do a lot of good for society," Slava says.

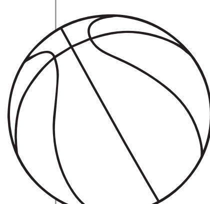
In fact, according to all three, one of the biggest challenges since leaving high school has been learning to rely on something they had honestly never needed before now: study groups. —*DZ*

Insider Info

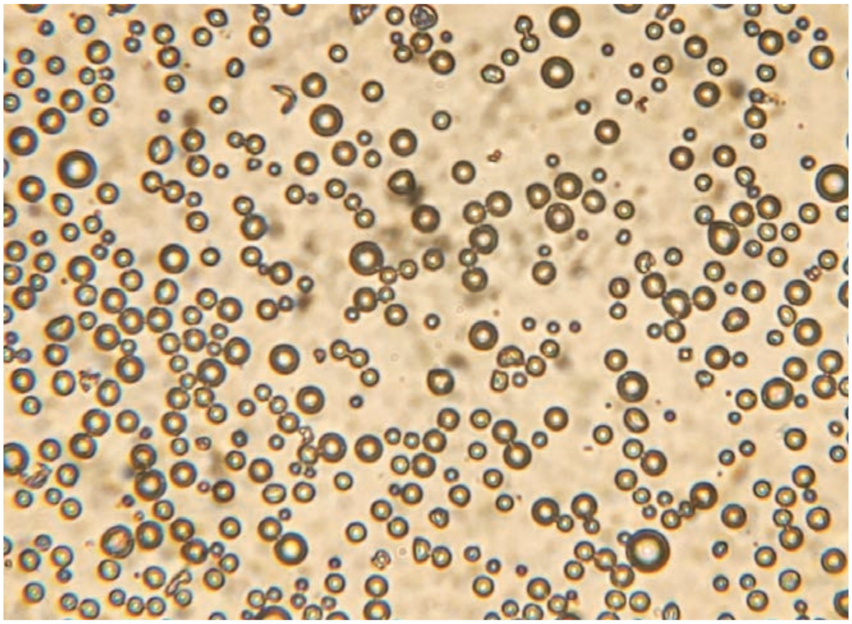
Former *E&S* editor Doug Smith contributed to more than **85** issues of the magazine prior to his retirement in November 2015.



2 alumni, Arthur McDonald (PhD '70) and Ian Agol (BS '92), have been named recipients of 2016 Breakthrough Prize awards. Read about previous Caltech winners on page 24.



Sports Illustrated dedicated nearly **7,000** words to a story on the recent successes of the Caltech men's basketball team. Learn more about our stellar student athletes on page 18.



POP, FOCUS, DESTROY

A new technique developed at Caltech that uses gas-filled microbubbles for focusing light inside tissue could one day provide doctors with a minimally invasive way of destroying tumors with lasers, and lead to improved diagnostic medical imaging.

The primary challenge with focusing light inside the body is that biological tissue is optically opaque. Unlike transparent glass, the cells and proteins that make up tissue scatter and absorb light. "Our tissues behave very much like dense fog as far as light is concerned," says Changhuei Yang, professor of electrical engineering, bioengineering, and medical engineering. "Just like we cannot focus a car's headlight through fog, scientists have always had difficulty focusing light through tissues."

To get around this problem, Yang and his team turned to microbubbles, commonly used in medicine to enhance contrast in ultrasound imaging. First, gas-filled microbubbles encapsulated by thin protein shells and injected into tissue are ruptured with ultrasound waves. By measuring the difference in light transmission before and after such an event, the Caltech researchers can modify the wavefront of a laser beam so that it focuses on the original locations of the microbubbles. The result, Yang explains, "is as if you're searching for someone in a dark field, and suddenly the person lets off a flare. For a brief moment, the person is illuminated and you can home in on their location."

If the technique is shown to work effectively inside living tissue—without, for example, any negative effects from the bursting microbubbles—it could enable a range of research and medical applications. For example, by combining the microbubbles with an antibody probe engineered to seek out biomarkers associated with cancer, doctors could target and then destroy tumors deep inside the body or detect malignant growths much sooner.

"Ultrasound and X-ray techniques can only detect cancer after it forms a mass," Yang says. "But with optical focusing, you could catch cancerous cells while they are undergoing biochemical changes but before they undergo morphological changes." —*KT*

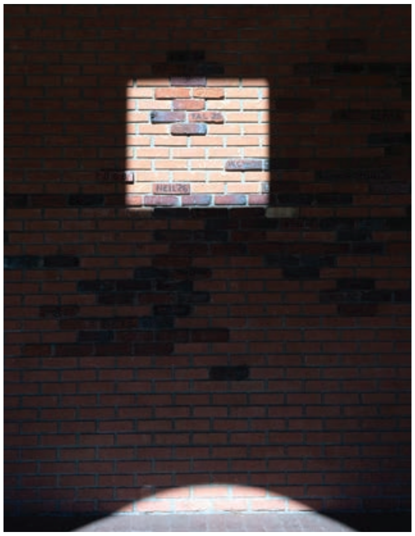
DID YOU KNOW?

The **2015–16** academic year marks the **50th** anniversary of the Division of the Humanities and Social Sciences. Humanities was one of the Institute's original divisions, dating back to 1926, but social sciences were not added until the 1965–66 school year. Learn more at hss.caltech.edu.

On the Grounds

Fire once illuminated these bricks, now seen warming in the midday sun. Originally placed on the interior chimney of the Throop Club—a student hangout built in the mid-1920s and dismantled in the early 1960s—the bricks were "sold" by students to raise money, and feature the names of individuals and clubs who donated funds. When the Throop Club was demolished, Caltech kept its promise that the bricks would never leave campus. So where did they end up?

Answer: The south-facing exterior wall of the Winnett Student Center.



BY THE NUMBERS

VOLUNTEERS FOR VETS

Just northeast of the Caltech campus, students and staff have been lending a hand as tutors at the Pasadena City College Veterans Resource Center (VRC)—established in 2010 under a grant from the California Community Colleges Chancellor's Office—to provide support and guidance to the campus veterans. Patricia D'Orange-Martin, coordinator of the VRC, calls the Caltech cohort "the core of our tutoring/mentoring team" and credits it with providing support, "particularly for veterans preparing to transfer to four-year colleges and universities."

Years that Caltech students and staff have been participating in the program	Number of student veterans who have received tutoring from Caltech volunteers	Number of Caltech tutors during the 2015 spring and fall semesters	Percentage of the program's support provided by Caltech volunteers	Number of subjects covered in tutoring sessions
3	50	30	60+	5

Serving veterans, says Mitch Aiken, associate director for educational outreach at Caltech's Center for Teaching, Learning, & Outreach, "provides our students with the chance to deliver meaningful one-on-one outreach." It also allows them to "give back, expand their own worldview, and get in some excellent real-world teaching experience," he says. *—DZ*

*FACULTY FOOTNOTES

Mansi Kasliwal is a new assistant professor but certainly not a Caltech newbie. The astronomer earned her PhD here in 2011, having helped design and build the Palomar Transient Factory (PTF), an automated wide-field survey at Palomar Observatory that systematically searches for cosmic transients—powerful events like supernovae that appear in the night sky with the light of a million to a billion suns, and then fade away.

"These are extreme events where a lot of elements that we see around us are actually synthesized," says Kasliwal.

Kasliwal continues to work with PTF and its successor, the Zwicky Transient Facility (ZTF), but is also leading a major international project devoted to chasing and studying transients using observatories around the globe. Known as GROWTH, for Global Relay of Observatories Watching Transients Happen, the project was recently granted $4.5 million through the National Science Foundation's Partnerships in International Research and Education (PIRE) program. Its goal is to detect transients and then "stay unbeaten by sunrise."

"We just go around the globe and keep passing the baton so that the sky remains dark," explains Kasliwal.

Here are a few more fun facts about Kasliwal:

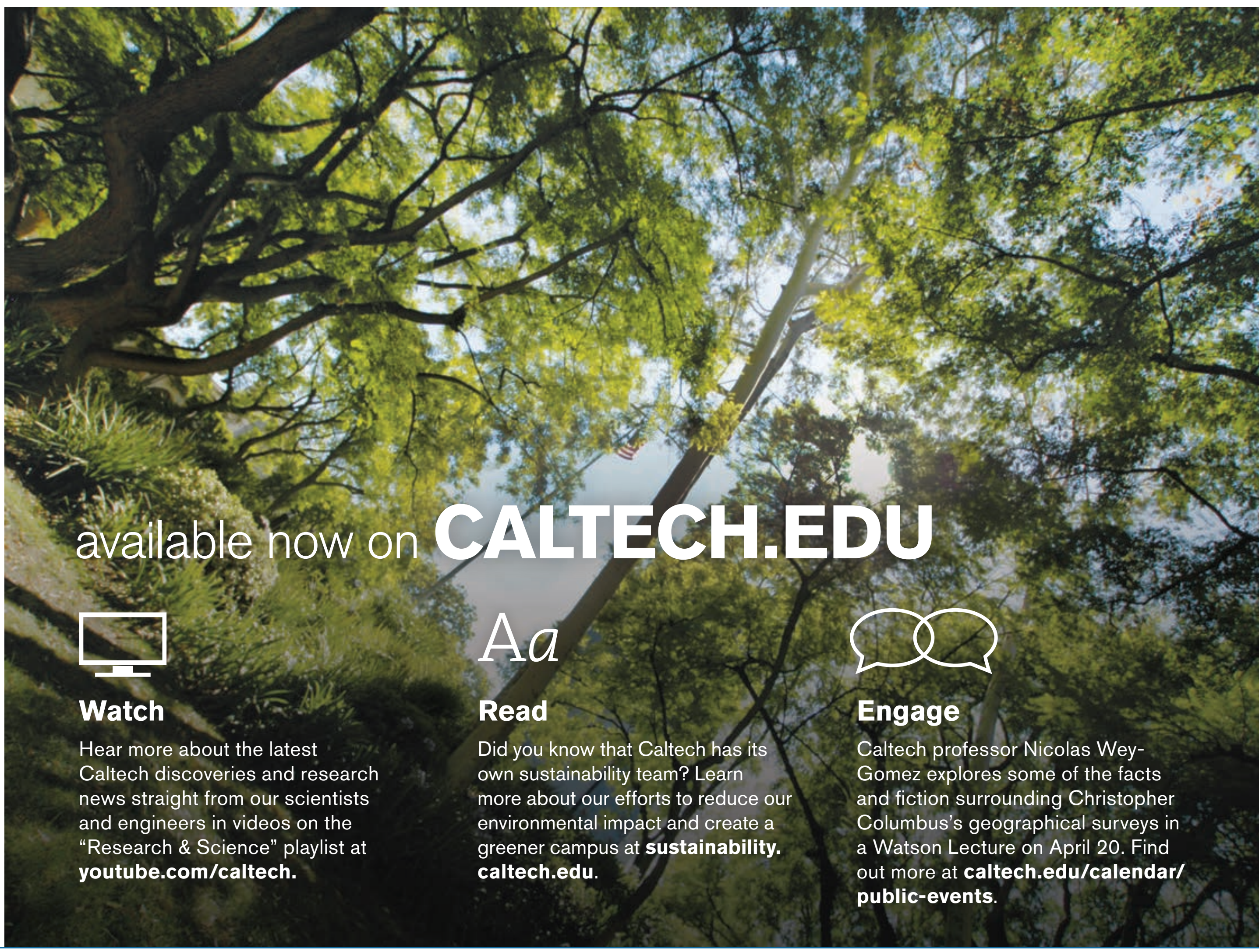
- **She grew up in Indore, India, and came to the United States as an adventurous 15-year-old.** Noting Kasliwal's love of the natural sciences, a teacher in India advised Kasliwal to apply to American boarding schools. She took her advice and attended a college-prep school in Connecticut for her junior year. She spent her senior year taking classes and working with a professor at Bryn Mawr College.

- **She studied applied and engineering physics as an undergrad at Cornell.** Astrophysics was only her concentration, but at Cornell she was able to work with the late Jim Houck, the principal investigator for the infrared spectrograph on NASA's Spitzer Space Telescope. "Spitzer was being launched, and I got to see the data start flowing in," says Kasliwal. "From then on, I was just completely hooked."

- **Her work has already made it into textbooks.** Kasliwal received a freshman astronomy textbook in the mail from a professor she had interned with and was astonished to find a page in it dedicated to a supernova that she had discovered. "It was one of the most awesome moments for me," she says.

Celebrating the Shared Legacy of Beckman and Gray

In November 2015, Caltech marked both the 25th anniversary of the Beckman Institute and the 80th birthday of chemist Harry Gray with a two-day "Invention and Imagination in the Molecular Sciences" symposium. Gray and the late Arnold Beckman (PhD '28), former Caltech professor and chairman emeritus of the Caltech board of trustees, began a close working relationship in the late 1960s, when Gray arrived at Caltech. Beckman (left) congratulates Harry Gray on becoming the first Arnold O. Beckman Professor of Chemistry in 1981. Gray is also the founding director of the Beckman Institute, a multidisciplinary center for research in the chemical and biological sciences that was dedicated in 1989 with funds from the Arnold and Mabel Beckman Foundation.



FROM FRATBOYS TO FLEMS:
The History of Caltech's Unique House System

For nearly 85 years, the House system at Caltech has played a critical role in undergraduate social and residential life. In 2002, Ted Jou (BS '03) wrote "A History of Undergraduate Self-Governance at Caltech" for a Student Undergraduate Research Fellowships (SURF) project, which, among other things, outlined the origins of Caltech as a residential college. Excerpts from his paper tell the tale of the first four Houses (or Hovses, as inscribed on the actual buildings).

Fleming Hovse

On his seventy-fourth birthday, the President of the Caltech Board of Trustees, Arthur H. Fleming, was surprised with the announcement that the last unit of the new student dormitories would be named in his honor. In 1930, twenty donors gave $10,000 each to fund the construction of Fleming House, and a new era in Caltech undergraduate student life was born.

Before that time, there was only room for about 60 students on campus in a single dormitory. Caltech students were spread throughout a variety of off-campus housing, which included five fraternity houses: Sigma Alpha Pi (est. 1914), Pi Alpha Tau (est. 1921), Gamma Sigma (est. 1925), Kappa Gamma a.k.a. Gnome (est. 1897), and Phi Alpha Ro a.k.a. Pharos (est. 1921). This still left about 350 of the enrolled undergraduates living in their own housing. The trustees decided that Caltech should seek to house as many of its students on campus as possible so a plan for a group of four undergraduate dorms was drafted. Construction began as soon as $200,000 per dorm was raised. On March 11, 1930, the *California Tech* proclaimed, "Dorms will Rise at Once!"

A committee of nine students was formed to investigate student living conditions and make detailed recommendations for the conduct and organization of the new undergraduate dormitories. Members of the committee toured the U.S., Europe, and Canada to find out what organization would be best for the student residences. On March 5, 1931, they published their findings in the *California Tech*. Their recommendations formed the foundation for the undergraduate Houses at Caltech, and many of their ideals hold true today. Here are some highlights from their report:

- *"Freshmen shall be distributed among the four houses as equally as possible."*
- *"Choice of rooms in each house shall be given according to seniority."*
- *"Students shall be given the opportunity to wait on tables."*
- *"Conduct of house functions and the maintenance of order shall be placed entirely in the hands of the students."*
- *"Social affairs and the entertainment of visitors should be strongly encouraged."*
- *"Inter-house and intra-house competitions should be fostered."*

Ricketts Hovse

The fraternities at Caltech all agreed to the recommendations with very little resistance and the next year, they each moved as groups into the four new Houses. The Gnomes moved into Ricketts House, the Pharos moved into Blacker, the Gamma Sigmas moved into Dabney, and Pi Alpha Tau, the smallest fraternity, joined Sigma Alpha Pi in colonizing Fleming.

Since the early 1930s, the four Houses have grown to eight, with Lloyd, Page, and Ruddock Houses coming on board in 1960, and Avery House—built in 1996—joining the roster of undergraduate-only student residences in 2005.

NO REST FOR A NOBELIST

If you were to write the life story of a Nobel laureate, you might be forgiven for wanting to make the early morning call and its immediate aftermath the zenith of the story's arc, followed by little more than a tuxedo, a speech presented before Swedish royalty, and several bottles of champagne.

You'd be wrong, but you'd be forgiven.

For the vast majority of the 34 Caltech faculty and alumni who have together won 35 Nobels—Linus Pauling (PhD '25) being the Institute's dual laureate, with a 1954 prize in chemistry and a 1962 peace prize—the award is just the beginning, an avenue-opening, support-generating, idea-spawning opportunity for a second, and sometimes a third or fourth, act. Caltech's Nobelists have picked up prizes only to switch fields, revisit dead-end questions, or dig deeper into the work that garnered them the award in the first place. They've gone birdwatching, fought for recognition of the dangers of radiation to the human body, worked to revamp education, and been named president of the California Institute of Technology.

In other words, they've taken the Nobel Prize, and the opportunities and possibilities it affords, and made the very most of them. Here is just a taste of where Caltech's Nobel laureates have gone, what they've done, and how they've impacted our world. —*LO*

Throop University is founded. The school would go by three different names before becoming the California Institute of Technology in 1920.

1891

Robert A. Millikan (1868–1953)
Nobel Prize in Physics in 1923 "for his work on the elementary charge of electricity and on the photoelectric effect"

Two years prior to winning the Nobel Prize, Millikan became the director of the Norman Bridge Laboratory of Physics and the inaugural chairman of the Executive Council of Caltech, meaning he was effectively the school's first president. He served in this position until his retirement in 1945. Millikan also coined the term *cosmic ray* when, after receiving the Nobel, he focused his research at Caltech on radiation from outer space.

"Millikan was doing all these wonderful things with cosmic rays, and we all measured the charge on the electron in the laboratory, so his name was known to every interested student," recalled William A. Fowler (PhD '36), in a 1994 oral history about why he came to Caltech. Fowler himself won a Nobel Prize in Physics in 1983.

Carl D. Anderson
(1905–1991; BS '27, PhD '30)
Nobel Prize in Physics in 1936 "for his discovery of the positron"

Anderson studied under Robert A. Millikan and spent his entire academic and research career at Caltech. In the same year that he won a Nobel at the age of 31 for the discovery of the positron, Anderson and a graduate student discovered a subatomic particle similar to the electron called the muon. He then went on to conduct research in rocketry.

Anderson described the financial impact of the prize in a 1979 oral history: "I happened to get it when I was young—I was an assistant professor, I think. I, of course, didn't have much money, and I had a mother to support, who was not well and had to make several trips to the hospital. . . . So it was a great help to me financially. Incidentally, I didn't have enough money to get to Stockholm. So Millikan loaned me $500 for a one-way ticket, which I paid back when I came back from Stockholm."

Edwin M. McMillan
(1907–1991; BS '28, MS '29)
Nobel Prize in Chemistry in 1951 (with Glenn T. Seaborg) "for their discoveries in the chemistry of the transuranium elements"

In 1954, McMillan was appointed associate director of the Berkeley Radiation Laboratory and became director in 1958, a position he held until his retirement in 1973. During that time, he also served in several other leadership positions, including as the chairman of the National Academy of Sciences from 1968 to 1971. After retiring, McMillan spent a year working on an experiment at CERN to measure the magnetic moment of the muon.

Robert A. Millikan
Physics
1923

Thomas H. Morgan
Physiology or Medicine
1933

Carl D. Anderson
(BS '27, PhD '30)
Physics
1936

Edwin M. McMillan
(BS '28, MS '29)
Chemistry
1951

Linus Pauling
(PhD '25)
Chemistry
1954

As for how this work would impact the world, Einar Löfstedt, Member of the Royal Academy of Sciences, summed it up in an address to McMillan and Seaborg at the 1951 Nobel banquet: "You have succeeded in augmenting the well-known periodical system with no less than six new elements. The result is, even for the layman, imposing in itself; in addition, among the many new kinds of atoms you have produced, are those which can be used for generating atomic energy—let it be noted, not merely for military, but also for peaceful ends. This is a vast perspective for future development which opens up before the imagination."

Richard Feynman (1918–1988)
Nobel Prize in Physics in 1965 (with Sin-Itiro Tomonaga and Julian Schwinger) "for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles"

In January 2016, Caltech held an event celebrating the legacy of Richard Feynman, which included a long and revered teaching career both at the Institute and through a series of lectures aimed at laypeople interested in physics.

In a blog tribute titled "The Best Teacher I Never Had" and written for the event, Bill Gates remembers how he stumbled upon Feynman's lectures.

"A friend and I were planning a trip together and wanted to mix a little learning in with our relaxation. We looked at a local university's film collection, saw that they had one of his lectures on physics, and checked it out. We loved it so much that we ended up watching it twice. Feynman had this amazing knack for making physics clear and fun at the same time. I immediately went looking for more of his talks, and I've been a big fan ever since. Years later I bought the rights to those lectures and worked with Microsoft to get them posted online for free.

"In that sense, Feynman has a lot in common with all the amazing teachers I've met in schools across the country. You walk into their classroom and immediately feel the energy—the way they engage their students—and their passion for whatever subject they're teaching."

Max Delbrück (1906–1981)
Nobel Prize in Physiology or Medicine in 1969 (with Alfred D. Hershey and Salvador E. Luria) "for their discoveries concerning the replication mechanism and the genetic structure of viruses"

Delbrück recalled the experience of winning a Nobel in a 1978 oral history.

"It's not like if you are a writer, let us say, and you have struggled for 30 years to establish a name for yourself, and all of a sudden you get this bonanza, all this recognition. For many scientists that is not so. I mean by the time they get the Nobel Prize they have long since become full professors, they have all the grants, they have got everything they want. It doesn't mean anything except that they now get a lot of solicitations to contribute to that, and a lot of solicitations to put their name onto this, and it's a lot of minor nuisances and minor ego trips involved with it."

After receiving the prize, Delbrück returned to Caltech—where he had had a lab since 1947—and continued his research until his death in 1981.

David Baltimore (1938–)
Nobel Prize in Physiology or Medicine in 1975 (with Renato Dulbecco and Howard Martin Temin) "for their discoveries concerning the interaction between tumour viruses and the genetic material of the cell"

Baltimore, the Robert Andrews Millikan Professor of Biology, and President Emeritus of Caltech, was interviewed recently about his life and work after the prize.

"When you win the Nobel Prize, you become much more visible as a member of the scientific community. Visible to the press, visible to your colleagues, visible to students. Today, and ever since, when I meet a student, I know that they're looking at me and saying, 'That's a Nobel Prize winner.' And it actually makes normal communication more difficult because they think I come from some other planet.

"I had to accept the medal of speaking for the scientific community and have spent now basically almost all of my career as a sort of visible member of the scientific community, conscious of a responsibility and an opportunity.

"I've been involved in some of the biggest changes in the nature of biology, the way we do it, and the controversies that have been associated with that. Probably the biggest one was the recombinant DNA controversy in 1975, partly as a result of my work. We suddenly realized that there was a new capability, the capability to cut and paste DNA and therefore to move genes from one organism to another, to modify genes, to capture genes, to use them in biotechnology, and that was a monumental new way of looking at biological experimentation and the

1956 — William B. Shockley (BS '32), *Physics*

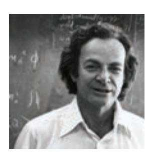
1958 — George W. Beadle, *Physiology or Medicine*

1960 — Donald A. Glaser (PhD '50), *Physics*

1961 — Rudolf L. Mössbauer, *Physics*

1962 — Linus Pauling (PhD '25), *Peace*

1964 — Charles H. Townes (PhD '39), *Physics*



1965 — Richard P. Feynman, *Physics*

1969 — Max Delbrück, *Physiology or Medicine*; Murray Gell-Mann, *Physics*

capabilities of our profession. But it also raised the issue of whether we were going to create some kind of monster, some kind of problem, disease-causing organisms. And so the world got pretty worried about that.

"I was part of the organization that put together the Asilomar Conference, a conference that looked at this question of danger coming from the new capabilities and put in place a procedure whereby we could slowly extend the capabilities to new organisms and new ways of doing science with safe checks along the way so that this was done carefully over a decade. And I think that gave the general public a sense that we were being responsible as scientists.

"Inevitably the biggest impact that people will have seen from my career is the discovery of the reverse transcriptase because that won the Nobel Prize and stood out. I think that in all of the areas where I've worked, there are personal satisfactions which are as great as that—the success of my students."

Renato Dulbecco (1914–2012)
Nobel Prize in Physiology or Medicine in 1975 (with David Baltimore and Howard M. Temin) "for their discoveries concerning the interaction between tumour viruses and the genetic material of the cell"

In August 2005, Dulbecco added an addendum to the biography he wrote for the Nobel Prize website, reflecting on his life after the award.

"After I received the Nobel Prize my research interest shifted to the study of naturally occurring cancers. I concentrated on a model system, mammary cancers induced in rats, and I spent some time learning how to work with them. . . . Using monoclonal antibodies against our cells we could identify several different types of cells, and proposed a role for them in the development of the gland.

"During this work I became aware of the major difficulty in trying to identify cell types and their roles in both development and carcinogenesis. It became obvious to me that some major effort had to be made to gain knowledge of the genes active in cells; the determination of the genes present in a given species would be the starting point. I thus suggested the starting of a genome project in two lectures I gave in 1985 and 1986. These suggestions remained without consequences. Thus I wrote a paper to the same effect in *Science* in 1986. The paper had enormous resonance, at first mostly negative, but very soon converted into positive. In the end it helped the emergence of the genome project."

William A. Fowler (1911–1995)
Nobel Prize in Physics in 1983 "for his theoretical and experimental studies of the nuclear reactions of importance in the formation of the chemical elements in the universe." He split the prize with Subramanyan Chandrasekhar, who received the award "for his theoretical studies of the physical processes of importance to the structure and evolution of the stars."

In 1984, just a year after receiving the Nobel Prize, Fowler was interviewed for an oral history and talked about his then-ongoing projects.

"So the current situation is that a really very elegant theory, which has had an incredible number of successes, predicts that the current density of the universe on average is five times 10^{-30} grams per centimeter cubed, whereas our work on the production of the light isotopes in

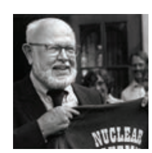
1975
Renato Dulbecco
David Baltimore
Howard M. Temin
(PhD '60)
Physiology or Medicine
Leo James Rainwater
(BS '39)
Physics

1976
William N. Lipscomb
(PhD '46)
Chemistry

1978
Robert W. Wilson
(PhD '62)
Physics

1981
Roger W. Sperry
Physiology or Medicine

1982
Kenneth G. Wilson
(PhD '61)
Physics

1983

William A. Fowler
(PhD '36)
Physics

the Big Bang gives a baryon density—that's ordinary matter—of only five times 10^{-31}. So there's a deficiency, ninety percent, and one of the fashionable suggestions for what makes up the deficiency is massive neutrinos. By 'massive,' I mean something of the order of 1/100,000 of the mass of the electron.

"That's the problem that—when I'm able to do so—I'm mainly working on. If neutrinos are massive, that can also explain the solar neutrino problem, because if neutrinos are to oscillate or transform from one form to the other, which would explain the solar neutrino problem, they have to have a mass and they have to have slightly different masses. And Felix Boehm, by looking for oscillations on a terrestrial scale—a few meters—has shown that the mass differences have to be very small; but the differences could be incredibly smaller and still give oscillations in the great distance between the sun and the earth."

Rudolph A. Marcus (1923–)
Nobel Prize in Chemistry in 1992 "for his contributions to the theory of electron transfer reactions in chemical systems"

Marcus, the John G. Kirkwood and Arthur A. Noyes Professor of Chemistry, discussed his post-Nobel experience in a recent interview.

"Life certainly became busier. I tried and did maintain the research program at the same rate as before in terms of number of people that were with me and in terms of doing things on my own. All along, I continued to do some thinking on my own; I just enjoy playing with ideas involving theory and trying to understand some experiments.

"In addition to having what I had before, then there were all these invitations that really arose primarily because of the Nobel Prize.

"But it meant for a far busier life, and doing new activities that took a lot of time made doing research on one's own a little more difficult.

"There are various unanswered problems in fields that I've been involved with, including some that my group and I are working on currently, so I am excited to find the answers to those problems. For example, the field of 'single molecule' experiments has provided new challenges. In one study of a biological molecular motor, we have applied theories about how chemical and mechanical aspects within the system might work to data from single molecule experiments to build a more detailed model of the motors. To learn more, we are applying the same method to another type of single molecule experimental results on the same system."

"The common theme is seeing something which is a puzzle and trying to find an answer to it. . . . It goes back to doing puzzles as a child, actually."

Ahmed H. Zewail (1946–)
Nobel Prize in Chemistry in 1999 "for his studies of the transition states of chemical reactions using femtosecond spectroscopy"

Zewail is the Linus Pauling Professor of Chemistry and professor of physics at Caltech. In January 2006 he added an addendum to the biography he wrote for the Nobel Prize website, reflecting on his life after the award.

"After the awarding of the Nobel Prize in 1999, I continued to serve as a faculty member at Caltech . . . and as the Director of the Physical Biology Center for Ultrafast Science and Technology

1992 — Rudolph A. Marcus, *Chemistry*

1995 — Edward B. Lewis (PhD '42), *Physiology or Medicine*

1996 — Douglas D. Osheroff (BS'67), *Physics*

1997 — Robert C. Merton (MS '67), *Economic Sciences*

1999 — Ahmed H. Zewail, *Chemistry*

2001 — Leland Hartwell (BS '61), *Physiology or Medicine*

2002 — Vernon L. Smith (BS '49), *Economic Sciences* and the NSF Laboratory for Molecular Sciences. Current research is devoted to dynamical chemistry and biology, with a focus on the physics of elementary processes in complex systems. A major research frontier is the new development of '4D ultrafast diffraction and microscopy,' making possible the imaging of transient structures in space and time with atomic-scale resolution.

"I have also devoted some time to giving public lectures in order to enhance awareness of the value of knowledge gained from fundamental research, and helping the population of developing countries through the promotion of science and technology for the betterment of society. Because of the unique East-West cultures that I represent, I wrote a book *Voyage Through Time—Walks of Life to the Nobel Prize* hoping to share the experience, especially with young people, and to remind them that it is possible! This book is in 12 editions and languages, so far."

Robert H. Grubbs (1942–)
Nobel Prize in Chemistry in 2005 (with Yves Chauvin and Richard R. Schrock) "for the development of the metathesis method in organic synthesis"

Grubbs, the Victor and Elizabeth Atkins Professor of Chemistry, talked about life after the Nobel in a recent interview.

"I really liked doing what I was doing before [the prize], so I've mostly continued doing that. I think my wife had the best statement on it. She said, 'We now drink better wine and we dance more.'

"I'm getting old, so I'm going to have fun now. Part of what we're doing is making better catalysts. . . . We're also trying to define and find new transformations that use catalysts to convert a molecule, one into another one.

"There's a new Hepatitis C treatment, and one of the molecules that is involved in that new treatment, which finally cures Hepatitis C, is a molecule made using our chemistry.

"And then another whole area which I've been working on for a long time, which is sort of my hobby now, is developing materials for biomedical applications.

"We probably have 10 different projects going now that are developing materials for really interesting [medical] applications. . . . It's not biology; it's what I call plumbing, and we're having a good time developing these materials.

"The only thing going forward is that I hope we can have the opportunity to keep going for quite a while and these wonderful students keep showing up, and postdocs. I'd like to have a chance to do a few more things."

Eric Betzig (1960–, BS '83)
Nobel Prize in Chemistry in 2014 (with Stefan W. Hell and William E. Moerner) "for the development of super-resolved fluorescence microscopy"

Betzig, a researcher at the Howard Hughes Medical Institute's Janelia Research Campus, commented on the effects a Nobel Prize will likely have on his life in a biography written for the Nobel website.

"Being fundamentally a pessimist, I still have two fears. One is that the distractions from the Nobel will disrupt our research model and hamper our productivity, as it has already begun to do. The other is that I feel we've been too successful.

"I think it's my obligation, given the

resources at Janelia and the prestige and security of the Nobel, to throw the dice again, and do crazy, risky stuff. Harald [Hess] and I are working together again with our respective groups in this direction. Only time will tell if anything comes of it, which is just the way I like it." E&S

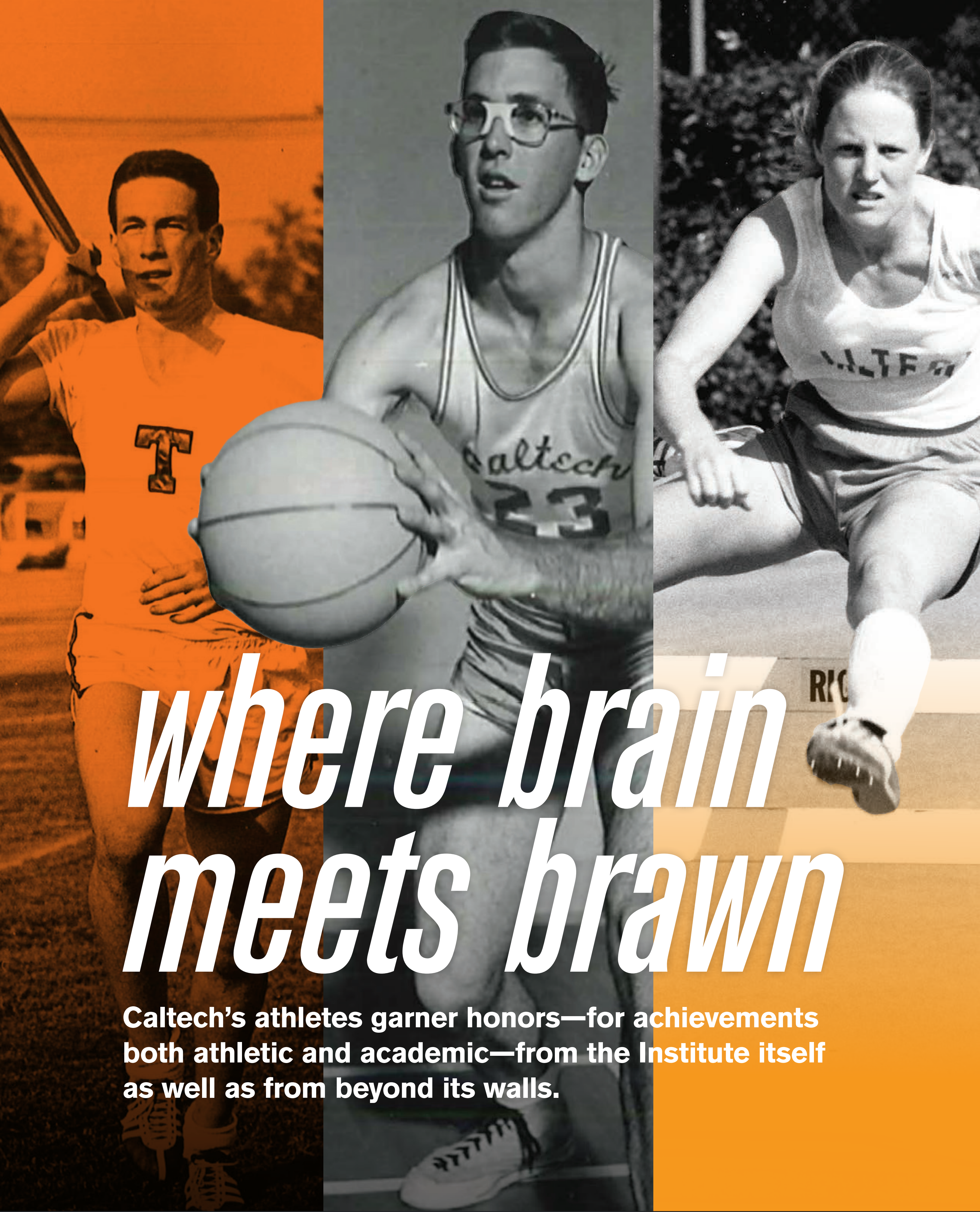
Hugh David Politzer
Physics
2004

Robert H. Grubbs
Chemistry
2005

Martin Karplus (PhD '54)
Chemistry
2013

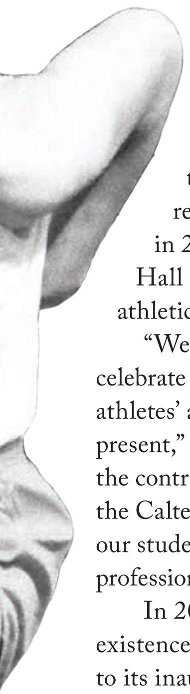
Eric Betzig (BS '83)
Chemistry
2014

Arthur B. McDonald (PhD '70)
Physics
2015



where brain meets brawn

Caltech's athletes garner honors—for achievements both athletic and academic—from the Institute itself as well as from beyond its walls.



Caltech students are certainly known more for their intellectual prowess than their athletic aptitude, but in fact the Institute has quite a history of educating and mentoring gifted athletes. So much so that when Betsy Mitchell—an Olympic gold medalist in swimming herself—joined the staff as director of athletics, recreation, and physical education in 2011, she decided to establish a Hall of Honor to recognize Caltech's athletic heritage.

"We created the Hall of Honor to celebrate and commemorate our student-athletes' achievements, both past and present," says Mitchell, "and to recognize the contribution that participating in the Caltech athletics program plays in our students' personal, educational, and professional development."

In 2014—the Hall's first year in existence—eight alumni were named to its inaugural class, for feats ranging from holding Caltech's career points record (1,199) in basketball, to winning a silver medal in pole vaulting at the 1924 Olympics (one of three Caltech graduates who have competed in the Games), to earning All-SCIAC (Southern California Intercollegiate Athletic Conference) honors in five sports.

In addition, a pioneer award was given to Angie Bealko (BS '96), who played on the men's basketball team for a year before starting the women's basketball club in 1995; that club played a major role in the creation of the Institute's NCAA program of today. A team award was also given to the 1969–70 wrestling team for winning that year's SCIAC title outright.

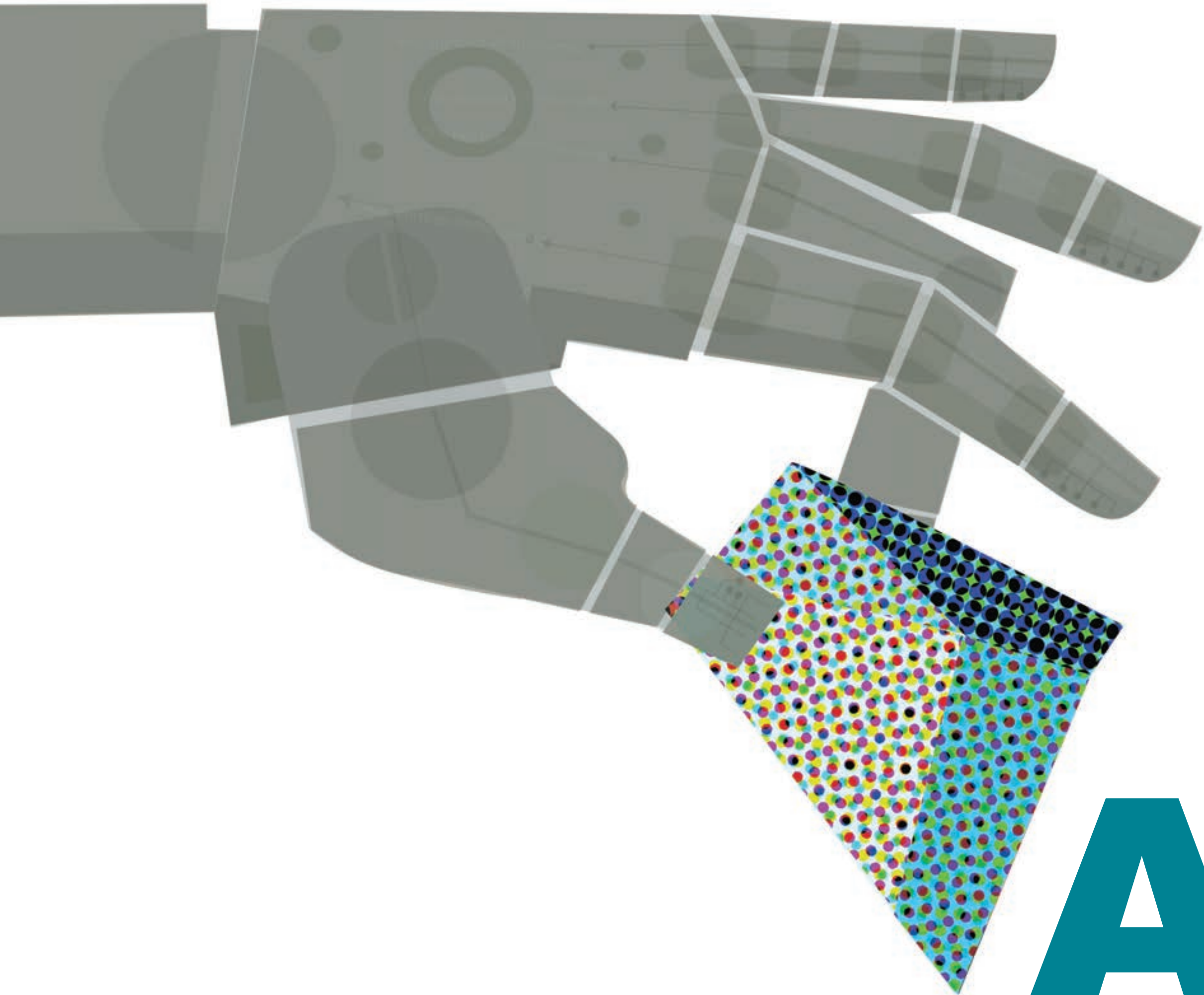
Six individual honorees were named in 2015, as was the first women's fencing team, which was formed in 1971—a year after women were admitted to Caltech. The individuals included a cross-country, shot-put, and discus star; the most decorated swimmer in Caltech history; and the only female recipient of Caltech's Goldsworthy Track Trophy for sportsmanship, team spirit, and proficiency.

Of course, there are many current students and recent graduates—those not yet eligible for or inducted into the Hall of Honor—who are nonetheless accomplished competitors in their own right and have garnered accolades for their achievements both on and off the field.

In recent years, three students—Christopher Bradley (class of '17), Aditya Bhagavathi (class of '16), and Jeremy Leibs (BS '06)—have been named Academic All-America honorees, in recognition of outstanding performance on the field and in the classroom. These students typically have GPAs of 3.8 or above and are accomplished athletes in their conference and nationally. During the 2014–15 school year, seven students received All-SCIAC Awards for exceptional performance within conference play, as voted on by coaches; eight received SCIAC Sportsmanship Awards; and 75 Caltech student-athletes received Academic All-SCIAC Honors for earning cumulative GPAs of 3.4 or better. Not too shabby for a school that also has one of the most demanding curriculums in the country.

"While Caltech is a world leader in research, educating 18- to 22-year-olds remains a core mission," says Mitchell. "This requires a broad perspective with attention paid to all parts of them as people. Nearly a quarter of our students are involved in sports at some level and pour their hearts into intercollegiate athletic competition, while as many as 80 percent of the study body is involved in sports at some level. This is reason enough to value their accomplishments and endeavors in the athletic realm, in addition to honoring the invaluable skills learned through the athletic curriculum in this very public laboratory. We are proud of our athletic accomplishments and strive to build on them every day." —AA/KN e&s

From left: Phil Conley (BS '56) placed 10th in the javelin competition at the 1956 Olympic Games. Fred Newman (BS '59) played four sports at Caltech and, after graduating, earned numerous world records for his free-throw shooting ability. Karen (Close) Tanaka (BS '83), a runner and a hurdler, was "one of the best athletes on campus in her era." Aditya Bhagavathi (class of '16) has received many honors for his performance as a runner. To learn more about Caltech student athletes, past and present, visit gocaltech.com



A Feeling Touch

By Katie Neith

Biologist Richard Andersen is using BRAIN awards to build on past successes and bring robotic-limb research to a whole new sensory level

The act of reading this article probably doesn't seem like a complex task to you—or much of a tactile one. Your eyes simply scan the text; your brain processes the sentences and images to give them meaning. But if you think about it, there's more to the reading experience. Chances are, you're using your hands to access these lines—either by turning the pages of the physical magazine, clicking around with a computer mouse, or tapping on a tablet screen. But these motions are so ingrained, so intuitive, you likely don't think of them as part of the reading process at all.

Now imagine what reading a magazine would be like if you weren't able to feel those movements, if you had to flip through the pages without being able to perceive their texture with your fingers, or if you had to type and click without any feeling in your hands, using only vision to guide you. It would change the entire experience—and make it much more difficult.

This is the challenge experienced by patients who, for whatever reason, have lost the use of their hands or arms, and thus have lost their sense of touch. And giving them back that critical yet oft-ignored sense is why Caltech biologist Richard Andersen is working so hard to incorporate a sense of touch into the neural prosthetics he's been helping develop for years—devices implanted in the brain that allow a paralyzed patient to manipulate a robotic arm.

Andersen and colleagues first reported success of his original implant in early 2015. The team, led by Andersen, placed their prosthesis in the posterior parietal cortex, an area that controls one's *intent* to move rather than controlling movement directly as previous experiments had done. This allowed Erik Sorto, a 35-year-old man who has been paralyzed from the neck down for more than 10 years, to use a robotic arm placed next to his body to perform a fluid hand-shaking gesture, play rock-paper-scissors, and even grasp a bottle of beer and bring it to his mouth for a sip—something he had long dreamed of doing.

"We showed that the posterior parietal cortex is an important source for gathering signals for the robotic arm that allow the patient to think just about the movement in general rather than in detail," explains Andersen. "As a result, we think moving the arm becomes more intuitive to the patient and requires less concentration. It's also faster and more efficient."

THE NEXT LEVEL

This kind of innovative reimagining of how to make a robotic arm move garnered Andersen a 2015 National Science Foundation (NSF) grant from President Obama's Brain Research through Advancing Innovative Neurotechnology—or BRAIN—Initiative, as well as seed money from the California Blueprint for Research to Advance Innovations in Neuroscience (Cal-BRAIN) program, the California complement to the federal initiative, which gave out its first-ever monetary awards last year to a group of researchers that included Andersen.

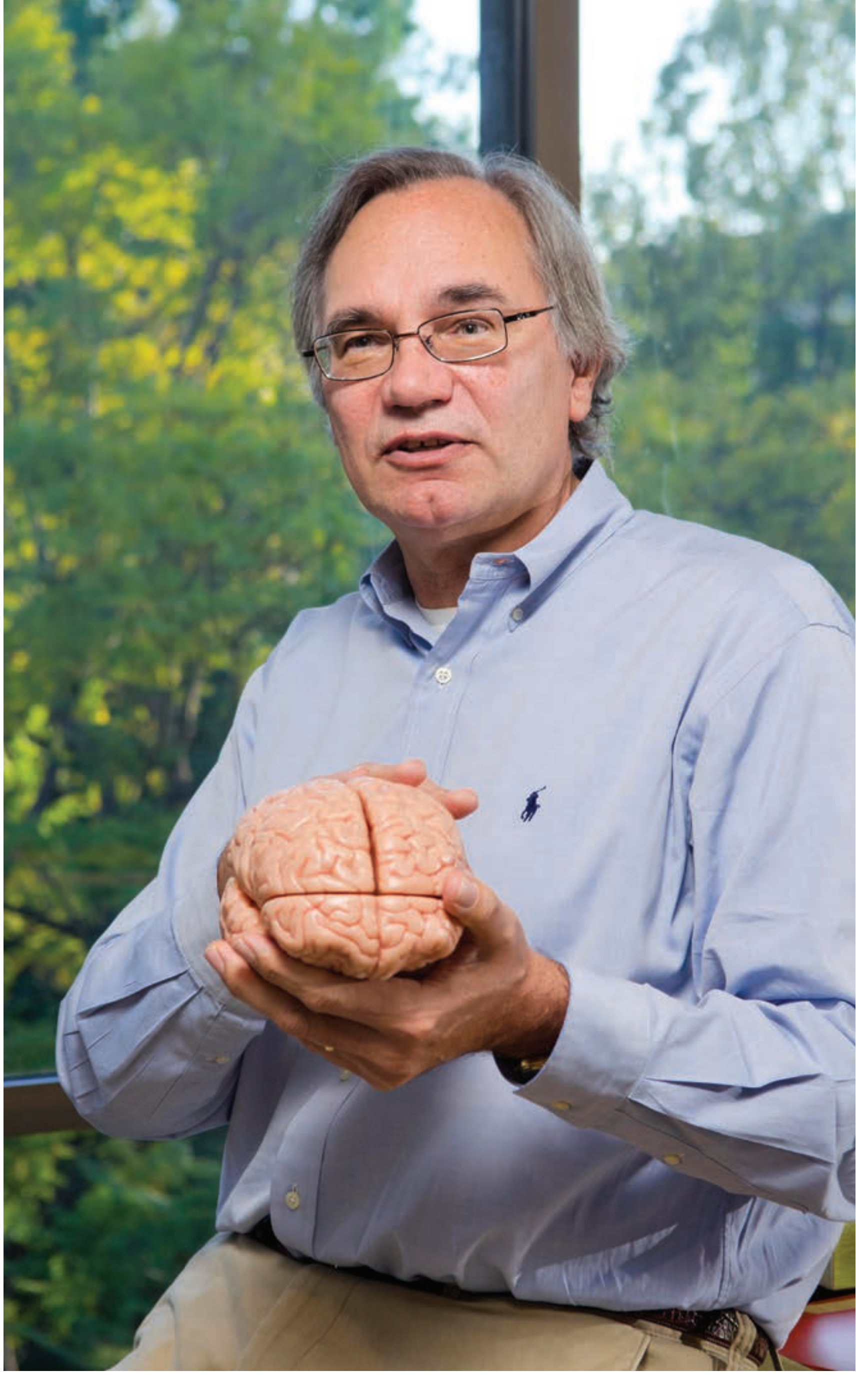
Andersen is now using those Cal-BRAIN funds—designed to bring together interdisciplinary teams of scientists and engineers from diverse fields for fundamental brain research—to take his team's work to the next level. His hope: to enable people using robotic arms to literally regain their sense of touch, their ability to feel an object in their "hands."

"Our patients with high-level spinal cord injuries are not only paralyzed, but they can't feel below their necks," explains Andersen. "The Cal-BRAIN grant is allowing us to put sensors on the hands of the robotic limbs, with the idea that these sensors will communicate with a prosthetic implant to stimulate an area of the brain that could reproduce a sense of touch when the robot hand touches an object."

Right now patients can use vision to guide the robotic arm. But that's far from ideal, says Andersen, who notes that if you anesthetize even just the fingertips of a healthy individual they will have great difficulty manipulating objects.

"It's hard to change the position of the object in the hand or to know if it's slipping or if the grasp is too tight if you can't actually feel it," he points out. "We want to return that sensation."

To make that possible, researchers will need to know exactly how sensations of touch may arise in the brain through electrical stimulation, so that they can implant prostheses to stimulate those neurons. Andersen decided it would be best to start with participants who do have a sense of touch. So he teamed up with the same colleagues from the University of Southern California who had also worked with Sorto to do a study looking at a subset of patients with epilepsy who have had



Richard Andersen is the James G. Boswell Professor of Neuroscience at Caltech.

temporary grids of electrodes implanted in their brains to find the source of their seizures—a fairly common diagnostic practice for epileptic patients who have not responded to drugs and for whom surgery may be an option. These patients are of interest not because of their epilepsy, but because the implanted grids—which often extend into the somatosensory cortex where the sense of touch seems to live—allow Andersen and his team to stimulate this specific area of the cortex, electrode by electrode. Each electrode produces sensations at a different location on the subject's hand, allowing the team to begin making a stimulation map of the hand.

"So far we've had two patients in whom we could map a hand representation using these grids," says Andersen, who stresses that the stimulation doesn't produce seizures or any other side effects.

Andersen and colleagues have also tested a healthy monkey's use of a virtual arm, represented as an avatar on a computer screen. The monkey used limb movements to control the avatar limb on a computer screen. When the virtual limb touched a virtual object, it produced the sense of touching the object.

"The idea here is that the subject is controlling the avatar hand movements with real movements of his own limb, but the sensation he feels in his hand is all coming from the brain," says Andersen. "And it works very well."

By combining the hand-representation maps and data from the virtual-arm avatar studies, Andersen and his colleagues have enough findings to implant a paralyzed patient soon.

"We'll be implanting the recording electrodes in two areas of the cerebral cortex—in the posterior parietal cortex where we implanted Erik Sorto's prosthesis, and one in the premotor cortex, an area in front of the motor cortex that's also important for grasping," says Andersen. Additionally two arrays of stimulating microelectrodes will be implanted in the somatosensory cortex. "That will help us see if we can use the sensory information as feedback to improve dexterity in activities that the subject performs with the brain-controlled robotic limb."

Since this would be their first attempt at providing sensory input to help a patient better use a prosthesis, there are a number of interesting challenges ahead, he says. For example, the team doesn't know if stimulation through the somatosensory cortex implants will reproduce sensations in the hand naturally, or if it will be a bit like the cochlear implant, which creates sensations similar to natural hearing—but not exactly alike—that the users must then learn to interpret as speech.

"We'd like it to be as natural as possible, but I have a feeling our subjects will need to do some interpreting of the signals, because even though the implanted electrodes are tiny, the stimulation will still likely activate hundreds of neurons, which may be too many neurons to produce a highly natural sensation" says Andersen. People with the implant, then, are likely going to need to learn how to use sensory signals that feel somewhat less natural.

A MORE HELPFUL ROBOT

Adding touch to a robotic arm isn't Andersen's only line of inquiry. Remember the story of Erik Sorto, who was able to reach out and drink beer for the first time since he had become a quadriplegic? That was a feasibility study to show that Sorto could make use of his desire to sip liquid at his own rate. But he didn't do it entirely on his own; he was assisted by "smart" robotics functions, such as the use of video cameras to look at the location and shape of the object in three dimensions and use that information to help form the correct grasp for the robotic arm so that its hand could grip the beer bottle. It also helped provide more precise control of the hand's digits (aka fingers) and determined how far the arm needed to reach for an object.

"By blending the intent of the subject with these smart robotics, it makes things much easier because the patient doesn't have to worry about all the small details," says Andersen.

It is to support this kind of research that Andersen received—and is using—his NSF award. The smart robotics study builds upon Andersen's prior experience with Erik Sorto and others like him, and brings together the same team: researchers and physicians from USC and Rancho Los Amigos National Rehabilitation Center. The Applied Physics Lab at Johns Hopkins, which does the robotic technology, is also involved.

"The NSF grant is allowing us to continue our collaboration with our robotics colleagues to move forward with the smart robotics, which is really how things in this area are going to work in the future," says Andersen. "Hoping that you can control everything you want the arm to do with just the few signals that you get out of the brain is not realistic. We need smart robotics to do at least some of the work." They plan to combine smart robotics with neural signals that select objects and the actions to be performed on the objects in order to increase the range of activities of daily living that can be performed by the subjects.

Ultimately, what Andersen hopes is to bring this work and the sensory-feedback prosthetic work together, providing people with paralysis from a variety of causes—strokes, nerve injuries, peripheral neuropathies—the control and ability to return to the most rewarding activities of their lives, like typing or playing the piano.

"Further down the line, with more grant funding and other support, we would like to combine a sensorized hand with smart robotics," says Andersen. "The idea would be to get to the point where the robotic arm is as good as a human arm."

But, he says, there are a lot of hurdles. "Among them is the current size of the system, which includes computers, cameras, and other machinery," says Andersen. "Another hurdle is that electrodes themselves need to be more biocompatible so more signals can be recorded in the brain for a much longer period of time."

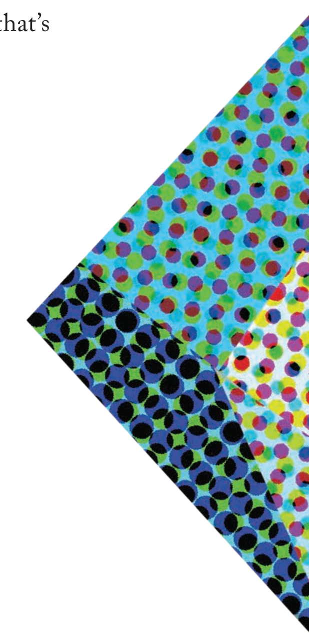
In the meantime, Andersen has come up with a bit of a workaround: he's helping restore some activities to paralyzed patients through the use of a computer tablet. In collaboration with UCLA, Andersen has been working with a subject, Nancy Smith, who has what he calls "really good bilateral finger representations," meaning that she can imagine finger movements to type or play the piano using a virtual keyboard or virtual piano keys.

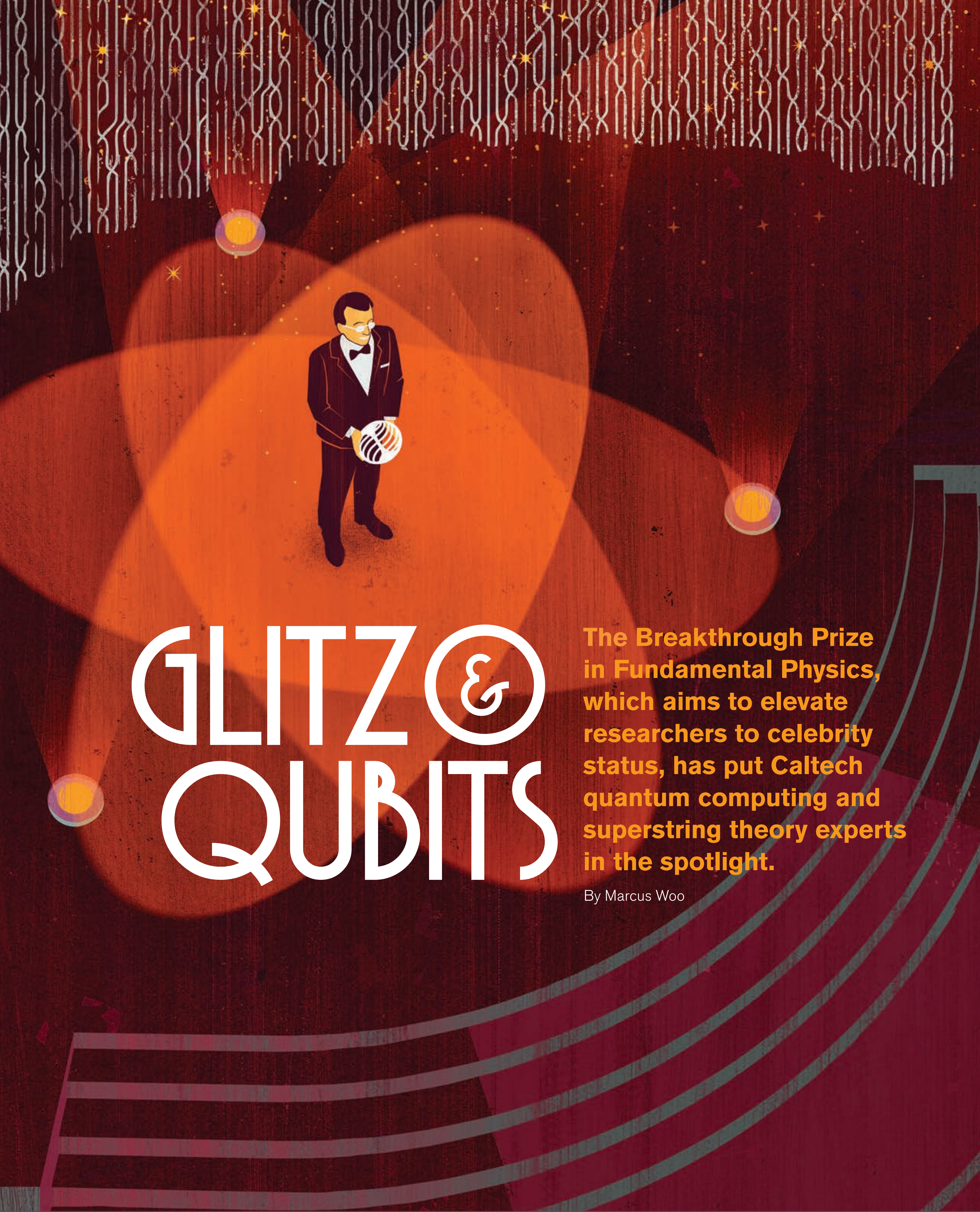
"We think an Android tablet or iPad is an especially valuable assistive device because so many functions are controlled by tablets now," Andersen says. "And all these projects feed into one another—as we learn different information in one, we might be able to apply it elsewhere or to the whole range of studies."

And all of this possibility and potential, he says, has come as a result of the awards he's been given by Cal-BRAIN and the NSF, among others.

The idea would be to get to the point where the robotic arm is as good as a human arm.

"Grants help to keep collaborations going and are beneficial to relationships that have been built through research," says Andersen. "In fact, our projects are examples of essential interdisciplinary funding and collaboration. If all of us weren't working on these projects, they wouldn't work. We think that collaboration is going to make a huge difference not only in our understanding of the brain, but also in the lives of the patients. And that's why we do this." e&s





GLITZ & QUBITS

The Breakthrough Prize in Fundamental Physics, which aims to elevate researchers to celebrity status, has put Caltech quantum computing and superstring theory experts in the spotlight.

By Marcus Woo

When the first email came, Alexei Kitaev ignored it. The subject heading said something about a physics award, but he thought it was just spam. "Then I received another email," says the Caltech physicist. "So I actually took a look and understood that it was real."

Real it was. Kitaev had won the first ever Breakthrough Prize in Fundamental Physics, established in 2012 by Russian billionaire entrepreneur Yuri Milner. And this new prize came with $3 million—three times what winners of the Nobel Prize get. Unlike the Nobels, the money isn't shared among the winners, of which there were eight others. "I couldn't believe that each person received $3 million," Kitaev says.

Milner meant the award to come with a significant chunk of change; his goal is not only to recognize scientists doing fundamental research, but also to raise their profiles among the general public to equal the likes of actors, sports stars, and other celebrities. "We have a disbalance in the world today that the best minds are not appreciated enough," Milner said at the 2013 prize ceremony.

Indeed, the big payout got plenty of media attention. It was probably one of the few times, if not the only time, that the topic of topological quantum computing—Kitaev's expertise—graced the pages of the *Los Angeles Times*.

A Quantum Future

Kitaev won the prize for laying some of the theoretical groundwork for quantum computers—machines that researchers say can far exceed the performance of conventional computers. By exploiting the complexities intrinsic to quantum mechanics, quantum computers could hypothetically do calculations that would take regular computers the entire age of the universe to accomplish. It's not hyperbole to say that, some day, quantum computers could change everything.

By comparison, conventional computers are relatively simple. They process information by turning a bunch of electronic switches on and off, with those states—units of information called bits—represented by a 1 (on) or 0 (off). Quantum computers are different; instead of simple on/off switches, they rely on quantum bits called qubits, which follow the weird rules of quantum mechanics.

Quantum theory has been a triumph: it forms the backbone of modern physics, explaining everything from the LED display on your TV to the MRI technique that doctors use to examine your insides. But the concepts are notoriously nonintuitive.

For example, one of the theory's principles is superposition, in which an object can occupy two states simultaneously. In other words, an electron can be spinning clockwise and counterclockwise at the same time. While a bit can be only on *or* off, a qubit can be both, a combination of 0 and 1. Then there's entanglement, in which two particles can be so intimately correlated that one gives you information about the other—even if they're separated by the length of the universe. Entangled qubits become inextricably correlated with one another.

Needless to say, computing with qubits is complicated. But it's this mind-bending complexity that endows a quantum computer with its unsurpassed processing power—in principle, at least.

Today's quantum computers are rudimentary, only capable of relatively simple tasks (e.g. factoring the number 21). No one's been able to engineer one that's particularly useful—that is, one that achieves what a regular computer can't. In a conventional computer, bits manifest themselves as tiny electronic switches called transistors, which are embedded in small silicon chips. Qubits, on the other hand, are really hard to make.

Researchers have tried to accomplish this by using different kinds of quantum systems, including charged atoms, whose clockwise or counterclockwise spins provide the two states of a qubit. But regardless of the design, quantum systems are extremely fragile, susceptible to stray particles that can bump into a qubit and ruin whatever calculation it's trying to make. These errors quickly accumulate, rendering the computer useless.

The first line of defense is to develop algorithms that weed out the errors. But these corrections are so difficult to do that the computer ends up spending much of its computational muscle fixing errors, rather than doing its intended task. Then Kitaev came up with a better solution—one worth $3 million.

He devised a way to build error-resistance into the computer's hardware itself, instead of relying on software to correct problems after-the-fact. According to Kitaev, you could construct qubits with exotic particles called anyons, which are thought to exist in certain quantum systems. Two anyons can share a single quantum state, and maintain that state even if separated. Their identities are so intertwined that if a stray particle wanted to disturb the qubit, it would have to perturb both anyons—which is harder to do, especially if the two anyons are separated. So by keeping the anyons apart, you can make an error-resistant qubit.

Kitaev proposed his idea in 1997, attracting enough attention to go on to win a MacArthur Fellowship in 2008. Since then, he says, physicists have realized that making qubits from actual anyons may be too difficult. Instead, researchers such as Caltech's Jason Alicea and Gil Refael are pursuing ways to apply Kitaev's ideas using another particle-like quantum object called a Majorana mode.

Such a qubit would be made of a thin, superconducting wire that traps a pair of Majorana modes, one on each end. To calculate something, the computer would change the voltage inside the wires, moving those Majorana modes around and thus manipulating the qubits' quantum states.

The Breakthrough Prize trophy was created by Danish-Icelandic artist Olafur Eliasson. According to the organization's website, "Like much of Eliasson's work, the sculpture explores the common ground between art and science. It is molded into the shape of a toroid, recalling natural forms found from black holes and galaxies to seashells and coils of DNA."

This general strategy, which Kitaev helped pioneer, is called topological quantum computing. While others are using it to design a bona fide quantum computer, he's focusing on the theory behind it, trying to gain a deeper mathematical understanding of how these topological systems work.

Topology is like a fancier version of geometry; it's a mathematical study of spaces and the properties of those spaces, which can occupy any number of dimensions. Topologically, a doughnut is the same as a coffee mug, since they have the same basic property of having a hole (the mug's handle forms its hole).

In the case of quantum computing, topology comes in a bit more abstractly. With Kitaev's proposal, for example, information processing would happen when anyons (or Majorana modes) move around. Their motion through time can be depicted in what's called a space-time diagram, in which an x-axis and a y-axis represent space, while time lies on a third axis. A pair of stationary anyons would be represented by two parallel lines pointing up. But if one anyon moves around the other in the x-y plane, their motion would be depicted as two lines wrapped around each other like a braid. By studying the topology of these braids, Kitaev can explore the mathematical properties of these systems and how they could function as a quantum computer.

While a real, useful quantum computer could still be decades away, Kitaev's work has been fundamental, carving out a new potential path toward such a machine. Which, of course, is why in 2013 he found himself onstage with eight other preeminent physicists—and actor Morgan Freeman.

The aspirations behind the Breakthrough Prizes, to imbue glitz and glamour to basic science, were clear as the evening proceeded like a Hollywood-style, red-carpet event. "You can think of it as being like the Oscars," said Freeman, who hosted the ceremony. "Only this time, you're in the presence of some of the greatest minds on the planet."

Stringing It All Together

The next year, Kevin Spacey hosted the affair, which also saw Glenn Close and Conan O'Brien—among other Hollywood celebrities—in attendance. And Caltech had two more representatives: biologist Alexander Varshavsky, who won the 2014 Breakthrough Prize in Life Sciences (read more at eands.caltech.edu/plus) and another theoretical physicist, John Schwarz, who won the 2014 Breakthrough Prize in Fundamental Physics.

Schwarz and his corecipient, Michael Green of the University of Cambridge, were recognized for perhaps the most fundamental kind of physics: their efforts to develop a unified theory that describes all the basic forces and particles of nature—a theory of everything.

Physicists from Albert Einstein to Stephen Hawking have searched in vain for a grand unified theory. And while such a theory remains elusive, physicists like Schwarz have made tremendous progress over the decades. Indeed, the best—and only—candidate for a unified theory today is string theory, an idea that Schwarz pioneered in the 1970s.

According to string theory, the fundamental building blocks of reality consist of vibrating stringlike objects. These strings have different properties, such as tension, that determine how they vibrate. And those modes of vibration, like notes on a plucked guitar string, are the elementary particles of the universe.

But when physicists were first developing the theory in the 1960s, they had no inkling it could be a theory of everything. Instead, they were trying to use it to explain the aptly named strong force, which holds atomic nuclei together. After physicists like Caltech Nobel laureate David Politzer developed the theory of quantum chromodynamics to describe the strong force, researchers tossed string theory aside. Except for Schwarz.

He thought the mathematical beauty of string theory must hint at some underlying, fundamental truth. It took more tinkering—with the late Joel Scherk, who was a senior research fellow at Caltech at the time—to find out what that truth was. In 1974, Schwarz and Scherk realized that string theory predicted the existence of a particle that resembles the graviton, a hypothetical particle thought to be responsible for gravity. That prediction was a breakthrough because in the efforts to unify the four fundamental forces—the strong force, the weak force, the electromagnetic force, and gravity—incorporating gravity was the biggest hurdle.

Compared to the other forces, gravity is a problem child. Physicists were able to describe and even unify the other forces using quantum mechanics. But gravity, which Einstein described as the warping of the space-time fabric of the cosmos, wouldn't play nice with quantum mechanics. Any attempts at a quantum theory of gravity gave nonsensical results incompatible with reality.

So when Schwarz and Scherk showed that string theory predicted the graviton—and thus gravity—they also realized it could be the long-sought unified theory. But the excitement was short-lived. They soon ran into mathematical inconsistencies in the theory that would stymie the field for a decade.

Schwarz and his longtime collaborator Green (Scherk died in 1979) became essentially the only ones pushing forward with string theory. "It was viewed quite skeptically by most of the theoretical physics community," Schwarz says. "But some people seemed to realize it was a worthwhile gamble."

Luckily, one of those people was Caltech's Murray Gell-Mann, who had helped bring Schwarz to Caltech in 1972 as a research associate. With Gell-Mann's support, Schwarz kept working on his theory. Finally, in 1984, he and Green found a way to cancel out the previously problematic mathematical inconsistencies, removing what had been a major roadblock.

"John is a visionary," says Hirosi Ooguri, the Fred Kavli Professor of Theoretical Physics and Mathematics at Caltech. "He pushed this for 10 years, and then finally found a solution that convinced the rest of the world that this is the right direction."

Suddenly, string theory became one of the most exciting areas of physics, and physicists like Ooguri wanted to be part of it. Today, the field continues to attract interest from younger generations of scientists. "There's more optimism than ever," Schwarz says. But despite decades of progress, researchers still have a way to go. One major reason for skepticism, for instance, is the lack of experimental evidence.

But many physicists are hanging their hopes on the Large Hadron Collider, located under the border of France and Switzerland. As the most powerful particle accelerator in the world continues to ramp up its current round of collisions, which will run through 2018, Schwarz hopes it will discover evidence for supersymmetry, a theory that, among other things, posits that every particle has a supersymmetric partner (an electron, for example, has a partner called the selectron) to help explain why particles have mass.

Supersymmetry is a feature of nature that's necessary for string theory. "I would say the probability is on the order of 50 percent or so that it will show up," Schwarz says. "If they do find supersymmetry at the LHC, this would be absolutely revolutionary in terms of impact on fundamental particle physics. It would pretty much set the agenda for the experimental side of particle physics for the next half century."

The cachet of an award like the Breakthrough Prize in Fundamental Physics also helps set the agenda, by bringing much-needed attention to this basic research. "It's important that the United States continues to be a leader in high-energy physics," Schwarz says. "Public recognition of a field of science is good. It helps make decision-makers in the government and so on more cognizant of the work and more predisposed to support it."

As for the Hollywood effect, Schwarz thinks it might take more than a couple of awards ceremonies to turn theoretical physicists into household names. At the 2014 award ceremony, Schwarz says, he and his wife, Patricia, were "both struck by the fact that the Hollywood types showed no interest in mingling with scientists." And the media coverage also seemed to focus on the movie stars rather than the award winners.

But for Kitaev, the biggest impact of awards like the Breakthrough Prize in Fundamental Physics is on his family. "They don't really understand what I'm working on," he says. But thanks to these awards, they at least realize his research is a pretty big deal. "It helps me do more work because they have more respect for it," he says. "My wife is really proud of me." e&s

Alexei Kitaev is the Ronald and Maxine Linde Professor of Theoretical Physics and Mathematics. His work is supported by the Simons Foundation, the National Science Foundation, and Gordon and Betty Moore Foundation.

John Schwarz is the Harold Brown Professor of Theoretical Physics, Emeritus. He remains an active participant in Caltech's Walter Burke Institute for Theoretical Physics.

Beyond the Beaten Path

Embracing the Unexpected

By Lori Dajose

Caltech undergraduates often spend their senior years casting a wide net of applications for graduate school funding. While all fellowships are prestigious, there are a few that are unusual in that they are intended to send students out for international experiences, typically before graduate school or even in lieu of it. The Marshall Scholarship and the Rhodes Scholarship, for example, fund students to do several years of research or study in the United Kingdom. The Watson Fellowship awards recipients with a yearlong stipend to pursue a creative, not necessarily academic, project almost anywhere in the world. And the Fulbright Scholarship sends students to study in a foreign country for up to a year, often creating a political and cultural connection in addition to an academic one.

We talked to some young alumni who have received these somewhat nontraditional fellowships about the impact that these unique experiences have had on their lives, both during and after the prize.

Iram Parveen Bilal (BS '04) had a meticulous plan for her Watson Fellowship, at the time a $25,000 prize—now $30,000—that allows recipients to travel the world in pursuit of their "deepest interest." Though she majored in environmental science and engineering, she had a deep passion for dance—an activity that her mother, with the weight of a conservative society behind her, thought was inappropriate as a career. Bilal was determined to use her Watson year—from August 2004 to August 2005—to provide an alternative reality to the taboos against dance.

Bilal had always been interested in the performing arts, Bollywood, and dance, even while at Caltech. She took all the film courses offered at the Institute and led various performance-oriented activities, from public speaking to dancing. Nonetheless, upon getting in with a full scholarship, she attended Caltech "with vigor," she says, to appease her parents and partly to play "safe"—until her very first research project, where being stuck in a subbasement, redundantly stringing DNA strands onto semiconductor chips, made her realize that she was made for a career with more human to human interaction. She felt she was too impatient to have an impact on others through science—she needed a more interactive form of dialogue. So her senior year she applied to film schools, at the same time applying for a Watson, hoping to use the year to learn more about the world and to challenge the opinions of dance she had grown up with. "I grew up in a family where dance was frowned upon," she says. "My mom thought dancing was just bad. She was very resolute about it, but I was also very determined to provide her with alternate explanations." When she received the prestigious prize, Bilal made it a goal to uncover the depths of complexity behind the seemingly simple question, why do people dance?

She spent months preparing, proposing, and planning. The fellowship took her through India, Tanzania, and Ireland, studying the motives behind dance: worship, social and religious rebellion, tribal identity. She traveled through temples and dance villages in India, to Maasai villages and tribes in Tanzania, to Irish step dancer clubs in Ireland, interviewing everyone she met. In the end, she found that she still didn't have a concrete answer for why people dance. What she did find, however, was that rhythm and a sense of body movement was natural and woven into the fabric of life.

"Dance is a very intrinsic, innate thing," she says. "I set out with this mission of proving something, that dance wasn't bad, but the more you dive into knowledge, the vaster the unknowns are. Whilst I can qualify by examples that dance is innate, I can't possibly pass a judgment one way or another. That would be too immature and impatient."

Through her travels, though, Bilal was able to arrive at an unanticipated conclusion—that things in life don't always work out as planned. "The Watson wasn't really about this project, it was about the experiences," she says.

While she traveled and wrote and filmed and researched, Bilal spent much of her time alone. "I know myself very well, and a lot of that has to do with the amount of time I spent by myself," she says. "The Watson is all about isolation -driven learning. And through that, I found that I'm a very free soul. I'm not rigid about ideology; I'm very liberal. And, I'm bloody persistent."

In the years following her Watson adventure, the effects of Bilal's time abroad reverberated throughout her life. Currently, she is working on a feature film about Islamophobia and dance.

"A lot of this project has to do with the same ponderings that were the propulsion for my Watson project," she says of the movie, called *Forbidden Steps*, that she began writing in 2006 and has since put aside, resurrected, and rewritten many times. "There's something very pure and personal with this film—the research I did during the Watson is definitely going into the emotional moments in the narrative of the film."

Plus, seeing the world alone has given Bilal a solitary travel bug. "Every six months I try to take a trip by myself to settle back and reevaluate where I'm going with my life," she says, "to try to live in the moment, whilst still reflecting."

ON BEING AMERICAN

Moving to a new country on a new continent was a familiar feeling for Pradeep Ramesh (BS '11). After spending his early childhood in India, he and his family moved to Singapore, where they lived for five years before moving to the United States when Ramesh was 12. So after finishing his bachelor's degree in applied physics in 2011, it seemed natural to keep exploring the world.

Luckily for him, upon graduation Ramesh was awarded a Fulbright Fellowship to live and study in Denmark, studying biophysics at the Niels Bohr Institute in Copenhagen. At the time he began the fellowship, he had been a U.S. citizen for just under three years.

"I was totally surprised when I got to Denmark, because suddenly I was 'The American'" Ramesh says. "I didn't really even think of myself as an American until recently. And suddenly here I was in Denmark—a country of five million people, 90 percent of whom are ethnically Danish—and there was some sort of expectation that I represent and 'defend' my country's ideology and policies."

(cont.)

Adding to that pressure, each year the Fulbright committee selects one student studying in each participating European Union country and brings them to Brussels, the capital of the EU, for a week of visiting parliament and NATO headquarters—and Ramesh was selected as the Denmark representative, a task that included conversations with EU justices, members of parliament, and ambassadors.

"I felt very lucky to be selected," he says. "You meet some very high-profile political figures. And here we were, talking to them face to face, off the record, and they really opened up. They're not just political 'figures'—they're other human beings."

One particular experience stuck with Ramesh. "We were having dinner with the commanding general of NATO, around the time that the military campaign against Libyan leader Qaddafi began," he remembers. "The general said that one of the biggest challenges was the unit system—American fighter pilots would report the target distance in miles, and here are the British and French and Danish who are actively flying planes and trying to quickly do conversions to meters. It was so funny. We're on the same side but we can't seem to come to agreement on something like units or language.

"I got to learn about the nuances of diplomacy, the complicated times when there really is no right or wrong answer—it kind of banishes that subconscious idea you might have that 'America is always right,'" he says.

When not meeting with ambassadors or traveling throughout the EU, Ramesh did have a job to do—his Fulbright research straddled the intersection of physics and biology, examining the basic compartments of life: membranes. "All forms of life on Earth are compartmentalized," he says. "You rarely get naked DNA or RNA just floating around. I wanted to better understand the physical forces that drive compartmentalization and affect the shape of lipid membranes, which form the boundaries of cells. How did these forces then shape the evolution of life on Earth?"

Though the fellowship is intended to provide a stipend for scientific research, another big takeaway, Ramesh says, was the global perspective he gained. "Cellular life may be compartmentalized, but there's not such distinct delineations between science, culture, people, and policies," he says. "Science is not a pure little bubble—you can't separate it from cultural, political, and geographical contexts."

Ramesh's winding journey through the world has also been a winding journey through biology. After his work on membrane biophysics, he went on to graduate studies at UC Berkeley, where he wanted to model cancer dynamics using the principles of evolutionary game theory. While there, he met Mikhail Shapiro, with whom he moved back to Caltech—where Shapiro is now an assistant professor of chemical engineering—in order to start a new lab in molecular imaging. Ramesh is currently working to advance the nascent field of magnetogenetics by trying to engineer mammalian cells to be magnetic. This would allow researchers to control cellular function noninvasively using magnetic fields.

A GLOBAL TAKE ON MEDICINE

Cindy Ko (BS '07) always knew she wanted to study medicine. So when she applied for and received the Watson Fellowship during her senior year at Caltech, she designed it to expand her love for medicine globally by applying to study the relationship between indigenous medicine and Western medicine in a number of countries, including Peru, Chile, South Africa, Ghana, Benin, India, and China.

"I tried to pick locations where there was a site or particular kind of medicine that showed the day-to-day interplay between indigenous medicine traditions and Western medicine," Ko says. "There are countries where the relationship is harmonious, like in India or China, and there are countries where the relationship is antithetic. Patients with a range of mild to serious illnesses have to do their own navigation between the two worlds, and it's always changing."

She had already taken a nontraditional undergraduate path to a career in medicine by majoring in mechanical engineering instead of biology. "I liked the idea of building and creating new solutions," she says. And this experience prepared her to boldly and creatively tackle problems she encountered throughout her Watson year.

"Being a Mech-E student taught me to appreciate many ways to solve the same problem," Ko says. "The human spirit is inventive, resourceful, and playful." Her resourcefulness came in handy many times during her travels, such as when a computer charging cord snapped on a remote island in Chile. A replacement part was out of the question, so Ko fashioned her own repair using whatever was lying around, including the cap from her pen.

After the Watson, the transition seemed almost seamless to medical school in New York City. "New York is the best place to come back to, post-Watson," says Ko. "I could get all my favorite West African foods just one train ride away, hear seven different languages being spoken while working at a hospital in Queens, and interact with a diverse patient population while learning medicine."

Though indigenous medicine can sometimes be radically different from Western, the experience didn't necessarily revolutionize Ko's perspective on medicine. "I didn't really have a fixed view of medicine or engineering before I left that was drastically changed by my year abroad. It felt more like I was adding to a big tapestry of things I learned and wanted to learn. Every experience has been transformative—from Caltech, to the Watson, to medical school itself."

Ko is currently a resident in radiation oncology at the University of Wisconsin. "From my Watson experience, I've learned that the patient drives their own care no matter who they are seeing as their doctor," she says. "I've had cancer patients who want to participate in both Western and non-Western treatments. It's our job as physicians to keep our eyes, ears, and minds sensitive to our patients and help them find their best path."

LIFE ON THE EDGE

Peter Buhler (BS '12) has been on a journey through every major geological epoch—by studying fossils, that is. After finishing his bachelor's degree in geology, Buhler was awarded a Watson Fellowship to travel the world for a year studying the origins and evolution of life. The journey took him through space and time—across six continents and from the Hadean era to the Holocene.

A younger version of Buhler might be surprised at all this globe-trotting. "I grew up in the smallest state of them all—Rhode Island—living in the same house for eighteen years and attending the same school across the street for fifteen of them," he says. "I had never really spent much time outside of the United States."

And yet, Buhler's Watson project was all about life that pushes the edge of biological comfort zones. He was hunting for extremophiles: organisms that live and thrive in extreme, harsh conditions. His Watson year began in Canada, where he dug up and examined dinosaur fossils; continued in Australia, where he studied stromatolites, bacterial waste products that harden into distinctive rocks; then took him to Taiwan, where he experienced an isolated island ecosystem where 25 percent of the species are endemic. Next he went to Spain, where life in the Rio Tinto survives at a pH of 2 (similar to battery acid) and provides an analog for the martian environment; then to the Atacama Desert in Chile, where photosynthetic bacteria live inside salt crystals; and finally to Peru, where Buhler observed examples of recent human evolution and the integration of indigenous people with modernized society.

"Getting my hands on fossils and seeing the crazy ways that life evolves made a deep impression on me," he says. "Life is so adaptive, so varied, and can survive in so many ways."

Bacteria weren't the only organisms Buhler observed to survive in myriad ways—the scientists he interacted with around the world all had unique approaches to doing science.

"In Spain, I was at an institute a lot like Caltech—there was lots of funding, and lots of instruments," he explains. "There's a lot of freedom in that; it's a privilege. But in Chile, I was basically working out of a shed with makeshift equipment. Just like different life forms can survive in different environments, scientists can survive in different working environments. And this environment shapes the way they approach their work."

(cont.)

But whatever the scientific method, Buhler found one thing remained the same: people are people. "No matter where you go, there are people who will take you in and make you feel part of a community," he says. "Each place I went, I had to explain my work often. But every time I did, I was just really excited to share my passion—the crazy ways life can survive and be resilient—with people who are figuring out their own ways to survive. No matter who they were, my work was a concept that they could relate to."

Sharing his work became a huge part of the Watson experience for Buhler, and he started a blog titled *Geolog: A Slice of Science, Topped with Humanity.*

"It's changed my mind-set from just getting work done, to really making sure it's accessible to the public," says Buhler. "I want to help people understand how exciting and awesome the world around them is!"

After a whirlwind adventure with the Watson, Buhler returned to Caltech for graduate school. As a third-year student, he's not entirely sure of his plans for after his doctorate, but he has a feeling they will fall into place. "The Watson made me more aware of the opportunities I'll have after grad school, because my field is such a big international community," he says.

SEEKING A BROADER HORIZON

Todd Gingrich (BS '08) was interested in a Rhodes Scholarship because the program *wasn't* exclusively about the science he was hoping to pursue.

"The committee likes to select people who can make things happen out of nothing," he says, which was a concept that intrigued him. "I like the language in the selection criteria that talks about people who are 'not mere bookworms.'"

The Rhodes funds between one and three years of study at Oxford, where students can use the grant for a master's degree or three years of a PhD. Students selected to receive the Rhodes Scholarship are notified in person and are required to accept or reject the opportunity on the spot. Often, students haven't had a chance to visit Oxford first—which means that expectations sometimes need to be revised.

"I only expected to do a one-year master's program in theoretical chemistry in what Oxford calls a 'taught course'—meaning that you take classes, do coursework, and have heavy supervision," says Gingrich. A few months into the program, he realized that Caltech had prepared him incredibly well. "I wanted a little more of a challenge, so I switched to do a two-year research course, which is a lot more free-form."

Gingrich wanted a change from the "trial-and-error" experimental research he had conducted at Caltech, so he applied his broad physics background to the study of theoretical chemistry at Oxford. "My master's degree was about computational simulation methods for trying to predict the structures that certain molecules would adopt," he says.

Gingrich liked the field so much that he went on to do a PhD in theoretical chemistry at UC Berkeley.

"Science is a rough thing to pursue, and it's really easy to feel overworked and underappreciated. To that end, my experience with the Rhodes was actually really comforting and encouraging," he says. "There was a broad group of people from all sorts of disciplines—law, literature, science—who were validating what I was working towards, even when it wasn't entirely clear what I would achieve. It's a nice feeling and it gave me a lot of confidence heading forward in my career. When science isn't working out and you feel self-doubt, it's amazing to have the support of these people."

Right now, Gingrich is still pressing strongly along the academic path as a postdoc at MIT. "Academia is a little terrifying—there's no certainty that you will get a faculty position," he says. "But I try to stay calm about it. My experiences with the Rhodes and at Berkeley have taught me that there's no shortage of other interesting things in the world to do."

To the U.K., with Love

If you had told Emma Schmidgall (BS '07) as an undergraduate that she would earn a Doctor of Philosophy in physics in 2015, she probably wouldn't have been surprised. But Schmidgall would never have guessed that she would receive said degree from the Technion Israel Institute of Technology, by way of the United Kingdom.

"During undergrad, I studied abroad in England, and really I was just so excited to return," she says of the prestigious two-year Marshall Scholarship that landed her back in the U.K. after graduation. There, she planned to spend one year at Cambridge University, studying physics for a Master of Philosophy degree, and one year at the University of Edinburgh, studying science policy. But ultimately Schmidgall decided against the cold, dark, and rain of Edinburgh, and she spent the second year of her Marshall Scholarship at Imperial College London studying nanomaterials.

"Everything I learned in my two years are things I use every day," she says of the research she conducted in Cambridge and London on quantum information in semiconductor quantum dots. She loved the subject so much that she specifically sought out similar research groups when applying for her PhD.

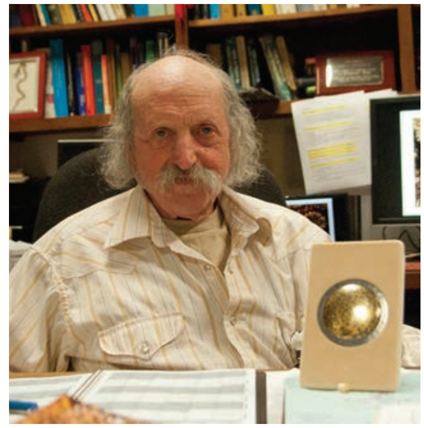
Technion had just the sort of quantum information research Schmidgall loved—and it just so happened to be in a country that she had spent some time in. Just before she left with her Marshall Scholarship in 2007, Schmidgall ran into an old high school friend, Shachar Raindel, who lived in Israel. They hit it off and went on to date long-distance for the entirety of Schmidgall's time in the U.K. The flight to Israel was only four hours, so she alternated weekends between traveling Europe and visiting Raindel. After her two Marshall years, Schmidgall moved to Israel to work as a process engineer at a semiconductor laboratory, and later began graduate school.

"We've been married for three years now!" she says.

The Marshall Scholarship seemed to guide Schmidgall quite naturally into her current line of research, but the full effect on her life is yet to be determined, she says.

"It was an amazing, awesome experience, and I'd highly recommend it," says Schmidgall. "There's this beaten path at Caltech that so many people take, where you go straight to grad school and never really get a chance to stop and look around. So for me, having two years to do something totally different was just fantastic!" E&S

Eric H. Davidson 1937 – 2015



Eric Harris Davidson, Caltech's Norman Chandler Professor of Cell Biology, died on September 1, 2015. He was 78 years old.

Davidson, a developmental biologist, was a pioneer researcher and theorist of the gene regulatory networks that perform complex biological processes, such as the transformation of a single-celled egg into a complex organism. His work helped to reveal how the DNA sequences inherited in the genome are used to initiate and drive forward the sequence of steps that result in development.

For the last 40 years, Davidson's work centered on the purple sea urchin, *Strongylocentrotus purpuratus*, whose range includes the waters off Caltech's Kerckhoff Marine Biology Laboratory in Corona del Mar, California.

Davidson earned his bachelor of arts degree from the University of Pennsylvania in 1958 and his doctorate from Rockefeller University in 1963. He worked as a postdoctoral researcher and then as a member of the Rockefeller faculty before coming to Caltech as a visiting assistant professor of biology in 1970. He became a Caltech associate professor in 1971, a professor in 1974, and was named Chandler Professor in 1982.

He was a member of the National Academy of Sciences and a fellow of the American Association for the Advancement of Science. In 2011, he was awarded the International Prize for Biology by the Japan Society for the Promotion of Science. He was also the recipient of the Lifetime Achievement Award from the Society for Developmental Biology and the A. O. Kovalevsky Medal from the St. Petersburg Society of Naturalists.

He authored six books, ranging from his classic 1968 monograph, *Gene Activity in Early Development*, to *Genomic Control Processes*, published in 2015 and coauthored with Caltech research assistant professor Isabelle Peter.

He is survived by his daughter, Elsa Davidson Bahrampour.

To learn more about Eric Davidson's life and work, visit caltech.edu/news/developmental-biologist-eric-h-davidson-passes-away-47772.

We asked alumni to invent a Caltech-themed prize and to let us know who they would give it to, and why. Here's what a few of them had to say.

Linus Pauling Award for **IMPROVING THE HUMAN CONDITION** with Science, given to those who turn their scientific or engineering work to broadly benefit humanity.

Best Investment in the Future Award to Carl Larson, class of 1952, for his tireless support through the years of SURF.

The Ray Owens Award would go to a person who strongly **SUPPORTED DIVERSITY** and personally helped to improve equal treatment of all at Caltech.

A THINKING OUTSIDE THE DISCIPLINE prize to be awarded for the most compelling plan to investigate any specific scientific question with an approach that spans several different disciplines.

The **Infinite in Both Directions Award** for the best published idea, or paper, or broadcast of the year from the Caltech community.

To Thine Own Self Be True Award— for Carver Mead. Why is obvious.

OUR PLANET AWARD, recognizing key science advancements related to earth sciences for the solid, liquid, and gaseous portions of our home world.

Lifetime Achievement Award to Mr. Tsutomu Ohshima, karate teacher at Caltech, 1955 to 1994, for bettering the lives of numerous Caltech students, faculty, & alums.

Meet with a TIAA-CREF financial consultant to review your employer-sponsored retirement plan options and investment choices. This personalized one-on-one advice session is available at no additional cost to you. Our advice and tools are designed to help you pursue the kind of retirement you want and deserve.

Call 800 732-8353 to set up an appointment with a TIAA-CREF financial consultant.

Caltech | **The Science of Benefits**
Understanding the elements of finance

In Collaboration With TIAA CREF **Financial Services**