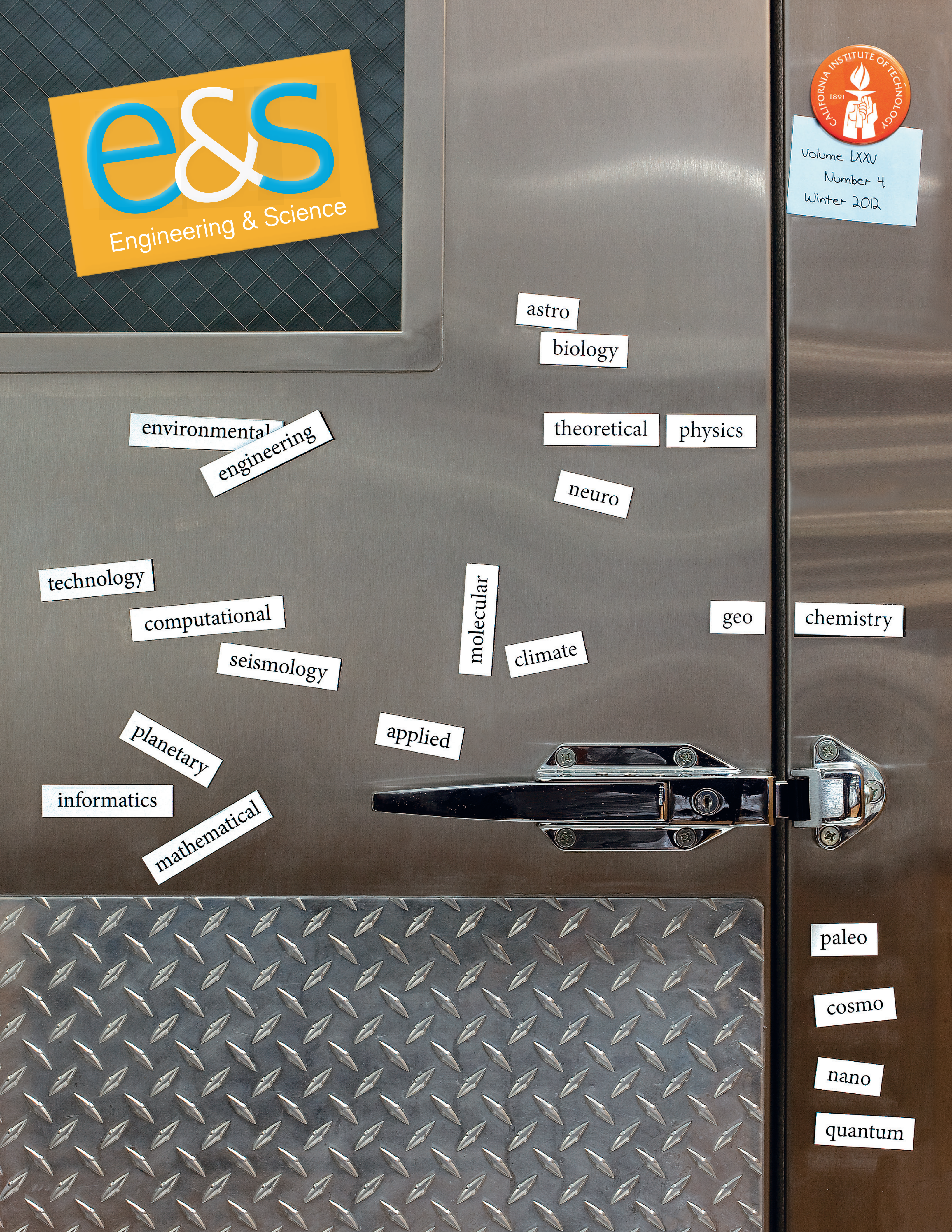
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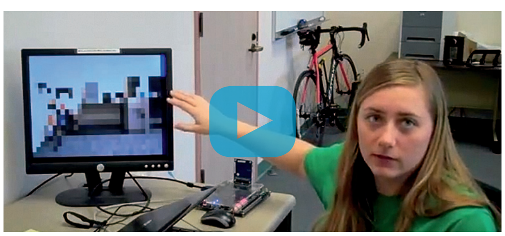
Forty Years at Caltech

Caltech Wins Toilet Challenge



SURF Student Video Diary

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@PopoagieForever: #1 Worldwide Again! (Proud Caltech Mom) "@Caltech: @timeshighered did the math and found that Caltech = #1! caltech.edu"

@timeshighered: @Caltech Congratulations on keeping top spot!

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Engineering & Science

VOLUME LXXV, NUMBER 4, WINTER 2012

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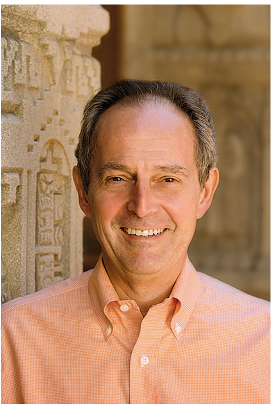
FROM THE PRESIDENT



Dear alumni and friends of Caltech,

When we reopened the Jorgensen Laboratory in October of last year after transforming it into a state-of-the-art facility for energy science, we filled its lab spaces with engineers and chemists who are working across disciplines to come up with clean-energy innovations for the future. “This facility capitalizes on Caltech’s extraordinarily collaborative culture,” remarked Jackie Barton, the chair of our Division of Chemistry and Chemical Engineering, on that occasion.

Our boundaryless environment, in which the world’s brightest and most talented scientists and engineers come together to dream with freedom and focus, is the cornerstone of what I call the Caltech Advantage. Caltech’s culture encourages physicists to learn from chemists, and biologists to partner with engineers, knowing that the best science—the truly cutting-edge discoveries and game-changing advances for which Caltech is known—comes from this place of intersection and collaboration.

Similarly, we recognize that the solutions to the global issues to which we are devoting so many of our efforts—developing alternative energy sources, finding a cure for HIV, improving information systems, engineering advanced materials—will only come from work done at the boundary between disciplines. That’s why this issue of *E&S* is devoted to looking at the ways in which our scientists are effortlessly crossing these boundaries, making critical scientific breakthroughs by ignoring artificial distinctions between fields, and insisting on following their best ideas wherever those ideas may take them.

In the end, what I find most inspiring about this aspect of the Caltech culture is that it is our faculty and our students who are its driving force. In fact, this spirit of collaboration and cross-disciplinary cooperation seems to be an intuitive trait among our student-scientists and their mentors—one that we need to not only encourage but actively cultivate. Indeed, it is incumbent upon all of us—administrators, staff, alumni, and friends of the Institute—to make sure they have the support they need; to nurture this unique and productive mindset so that every last one of our scientists can do their very best work. Our society will be so much the better for our efforts.

“Our boundaryless environment, in which the world’s brightest and most talented scientists and engineers come together to dream with freedom and focus, is the cornerstone of what I call the Caltech Advantage.”

Yours in discovery,

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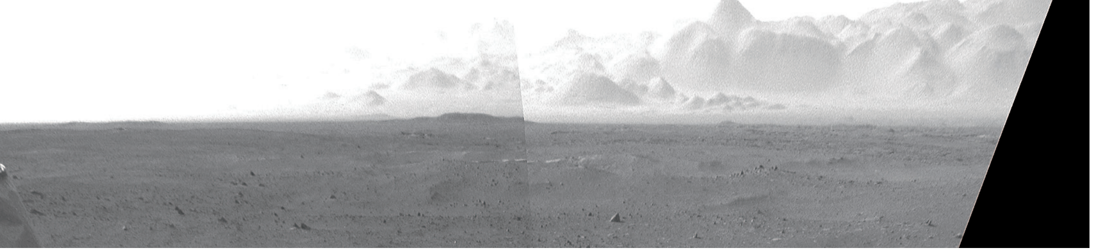
Random

Beneath the Surface: NASA's solar-powered Juno spacecraft has been hurtling toward Jupiter since August 2011, and it has a few more years of travel before reaching the gas giant. But here on Earth, Dan Goods, a visual strategist for JPL—which is managing the mission—is already envisioning what the spacecraft may see when it first arrives. Using a variety of imaging technologies, Juno will peer through the clouds at the top of Jupiter's atmosphere to reveal (among other things) how far down into the gaseous planet its lightning storms—phenomena visible on the surface and observed by previous NASA missions—go. Last fall, to show what these storms might look like, Goods built this installation (right) at the Pasadena Museum of California Art, using tap water to create a dry mist of clouds. Underneath the clouds is a system of computer-controlled infrared security-camera lights that are set to flash in sync with the sound of thunder. Infrared light is invisible to the naked eye but is visible to many cell-phone cameras; visitors must use this technology to "see" the lightning in a way similar to how Juno will detect storms underneath Jupiter's dynamic cloud surface. *—KN* e&s

View a video of the installation at http://directedplay.com/beneath_the_surface.html.

Walk

THINGS THAT CAUGHT OUR EYE . . .

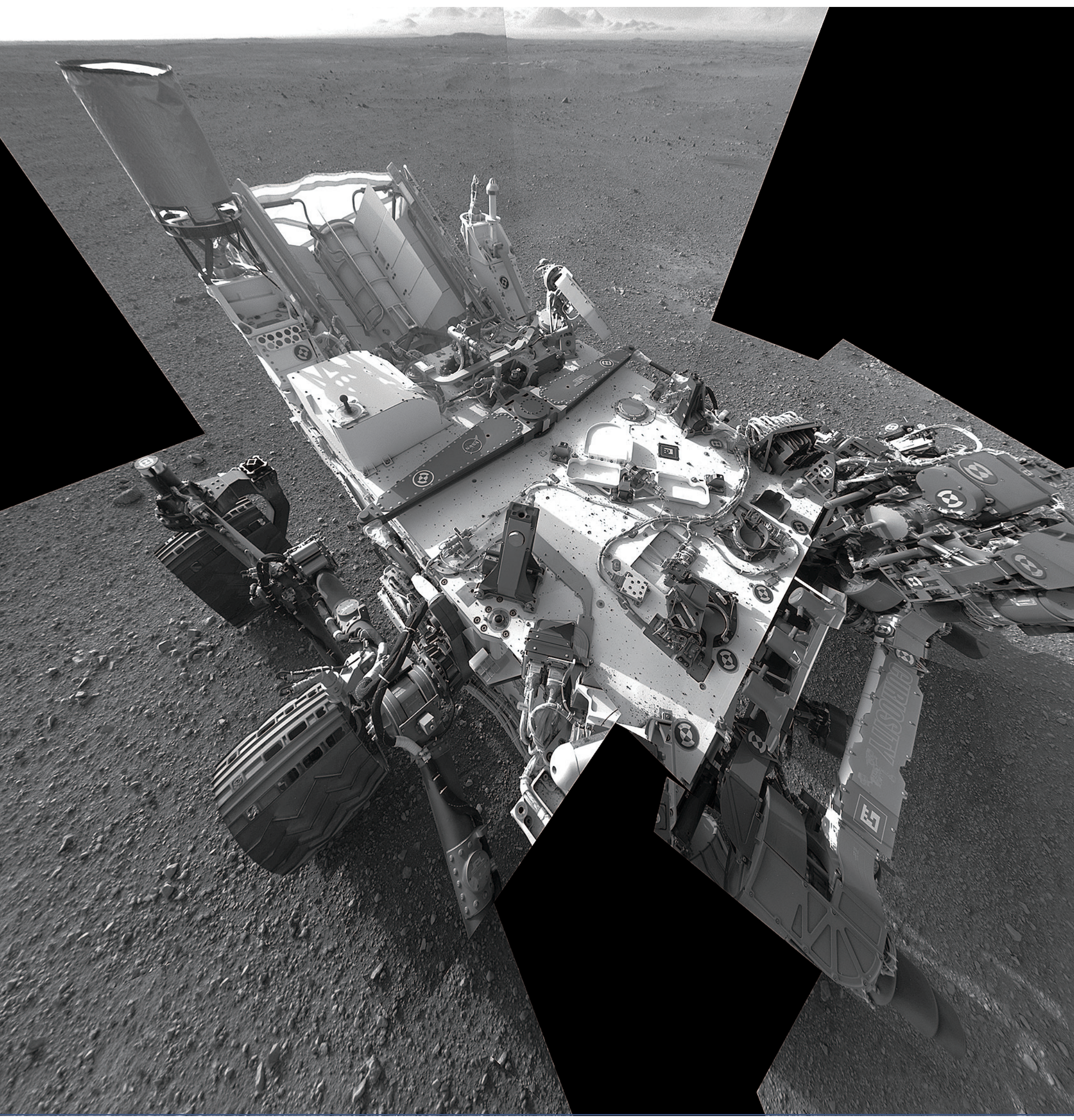


KEEPING UP *with*

"Touchdown confirmed. We're safe on Mars." With those six words, JPL engineer Allen Chen kicked off a celebration—not only in mission control at JPL but at viewing parties around the world. The Mars Science Laboratory (MSL) rover, Curiosity, had survived the much-hyped "seven minutes of terror" leading up to its landing on the Red Planet.

Engineers hugged each other and shed tears of joy. At a news briefing in JPL's von Karman Auditorium shortly after touchdown, the mood was overwhelmingly, almost deliriously, celebratory. A conga line of team members sporting light-blue polo shirts streamed into and coiled around the auditorium, each person high-fiving team managers at the front of the room. The entry, descent, and landing (EDL) team even chanted, "E-D-L! E-D-L!"

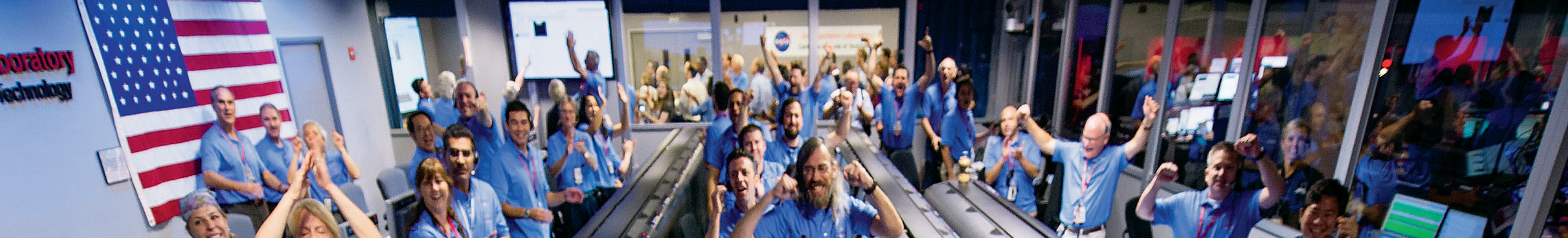
Caltech president Jean-Lou Chameau joined in the festivities. "This is a win for humankind—Curiosity belongs to everyone," said Chameau. "Exploring Mars will help us develop a greater understanding of the universe and our place in it. This extraordinary accomplishment is testament to the talent and hard work of the many dedicated scientists and engineers at JPL and Caltech."



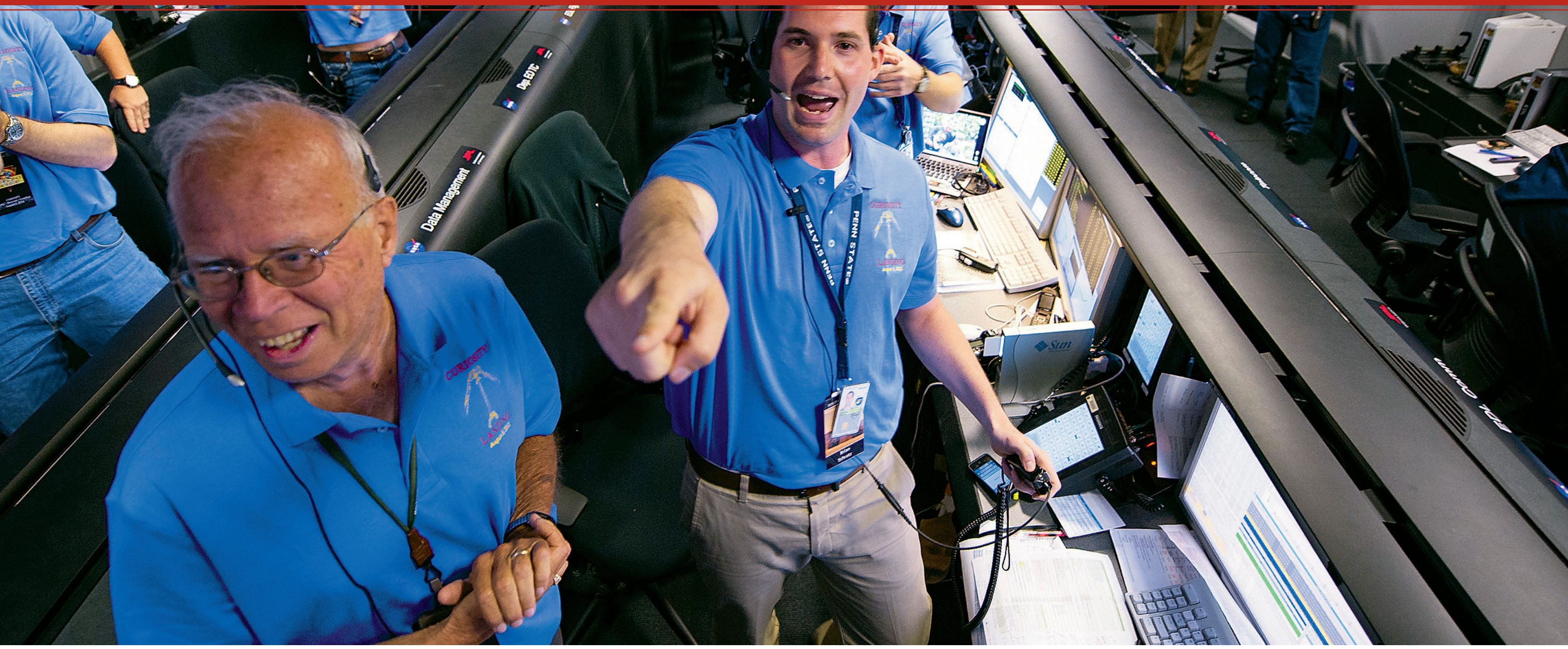
Almost immediately after touchdown, the rover started relaying images back to Earth showing one of its wheels and some of its surroundings on Mars. Curiosity has six such wheels, and carries 10 scientific instruments, 17 cameras, and a radioisotope thermoelectric generator that can keep the car-sized rover powered for years to come. Its goal? To explore its surroundings—an impact basin called Gale Crater that was formed more than three billion years ago—for evidence of environments that either once were or now are habitable. Indeed, some think of Curiosity as the first astrobiology mission NASA has launched since the Viking landers of the 1970s.

No matter what you call the mission, it's clear that its first weeks on Mars were a resounding success: all of the rover's systems proved to be working perfectly (save one of two twin booms designed to sense wind direction, which was damaged during or after landing), and the team was able to pinpoint the rover's position within Gale Crater, about seven kilometers north of the primary science target, Mount Sharp. Named in honor of the late Caltech geology professor Robert Sharp (BS '34, MS '35), the layered mountain holds the history of environmental conditions on Mars.

Once the rover ticked all the boxes for preliminary checkouts and downloaded new flight software, the science team, led by Caltech geologist John Grotzinger, was given "the keys." In short order, they had the robotic geologist on its way to a target called Glenelg, about 400 meters from its

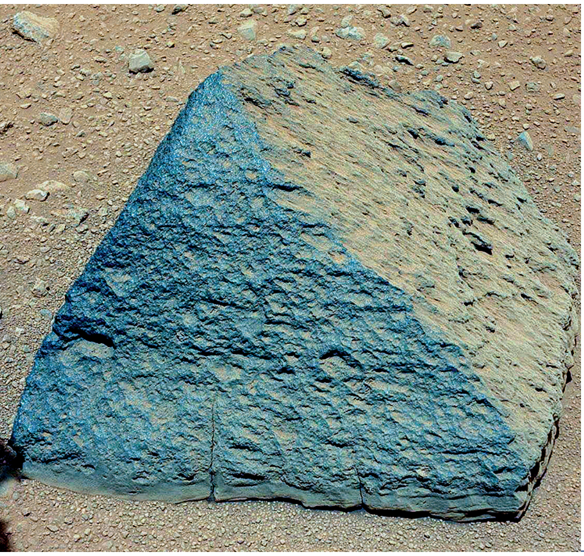


CURIOSITY



landing site, where three different types of terrain converge.

En route to that triple junction, the team encountered some surprises. Two exposed rock outcrops presented evidence that an ancient stream once flowed through the area. Curiosity imaged pebbles too large to have been transported by wind, which are now cemented together in tilted blocks of rock. "Curiosity's discovery of an ancient streambed at Gale Crater provides confirmation of the decades-old hypothesis that Mars once had rivers that flowed across its surface," Grotzinger says. "This is the starting point for our mission to explore ancient, potentially habitable environments, and to decode the early environmental history of Mars."



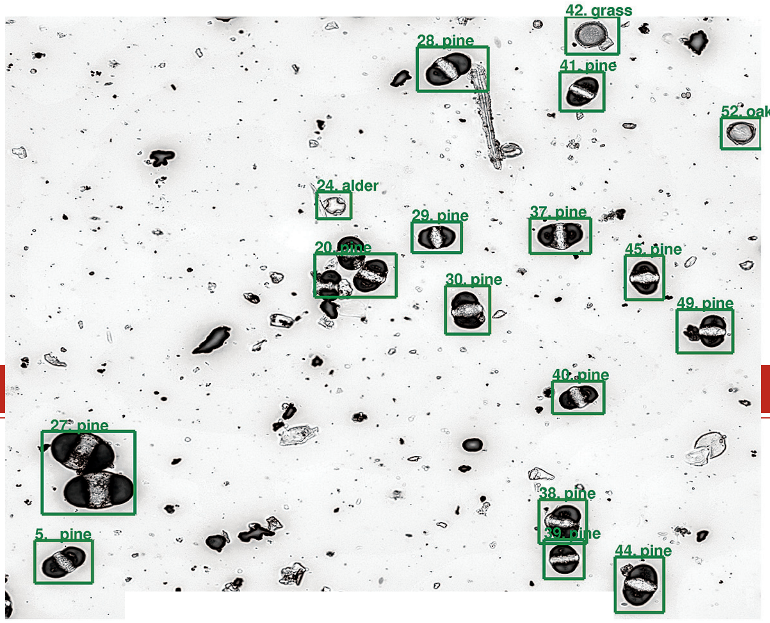
A second surprise came when the team selected a rock dubbed Jake Matijevic (in honor of a recently deceased team member) to be the first the rover would reach out and touch with its contact instruments. Despite having the appearance of a typical homogeneous martian basalt, the rock turned out to be heterogeneous in composition and unlike any basaltic rock ever seen on the Red Planet. Low in magnesium and iron, the rock is high in elements associated with the mineral feldspar. One formation hypothesis suggests that the rock crystallized out of water-rich magma under high-pressure conditions, perhaps within the planet's interior.

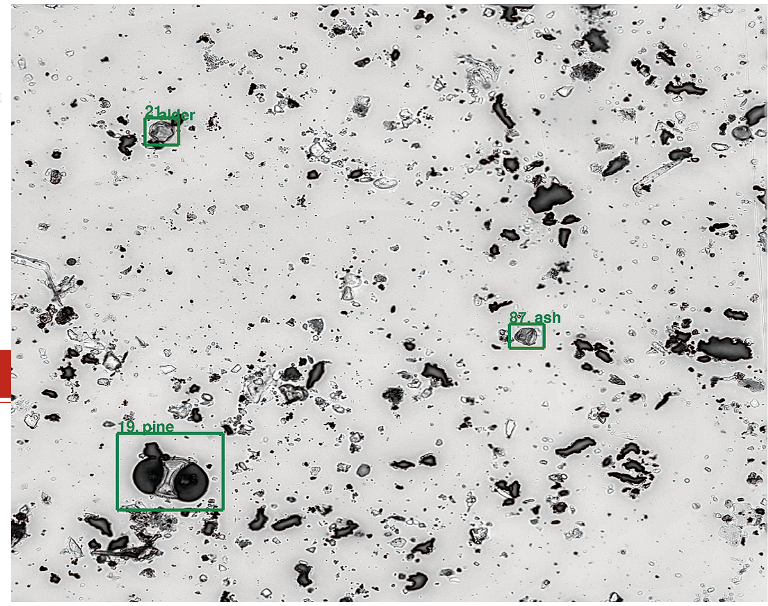
Curiosity has only just begun her two-year prime mission. The fact that she has already made some surprising discoveries bodes well for what lies ahead. And what lies ahead, once the scientists have seen enough at Glenelg, is a longer drive to the base of Mount Sharp, the towering feature that scientists can hardly wait for Curiosity to start investigating. —*KF* e&s

Above: Jubilation in the MSL mission-support area at JPL shortly after Curiosity's landing was confirmed and its first images started arriving back on Earth.

Left: The basaltic rock "Jake Matijevic" was the first martian rock Curiosity reached out and touched.

Far left: In this mosaic self-portrait captured by the rover just days after landing, the hills that appear in the distance form part of the rim of Gale Crater.





A Better Pollen Counter

Pollen is more than a seasonal annoyance for hay-fever sufferers. Indeed, the American Lung Association lists pollen as one of the most common triggers of asthma.

Pollen reports—which provide details about the number and types of pollen grains in a cubic meter of sampled air—can be useful tools for helping asthma and allergy sufferers avoid exposure to high levels of certain kinds of pollen. Such reports can also be useful to epidemiologists who hope to better quantify the relationship between pollen and asthma as well as to scientists who are looking to track the effects of a changing global climate—to see how the blooming seasons of various plants have shifted over time.

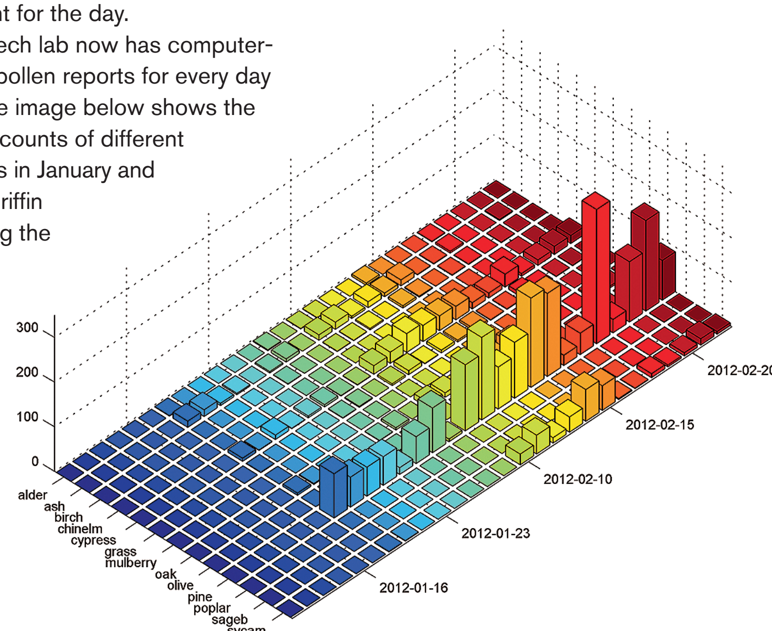
But acquiring detailed pollen counts is a tedious, eye-crossing process that has traditionally required people to spend hours staring through a microscope, identifying and counting individual pollen grains. That has been the way Caltech's Pollen Group, led by Irma and Ross McCollum–William H. Corcoran Professor of Chemical Engineering Richard Flagan, has been gathering data since 2002.

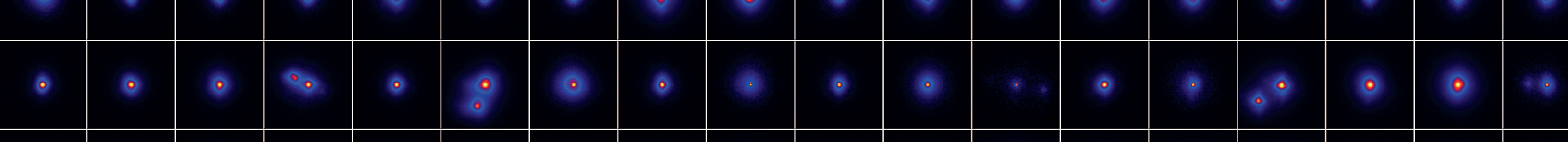
"If you're counting manually, it really takes an experienced counter a full day to count a day's worth of pollen," says Jim House, a visiting associate in chemical engineering who helps run the lab. "It occurred to us that this was no way to do business."

And so, a few years ago, Flagan and Caltech computational-vision expert Pietro Perona, the Allen E. Puckett Professor of Electrical Engineering, got to talking about a computerized system that could label and count pollen grains using image analysis. Now Greg Griffin, a graduate student in Perona's lab, has made that system a reality. The images above show portions of the pollen sample for Pasadena from February 12, 2012. Griffin's program inserted the boxes and assigned the labels, while tallying up the pollen count for the day.

The Caltech lab now has computer-generated pollen reports for every day in 2012; the image below shows the automated counts of different pollen types in January and February. Griffin is comparing the performance of the computerized system against the old-fashioned hand counts. "It's looking pretty good," he says. "But it misses some pollen grains when multiples clump together." So while the system isn't quite ready for the pollen prime time, the researchers are confident they will get there.

Since the system runs on nothing fancier than a light microscope with a computerized stage and a couple of computers, the hope is that once it's perfected, the bloodshot eyes of pollen-counters in labs around the world will finally get a well-earned rest. —*KF* e&s





SEEING STARS WITH ROBOTS

On a typical night, pockets of hot and cold air swirl overhead, turning what would otherwise be pinpoints of starlight into twinkles. But twinkling stars also mean blurry stars, and for astronomers who want the sharpest images of the heavens, the turbulent atmosphere poses a problem.

Enter adaptive optics.

Using tiny, moving mirrors that bend the incoming light just enough to compensate for the atmosphere's blur, adaptive optics have revolutionized astronomy, bringing into focus everything from asteroids and planets to star-forming gas clouds and distant galaxies. Adaptive optics were first developed for astronomical use about two decades ago, and today they're an indispensable part of all large telescopes.

Now, Caltech astronomers are making adaptive optics even better—by turning the process robotic. Current adaptive-optics systems and the telescope's scientific instruments—such as its cameras and spectrometers—are separate, independent devices. To run the telescope, you often need several people to monitor and operate each component.

But the new system, dubbed Robo-AO, is an all-in-one instrument that attaches with just three bolts to the back of the telescope for which it was designed—the 60-inch telescope at Palomar Observatory. And you don't need a whole team on hand because it's entirely automated. All Robo-AO needs is a list of the astronomical objects you want to look at and it will open the observatory dome, point the telescope, switch on the adaptive-optics system, and take the data all on its own. That makes observing easier and cheaper—a big plus given today's tight budgets.

"Not only is the equipment cost low, but the capital to keep it going is also low," says Christoph Baranec (BS '01), the Caltech postdoc who's leading the project. With a price tag of only half a million dollars, Robo-AO is a bargain compared to conventional adaptive-optics systems, which tend to cost several to tens of millions. This is a potential boon for the older, smaller telescopes, which usually have to forego traditional adaptive optics for financial reasons.

In addition, Robo-AO can more easily correct distortions of visible light, which is more susceptible to atmospheric bending due to its shorter wavelength. "Other systems around the world, including Caltech's flagship 10-meter Keck AO system, can't do that yet," Baranec says.

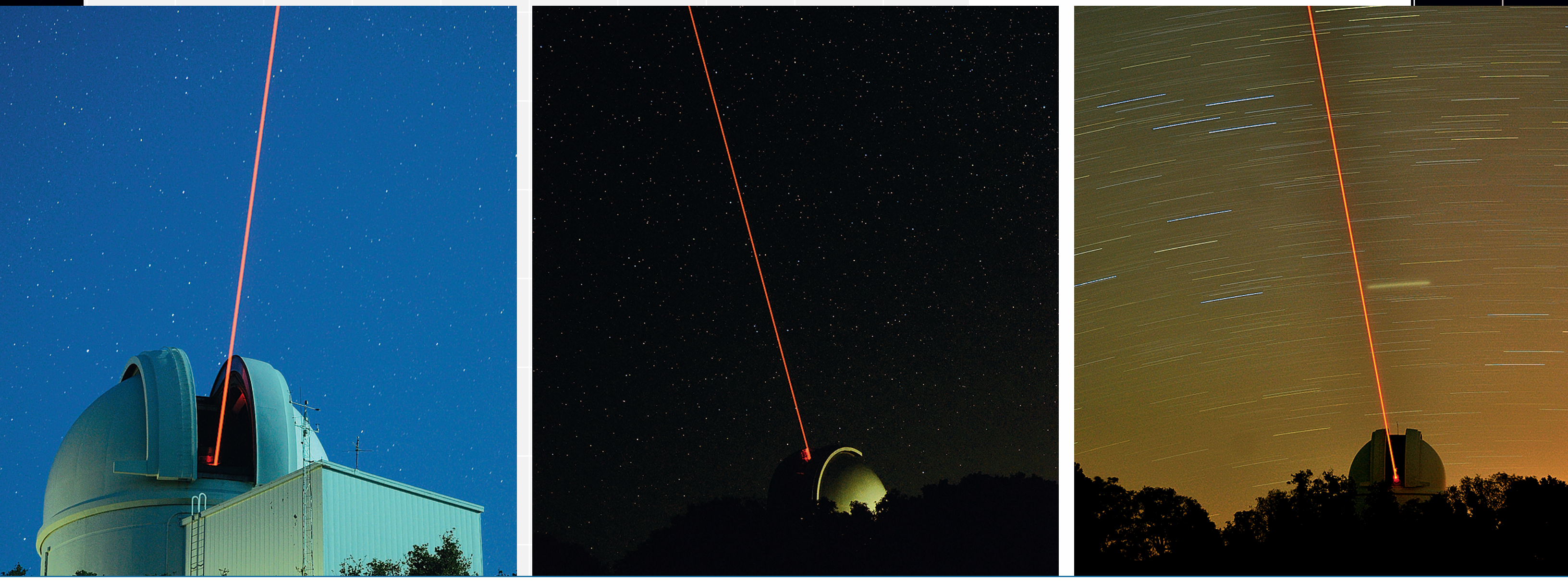
The team put the Robo-AO system to use for the first time last summer, and so far it's working smoothly. In a current project, the team is using Robo-AO to determine which of the more than 2,000 candidate planets discovered by NASA's planet-hunting Kepler space telescope are indeed alien worlds and not false positives. While it would take a human almost a year to follow up on all of them, Robo-AO can do the job in just a couple of weeks.

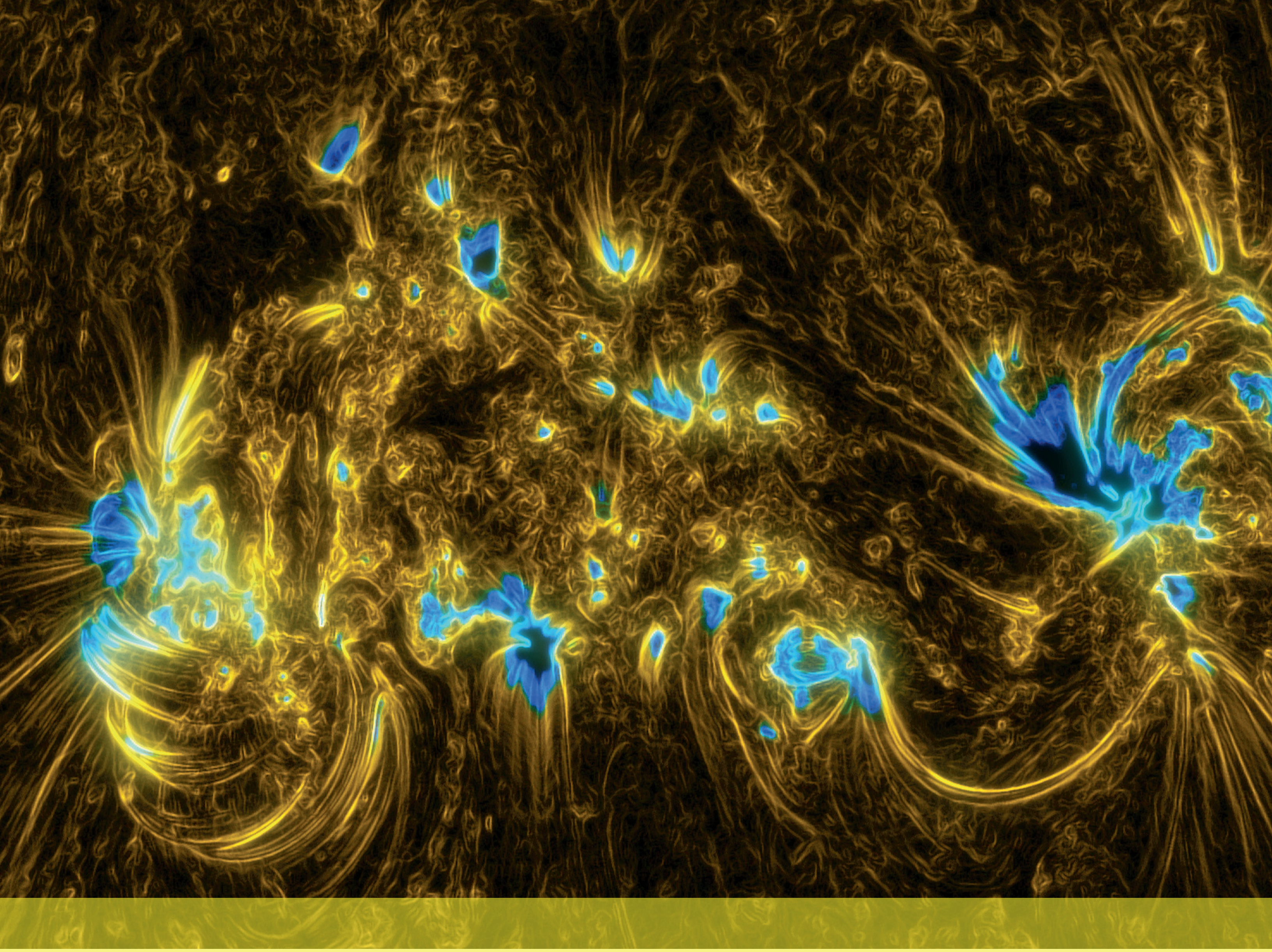
A group of collaborators at Pomona College has successfully tested its own Robo-AO system on Table Mountain, northeast of Los Angeles. The team is also collaborating with astronomers at the Inter-University Centre for Astronomy and Astrophysics in Pune, India, to install such a system on their two-meter telescope.

With an adaptive-optics-enabled telescope that works on its own, astronomers can do more science for less money in less time. And, Baranec adds, Robo-AO offers one other benefit: "We can all get more sleep." —*MW* e&s

Above (and background): Robo-AO took these 414 images over the course of just three nights; the images are 10 times sharper than they would have been without this new system.

Below: The Robo-AO system at work as part of the 60-inch telescope at the Palomar Observatory. By projecting an ultraviolet laser onto the sky and measuring how the atmosphere distorts the beam, the system can shift tiny mirrors just enough to counteract the blurring effects of the swirling air.





GETTING PHYSICAL WITH THE

It's hard to predict a hurricane if you don't know much about the events that precede it, such as the movements of high- and low-pressure fronts. The same holds true for weather on the sun. The large arcs of plasma that erupt from the sun's surface—called solar flares—can cause all sorts of damage to the wide range of satellites in orbit around Earth. We rely on such satellites for everything from television and radio feeds to Global Positioning System (GPS) navigation. Which is why physicists at Caltech are working to learn more about the possible precursors to solar flares—hot, ionized gas formations called plasma loops.

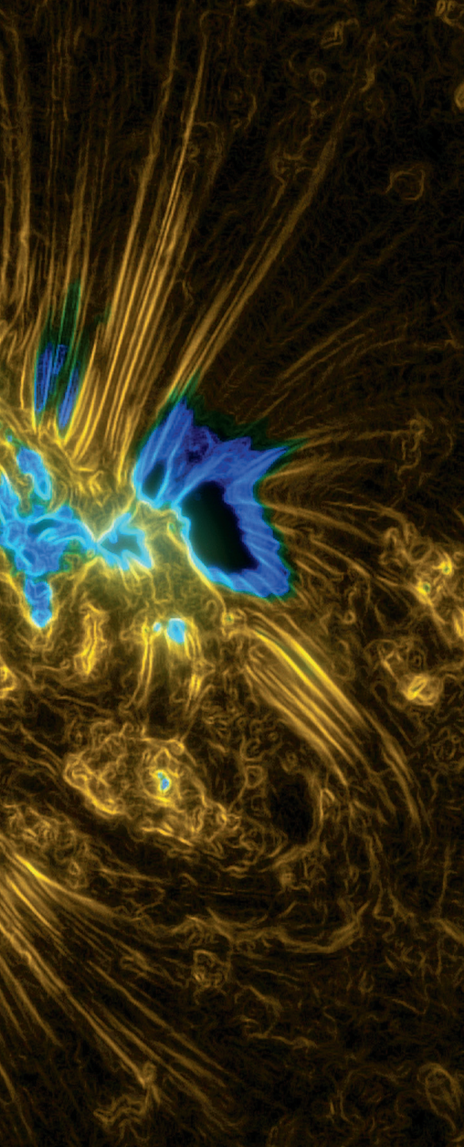
"We're studying how these solar loops work, which contributes to the knowledge of space weather," says Paul Bellan, professor of applied physics at Caltech.

To get a better sense of the physics behind these loops, Bellan—along with former grad student Eve Stenson (PhD '12)—recreated them in the lab using a pulse-powered, magnetized plasma gun.

Here's how it works: Two electromagnets create an arched magnetic field inside a vacuum chamber. Then, hydrogen and nitrogen gas is released where the arch touches the bottom of the chamber, its so-called footpoints. Finally, a high-voltage electrical current is applied at those footpoints, ionizing the gas and turning it into plasma, which travels at a minimum speed of about six miles per second.

"All three steps—the magnetic field, the gas, and the high voltage—happen in just a flash of light inside the chamber," says Stenson. "We use high-speed cameras with optical filters to capture the behavior of the plasmas."

What they saw with those cameras, as they watched the plasma



SUN

arching through the chamber, was that the plasma's behavior is controlled by two magnetic forces. One force expands the arch radius and so lengthens the loop, while the other continuously injects plasma into the loop from both footpoints. The latter force injects just the right amount of plasma to keep the density throughout the loop constant as it lengthens. Bellan and Stenson say that, in simpler terms, this process is like squeezing toothpaste into a tube from both ends, except that the toothpaste has little magnets in it, so that there are magnetic forces acting internally.

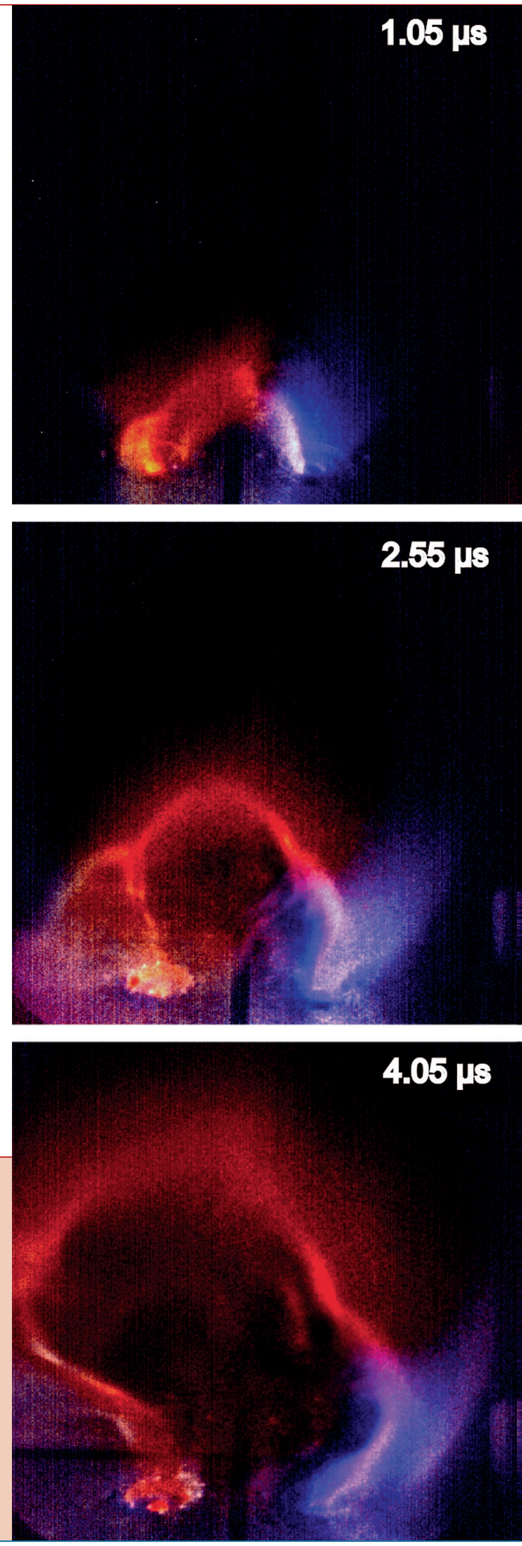
By color-coding the inflowing plasma, the camera's optical filters vividly demonstrated the flow from the two ends of the loop. On camera, red plasma flows into the loop from one footpoint while blue plasma simultaneously flows into the loop from the other end. Stenson explains that although they could only record the light from the hydrogen side *or* the nitrogen side during an individual experiment, the procedure is so reproducible that they were able to put separate images on top of one another in order to see how these two plasmas are actually interacting in the chamber.

Next, Bellan plans to see what happens when two loops come together. "We want to see if they can merge and form one big loop," he says. "Some people believe that this is how larger plasma loops on the sun are formed."

If that's true—and if giant loops lead to flares—then watching the sun's plasma loops could help us determine when solar flares are about to, well, flare up.

"It takes some time for the plasma to get to Earth from the sun," says Bellan, "so it's possible that with more research, we could have up to a two-day warning period for massive solar flares."

Stay tuned—maybe someday the evening news report will include a weather forecast from the sun. —*KN* e&s



Above: An image taken by NASA's Solar Dynamics Observatory, and processed to enhance the structures visible, shows the sun's surface in action. The yellow loops show plasma held by magnetic fields—plasma loops similar to those made in Bellan's lab, but much, much larger.

Right: The fast and furious plasma loops created in the lab were recorded using high-speed cameras. The elapsed time, as printed on the images, is represented in microseconds.

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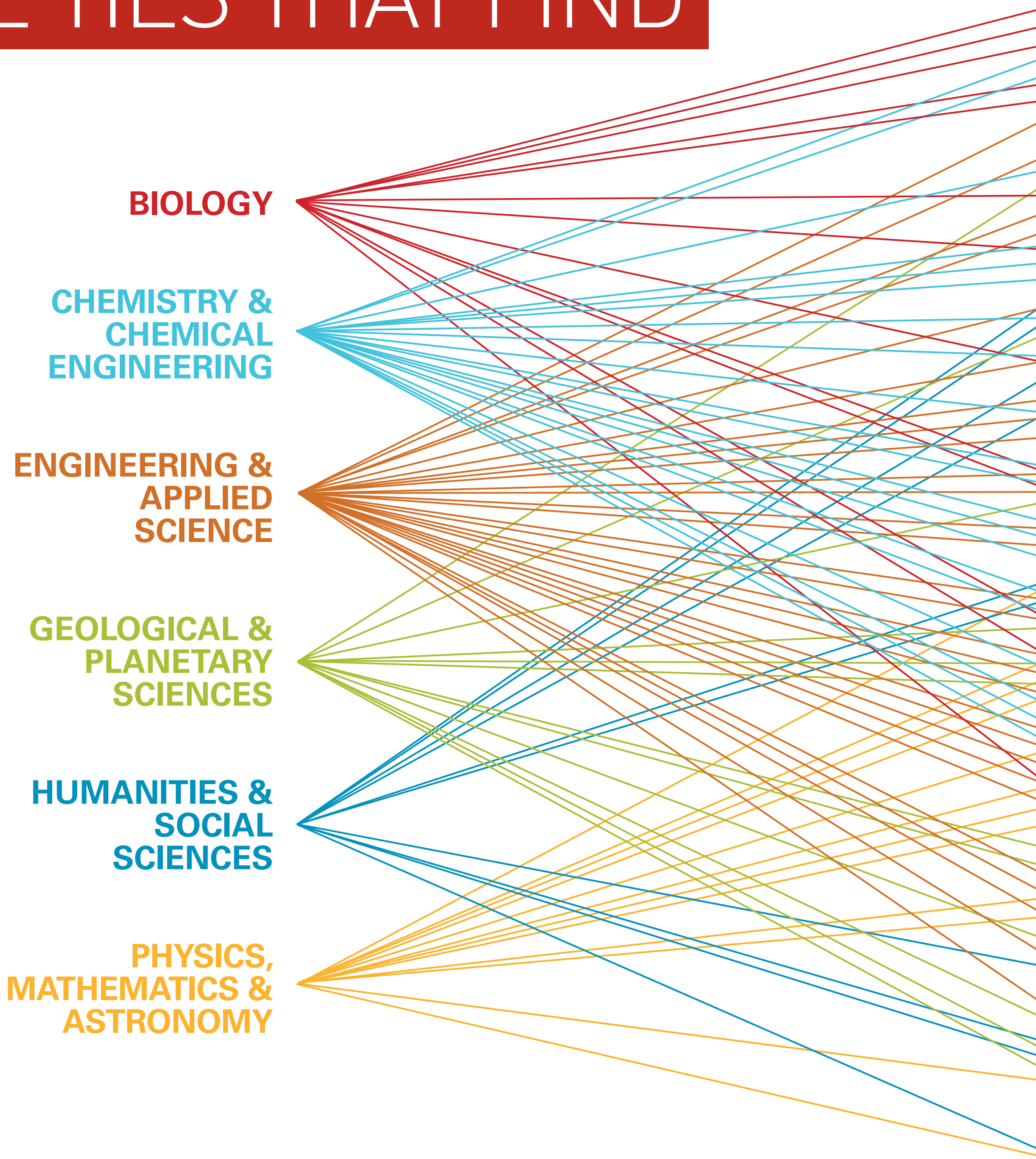
CROSSING BOUNDARIES

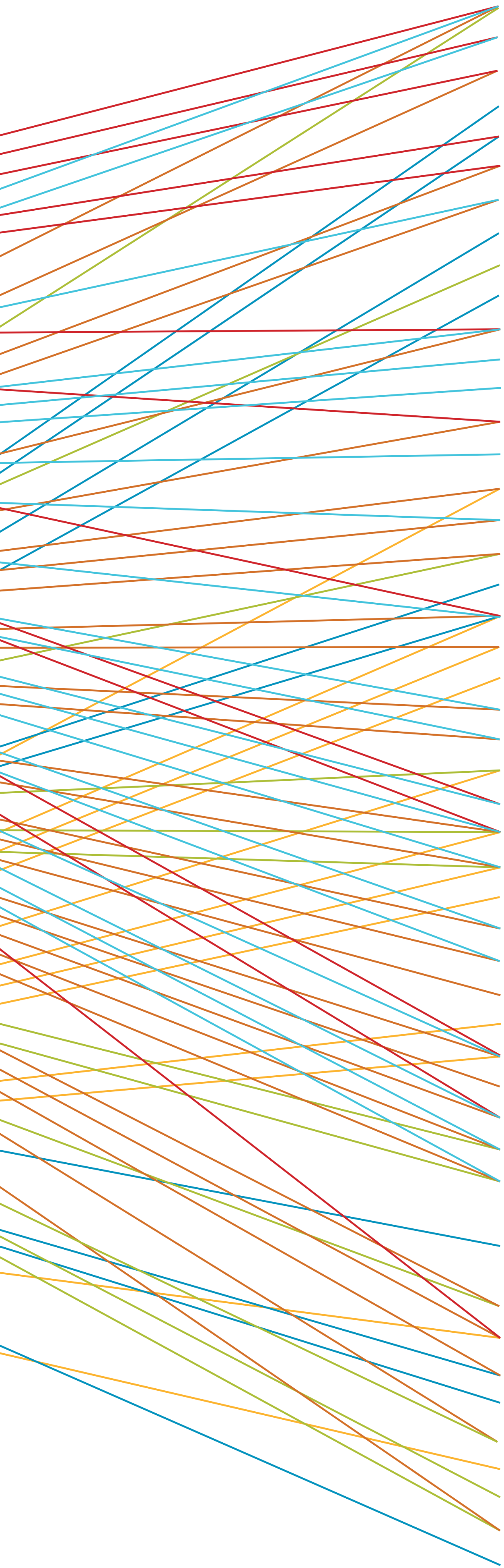
Science is a journey: You start in one place; you end in another. The path between the two is winding, circuitous even. But it's easy to traverse if you're supported along the way by collaborative colleagues, by barrier-clearing administrators, and by the science itself—which, most researchers would agree, is more likely than not to take the lead, rather than be led itself.

The stories that follow are all very different, but have one thing in common: They are tales of the science leading the scientists—across boundaries both physical and psychological, boundaries that lie between the unknown and the known and that convey the researchers toward ideas, fields, and even countries that are far, far different from those they began in.

But these tales are also about a coming-together. They're about taking disparate fields and uniting them in a single lab and a single career, a process that allows for the kinds of insights that wouldn't be possible from only a single vantage point. That is real science. That is real science at Caltech.

THE TIES THAT FIND





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Center for the Science and Engineering of Materials
Community Seismic Network
Einstein Papers Project
Information Science and Technology
Institute for Quantum Information and Matter
Institute for Theoretical Physics
Jacobs Institute for Molecular Engineering for Medicine
Joint Center for Artificial Photosynthesis
Joint Center for Planetary Astronomy
Joint Center for Translational Medicine
The Kavli Nanoscience Institute
Keck Institute for Space Studies
Laser Interferometer Gravitational-Wave Observatory
Light-Material Interactions in Energy Conversion
Materials and Process Simulation Center
Materials on the Brink: Unprecedented Transforming Materials
Moore Center for Theoretical Cosmology and Physics
Physical Biology Center for Ultrafast Science and Technology
Predictive Science Academic Alliance Program
Programmable Molecular Technology Initiative
Resnick Sustainability Institute
The Ronald and Maxine Linde Center for Global Environmental Science
The Ronald and Maxine Linde Institute of Economic and Management Sciences
Seismological Laboratory
Sloan-Swartz Center for Theoretical Neurobiology
Social and Information Sciences Laboratory
Social Science Experimental Laboratory
Southern California Seismic Network
Space Radiation Laboratory
Tectonics Observatory
Terrestrial Hazard Observation and Reporting Center
USC-Caltech Center for the Study of Law and Politics

BEYOND ROCKS

By Marcus Y. Woo

As relics of a long-lost time, artifacts tell stories. It was this hidden history that fascinated John Eiler as a boy, prompting him to plan on studying anthropology and archaeology when he went to college. Then, in his freshman year, he took a geology class to fulfill a science requirement—and his own history took a new turn.

When his professor learned that Eiler was an experienced outdoorsman—he'd canoed and fished as a teenager—the professor hired Eiler as a porter for his field expeditions. Eiler went on several excursions to remote areas of southern Canada, living the life of a field geologist. By his sophomore year he was hooked.

And so, in graduate school, Eiler became what you might call a traditional geologist. He studied metamorphic rocks—rocks like marble or quartzite that had been transformed by the tremendous heat and pressure deep beneath Earth's surface. When he arrived at Caltech as a postdoc, he turned his sights on the origins of igneous rocks—which are formed from magma or lava—earning an assistant professorship from the Institute.

But Eiler felt unsettled: "I felt like what was lacking from everything I had done to date was a sense of the unknown—a sense of exploration," he recalls.

One of the topics he had been working on was the geochemistry of isotopes—atoms of a particular element, but with different numbers of neutrons in their nuclei. Many of the tools used in the Earth sciences—those that measure the amounts of rare isotopes like oxygen-18 in order to analyze ancient climates, for example—had their roots in the 1930s and 1940s. Back then, chemists were discovering that a molecule's properties depend not only on whether it contains rare isotopes, but also on how those isotopes are grouped and arranged in the molecule. And, they found, certain chemical reactions or environments favor one configuration over another.

By identifying the isotopic arrangement of a naturally occurring molecule, then, a scientist could—in principle—figure out the conditions under which it formed, a prospect that piqued Eiler's interest. The information hidden in those isotopic arrangements, he believed, could open up vast new areas of research in everything from Earth history to medicine.

But first, he would have to do what no one had done before: measure those isotopic configurations. His initial plan of buying a supersensitive instrument that could make all the necessary measurements failed. No such tool existed; the assumption was that these isotopic species would be so rare that they'd be impossible to find in quantities sufficient to analyze. And without a demonstrated market for such a machine, no one would design and build one for him. "They laughed me out of the room," he says.

Eiler's backup plan was to tweak existing instruments to detect and measure those rare isotopic species. That's precisely what and he and his colleagues have been doing for most of the last decade, honing their methods while focusing on simple molecules like carbon dioxide. Indeed, Eiler made a splash in the media and the scientific world alike when he devised a way to measure how the clumping of heavier, rare isotopes in carbonate—the main component of seashells, eggshells, and a fraction of tooth enamel—correlate with the temperature of that carbonate when it was created. The cooler the temperature, the more the heavier isotopes—in this case, oxygen-18 and carbon-13—tend to group together. By gauging this tendency to clump, Eiler created a kind of paleothermometer, which he and his colleagues have since used to measure ancient climates on Earth and Mars and to pinpoint, for the first time ever, the body temperature of a dinosaur.

While other scientists are refining this technique, Eiler still has his sights set on measuring even rarer isotopic configurations. Over the past decade,

> "This [research] will impact medicine, the development of drugs, our understanding of metabolic disease, environmental chemistry, and biochemistry. There are just so many different subjects that will be touched by this."

he says, the field has advanced enough that instrument manufacturers are now building the types of machines he'd dreamed of years ago. This year, in fact, his lab bought a new mass spectrometer that can measure the isotopic arrangements of all kinds of complex molecules—not just simple ones like carbonate. He and his colleagues have already begun demonstrating this ability by developing a thermometer technique that analyzes natural gas, which is a more complicated problem than it is with carbonate.

Next up: the isotopic profiles of increasingly complex biological molecules, starting with amino acids and alcohols, then moving on to proteins, fats, and sugars. Indeed, within a year or two, Eiler expects that he and his colleagues will be able to measure and analyze the isotopic configurations of blood-sugar molecules—giving doctors a window into the workings of their patients' metabolisms, and enabling the diagnosis of diseases like diabetes before there are any obvious physiological symptoms.

But why stop there? says Eiler. You could even use this type of analysis to figure out how and where a biological or chemical weapon was made. "This will impact medicine, the development of drugs, our understanding of metabolic disease, environmental chemistry, and biochemistry," Eiler says. "There are just so many different subjects that will be touched by this."

But first, there is serious work to be done. After all, the number of isotopic configurations in any good-sized molecule is huge. In the biggest and most complex molecules, the combinations skyrocket into the millions. Encoded in each and every configuration is the history behind that molecule—such as information about the environmental conditions when that molecule formed. All together, then, these configurations form a true treasure trove of data.

"It's similar in scale to the information content in genetics," Eiler says; and, indeed, determining every isotopic combination in a molecule would be a task akin to that of sequencing an organism's genome.

Even when that's done, the game will not be over. Being able to identify all the isotopic arrangements in a complex molecule is one thing; learning how to extract useful knowledge from that mass of data is another. And so, Eiler admits, his broader, more ambitious goals—such as disease diagnosis—will still take some time. "We're not there today, but we can see how to get there," he says with characteristic optimism. "It's just a matter of elbow grease." E&S

***John Eiler* is the Robert P. Sharp Professor of Geology and professor of geochemistry. His research is funded by the National Science Foundation and Caltech.**

THE MOLECULAR GEOMICROBI

By Katie Neith

"I had an amazing teacher in the fifth grade," remembers Caltech geomicrobiologist Dianne Newman. "She gave us the opportunity to do our own experiments—I remember making a simple maze using tacks and wires that were attached to a battery and a small lightbulb. Every time you completed the circuit by touching the right tack with a nail, the bulb would light up. It made learning really fun."

Like that circuit maze, Newman's career path—set in motion by her fifth-grade science teacher—has been a series of twists and turns as she's tested out different disciplines to see which would set off a metaphorical lightbulb for her. After trying her hand at environmental engineering, materials science, and even German, she eventually settled on not one but two seemingly disparate fields: geology and microbiology, with some chemistry mixed in for good measure.

"For me, the allure of microbiology has always been the insight it provides into the chemistry that bacteria engage in," says Newman, who studies how such microbes adapt to the world around them—be they on a rock, under water, or in the human body. "They are phenomenal organisms whose

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activities are crucial in shaping the chemistry of their environment."

Newman was hired at Caltech as the Clare Boothe Luce Assistant Professor of Geobiology in 2000 to help shape the Institute's nearly brand-new geobiology program, which was intended to explore the coevolution of life and Earth. She was only a few months into her postdoctoral position when she got the job, so the Institute waited two years for her to complete her postdoc. Today, her lab—and the program she helped cultivate—is thriving.

"My lab is divided into two halves, and each half does geobiology in a different way," says Newman, who is the only faculty member at Caltech with a full joint appointment in both the Division of Geological and Planetary Sciences and the Division of Biology. "One problem we work on has clinical relevance—understanding how pathogens survive in the body—and the other has implications for Earth history."

She says that, initially, she started out with a problem that had a geological bent: How do bacteria respire—or breathe—on a rock? She soon realized that the strategies bacteria use to survive when they are growing on a rock are similar to how they manage to survive in the human body. If you have a mass of bacterial cells, those in the interior don't get anywhere near the oxygen (or, if they're on a rock, the iron minerals) because the guys on the outside consume it all, explains Newman. How the cells solve the problem of getting energy to those that are not in direct contact with its source is a broad problem, she says. When Newman was named a Howard Hughes Medical Institute (HHMI) investigator in 2005, it gave her an extra push to begin thinking about ways bacteria survive and thrive in clinically relevant anaerobic environments.

"The point is that, just as a rose is a rose is a rose, an environment is an environment—you can take the same way of thinking that you might have applied to a geological system and apply it to the environment within a human host," she explains. "We're framing microbiological problems in the human body the same way we would such problems in a sediment in a contaminated lake. We're doing the same types of measurements to garner ideas about how bacteria get energy given the constraints of the system. This mix of thinking can be very fruitful."

One particular environment that currently holds Newman's attention is the human lung. She's investigating *Pseudomonas aeruginosa*, the primary cause of morbidity and mortality in people who have cystic fibrosis (CF), a chronic lung disease. It also is an important hospital-acquired bacterium for people who are immune-compromised due to health issues such as cancer or HIV. Working with medical colleagues at Children's Hospital Los Angeles and the USC Adult Cystic Fibrosis Center, she and students in her lab are exploring how these bacteria manage to thrive in the lungs of CF patients.

"So far, it seems that one of the major predictions we made in the lab about how iron chemistry and microbial metabolism would coevolve is true in the context of the lung environment," says Newman. She points out that understanding what forms of iron are metabolized by bacteria is important for designing drugs effective at controlling infections. "There's potential for transformative work to be done at this interface where we bring ideas from geobiology and apply them in a medical realm to figure out what's going on."

The other part of her lab is working on a more obviously geobiological project related to interpreting the signatures of bacteria in really old rocks. In other words, how did bacteria make a living in certain ancient environments, and how did their metabolic processes affect the world around them?

"We can look for molecular fossils—or chemical traces of organisms—in these rocks, but how do we confidently interpret them?" says Newman. "One of the ways we can begin to gain insight into this is by using molecular biological approaches to figure out what the modern counterparts to these fossils do in modern cells, and from there, extrapolate back into the past. For example, we are trying to understand the cell biology of hopanoids—steroid surrogates in bacteria—so that when we see hopanes (the name of their corresponding molecular fossils) in ancient rocks, we can infer something specific about the organisms that produced them."

Once we understand what particular geostable compounds do in modern cells in a detailed way, that will help us better interpret some of the processes that took place in ancient environments, she says.

"Bacteria are the best chemists on the planet—they were the first in as the life forms that colonized the planet, and they will be the last out because they can survive just about anything," says Newman. "They have profoundly shaped every aspect of our Earth and they have profoundly shaped us." E&S

Dianne Newman is professor of biology and geobiology. Her research is supported by HHMI, the National Aeronautics and Space Administration, the National Institutes of Health, and the National Science Foundation.

HOW TO BECOME A SNOWFLAK

By Kimm Fesenmaier

Ken Libbrecht (BS '80) likes to follow his scientific fancy. Known today as the man who has revealed the secret life of the snowflake, this soft-spoken physicist was once entirely engaged in studies of the sun.

"Ever since I was a student, my life philosophy has been to just do something interesting," he says. "It doesn't matter what it is. It just has to be interesting to me."

That life philosophy was forged, in part, during his undergraduate years at Caltech, where he conducted research with physicists Tom Tombrello and Steve Koonin (BS '72). As Libbrecht says, "The idea of following your nose to sniff out interesting science is certainly not unknown at Caltech."

Later, in graduate school at Princeton, his interests led him to test Einstein's theory of general relativity—a task that involved gathering measurements of the shape of the sun. ("In the end, Einstein passed, as usual," he quips. "Darn!")

Following that passion paid off. Several professors at Caltech—including Rochus (Robbie) Vogt, who was then the Institute's provost—were so intrigued by Libbrecht's studies of the sun that they offered him a position as an assistant professor of solar astronomy. This despite fact that he had never taken a formal course in any type of astronomy.

When Libbrecht arrived on campus in 1984, helioseismology—a field that studies the sun by analyzing its internal sound waves—was just heating up. So Libbrecht set up a small telescope at Caltech's Big Bear Solar Observatory and started making measurements of the sun. Through careful observation, he was able to use solar sound waves as a sort of probe, helping to work out the sun's internal structure and measuring its internal rotation. Libbrecht and colleagues determined, for instance, that beneath the surface the sun's equator rotates quickly, while its poles rotate more slowly.

"A smallish number of us were just going at this like crazy, trying to figure it all out before anyone else did," Libbrecht says. "It was great, and I would have kept doing it forever, except it was kind of a finite thing: Once we made all the measurements we were after, we were basically done."

Right around that time, the Laser Interferometer Gravitational-Wave Observatory (LIGO) effort started ramping up, with Caltech playing a major role. Libbrecht was recruited to be part of the effort to detect gravitational waves, those ripples in the fabric of space-time that were, again, predicted by Einstein. He got to work, helping the team better understand the sources of noise that can limit LIGO's sensitivity, and measuring the properties of some of the detectors' components.

But even as he was working on that project, his interest was steadily being drawn to another—studying the physics of crystal growth, and of ice in particular. At one point, during a casual conversation with one of his postdocs, Libbrecht happened to mention that it would be neat to see a video of an ice crystal (which is to say, a snowflake) in the process of growing. After trying in vain to find any such video online, he started scouring the scientific literature for anything about the physics of snowflakes.

He found black-and-white photographs of individual snowflakes taken by Wilson Bentley beginning in the 1880s; a smattering of journal articles; and a book called *Snow Crystals: Natural and Artificial*, written by physicist Ukichiro Nakaya in 1954. In the book, Nakaya described the various categories of snowflakes and what he had discovered about their growth. In particular, Libbrecht was captivated by images of snowflakes known as "capped columns." Looking something like icy thread bobbins, these snowflakes feature a central column capped at either end with platelike structures.

"How come I've never seen one of these?" he wondered. After all, he'd been around plenty of snow, having grown up in North Dakota. On a trip back home that winter, he took his magnifying glass outside for a closer look. He was amazed by what he saw—a stunning array of delicate frozen doilies, including plenty of capped columns.

The diversity of snowflakes made Libbrecht think of his grad-school days, when he had roomed with an ornithologist who introduced him to bird watching. Libbrecht describes that introduction as a bit of an eye-opener. "I'd never really noticed birds much," he says. "And then all of a sudden, you get a field guide and you realize there are all these different types of birds. It enriches your life ever so slightly." As he delved further into studying ice crystals, he decided someone needed to make a field guide to snowflakes, giving people who live in cold regions a chance to enrich their lives by noticing the crystals all around them.

Today, Libbrecht has published seven books, including the wished-for field guide for other snowflake watchers. But what really hooked him on the study of snowflakes was their physics, and the opportunity to gain more insight into the molecular dynamics that dictate how ice crystals grow. Although he is still part of the LIGO team, he now spends most of his time thinking about ice.

Libbrecht says that, when he first started working in the field, no one really knew why snowflakes grow differently

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at different temperatures. "It just blew me away that people didn't understand that," he recalls. "And about five years ago I said, 'You know what? I'm going to buckle down and solve this problem.'"

He's not quite there yet but feels that he's very close to a solution—one that involves such complex concepts as structure-dependent attachment kinetics and diffusion equations. He refers to the solution as his standard model because, like the standard model (the general physics model that attempts to explain the interactions between subatomic particles), it's kind of ugly and yet accounts for much of what has been seen.

In his lab, where he generates snowflakes in cold chambers—controlling such variables as temperature and humidity—Libbrecht has recently started using his standard model to predict which types of snowflakes will form when he tweaks the chamber's conditions. "I'm starting to think I know what I'm doing," he says with a chuckle.

That's a major step forward for a scientist who has spent the past dozen years increasingly focused on a project that he still describes as his "science hobby." Even though he has never received a penny of grant funding for the project, it has captured and held his interest. For this reason, he says he feels privileged to be at Caltech, where he is given lab space to pursue his scientific interests even if they aren't "fashionable." After all, he adds, "I get the feeling that if I don't get up and do this, nobody else in the world will. That makes it a little bit special." E&S

Ken Libbrecht is a professor of physics and the executive officer for physics. His work on snowflakes is funded by sales of his books, the most recent of which is The Secret Life of a Snowflake.

HUNTING FOR SURPRISES

By Kimm Fesenmaier

In 2001, applied physicist Rob Phillips came across a press release from UC Berkeley that immediately caught his eye. Researchers in the lab of biophysicist Carlos Bustamante had measured how tightly packed the genome was inside a bacterial virus and had come up with an astounding result: they found that the DNA could be packed to a pressure of about 60 atmospheres, many times greater than the pressure champagne is subjected to in a corked bottle.

"It blew my mind," Phillips says. "It was what I call an experiment to change your life for."

At the time, Phillips was new to Caltech. He had spent seven years on the faculty at Brown University building up a reputation (and funding) doing multiscale modeling of materials, and had just written a book called *Crystals, Defects and Microstructures.* But even as he was settling into his new office in the Thomas Laboratory of Engineering, he knew that he was about to take an enormous scientific detour.

"In writing that first book, I realized that all the stuff that most excited me was the things that people had done 60, 70, or 80 years ago, in the back-of-the-envelope era when they were laying the foundations of the field," Phillips says. "I felt like I wanted to be a part of that kind of era, and I've always been interested in the living world, so I was looking for a biological problem that I could sink my teeth into."

Then came the release about Bustamante's work. The physics of viral infection seemed like an ideal candidate—not so much as an entrée into biology as a field, but as a physics problem that just happened to be set in a biological context.

Today, Phillips has a joint appointment in the Division of Engineering and Applied Science and the Division of Biology, and has recently coauthored a second book, this one titled *Physical Biology of the Cell*. He's interested in finding as many examples as possible that are like the viral DNA packing problem, in that they show the value of a quantitative approach to understanding a biological phenomenon. "I want to figure out how to be surprised by biological phenomena," he says, "and I'm searching for problems in which the only way you would know you're surprised is if you did some math and then did a quantitative measurement to check the results of that mathematical description of the problem."

Phillips insists, with what he calls "almost a philosophical puritanism," that the researchers in his group describe biological systems using equations and conduct their work with a modeling approach—using mathematical models to make predictions and to design and carry out quantitative experiments—that is more characteristic of physics or engineering than any type of life science.

Take his interest in the phenomena behind viral infections. While scientists have done admirable and important work using biochemistry and more conventional genetics, he says, "I'm claiming that there is also a completely legitimate approach to those problems which isn't based on doing genetics or biochemistry. It's based on saying 'I have an equation, I know how much energy it costs to put all that DNA inside of there, and there are useful things I can figure out based on that kind of information.'"

Most recently, his group, including then graduate students David Van Valen and David Wu, measured the rate at which a type of bacteriophage—a virus that infects bacteria—transfers its genetic material into a targeted *E. coli* cell. They used a fluorescent dye to stain the DNA of two mutants of the so-called lambda bacteriophage while that DNA was still inside the phage. One of those mutants has a short genome and one has a longer genome; the team wanted to see whether and how the transfer is affected by the amount of DNA in the phage. By tracing the glowing dye, the researchers were able to watch as individual viruses infected individual bacteria and to time the transfer of DNA from phage to bacterium. The mean ejection time was about five minutes, though it varied considerably.

This was quite different from what the group had seen previously when they ran a similar experiment in a test tube. There, they had essentially tricked the phages into ejecting their DNA into solution—a task the phages completed in less than 10 seconds. In that case, once the phage with the longer genome had released enough DNA to make what remained inside the phage equal in length to the shorter genome, the two phages ejected DNA at the same rate. Therefore, Phillips's team reasoned, it was the amount of DNA in the phage that determined how quickly the DNA was transferred.

But, as Phillips says, it turns out that "what is true in the test tube is not true in the cell." *E. coli* cells contain roughly three million proteins within a box that is roughly one micron on each side. Less than a hundredth of a micron separates each protein from its neighbors. "There's barely any room for anything else," Phillips says. "These cells are really crowded."

And so, when the bacteriophages try to inject their DNA into the cells, the factor that limits the rate of transfer is not how much DNA they need to spit out, but how jam-packed those cells are. "What we discovered is that the thing that mattered most was not the pressure in the bacteriophage, but how much DNA was in the bacterial cell," Phillips says.

That particular surprising result would never have come to light, he points out, without a little math and at least a few measurements.

Looking back on his decision to leap into a new field as an already established professor, Phillips has no regrets. In fact, he says, the move was actually more natural than it might seem. Growing up, he tended to dabble in subjects, following his interests. "I didn't have a particular attachment to thinking of biology as separate from physics," he says. "I learned a little bit of this and a little bit of that, and I didn't really care what things were called."

One thing he's always been interested in, however, is systems that are out of equilibrium. "And," he says, "there is no better example of that than life."

That surprising result would never have come to light without a little math and at least a few measurements.

Rob Phillips is the Fred and Nancy Morris Professor of Biophysics and Biology, and the option representative for biochemistry and molecular biophysics in the Division of Biology. His work is funded by the National Science Foundation, a National Institutes of Health Director's Pioneer Award, and the Fondation Pierre-Gilles de Gennes.

SEARCHING FOR MEMORIES

By Marcus Y. Woo

We're constantly inundated with information from our laptops, smartphones, and tablets. Indeed, today's technology can store and process more information than we ever thought possible. For example, the first hard drive—made by IBM in 1956—held about four megabytes and weighed a (literal) ton. Now, you can easily fit 128 *giga*bytes—more than 32,000 times that original amount—on a flash drive that doubles as a keychain.

It's the era of big data. Unprecedented amounts of information are being churned out by everything from scientific research—think genome sequencing, or particle physics at the Large Hadron Collider—to the billions of purchases, clicks, and "likes" on social media, which are a gold mine of data for companies. It's an era when anyone can blog, tweet, or send their thoughts and their lunch menus out into the electronic ether that is the Internet. "The challenge for the future is not that we will have a problem of how to store information," says Caltech's Shuki Bruck. "The challenge is that we will not know what we have."

> "The challenge for the future is not that we will have a problem of how to store information. The challenge is that we will not know what we have."

An electrical engineer by training, Bruck calls himself an "informationist." He's developing better ways for computers to process, access, and *use* information. He's both an academic who's immersed in theoretical ideas and an engineer who not only seeks practical, immediate applications but turns them into start-up companies.

Although most of his career has been spent thinking about silicon-based computers, Bruck is now finding inspiration in a different kind of computer: the human brain. By understanding and mimicking the brain, he says, we can design computers that can better access and manage information. After all, over the course of our lives, we absorb facts, ideas, sights, sounds—all of it information. And yet our brains are able to nimbly extract meaning from that database, enabling us to live without being continually overwhelmed by every detail or memory. "It's not like every second I remember everything that has happened to me—otherwise, I'd have a headache," Bruck says. "We are able to manage all the information we have amazingly well."

We're able to manage all that information because the human brain accesses its memories by association, allowing us to pick out the bits we need while ignoring everything else. For example, when you run into a long-lost friend, your brain grabs the memories associated with her: the last time you saw her, her family, the jokes she always used to tell. Once she's gone, those memories go back into storage, not to be recalled again until needed.

A conventional computer, on the other hand, works by storing pieces of information on virtual shelves. The computer knows and has to keep track of where everything is at all times, so that it is able to pull out that information whenever it's needed. But it can't associate a specific piece of information with others that may in fact be relevant. If our brain worked this way, Bruck says, we wouldn't be able to focus on the tasks necessary for survival. Nor would we have language, since we communicate by associating words with other words and concepts. (The word *horse*, for example, represents everything we've learned that's associated with the word, such as cowboys, races, and saddles.) Without being able to access the meaning of every word by association, our brain couldn't process language.

Right now, this is something that is beyond a computer's abilities. But Bruck is devising new theories and algorithms that will someday allow computers to retrieve data like the human brain does—and, in so doing, handle vast amounts of information quickly and efficiently. But that's not all. He hopes to build computers that actually *behave* like our brain—constantly making new connections and associations between pieces of data. "Suddenly, you'd have an extension of your brain," he says. "One of my dreams is that you can wake up in the morning and brainstorm with your very-smart phone."

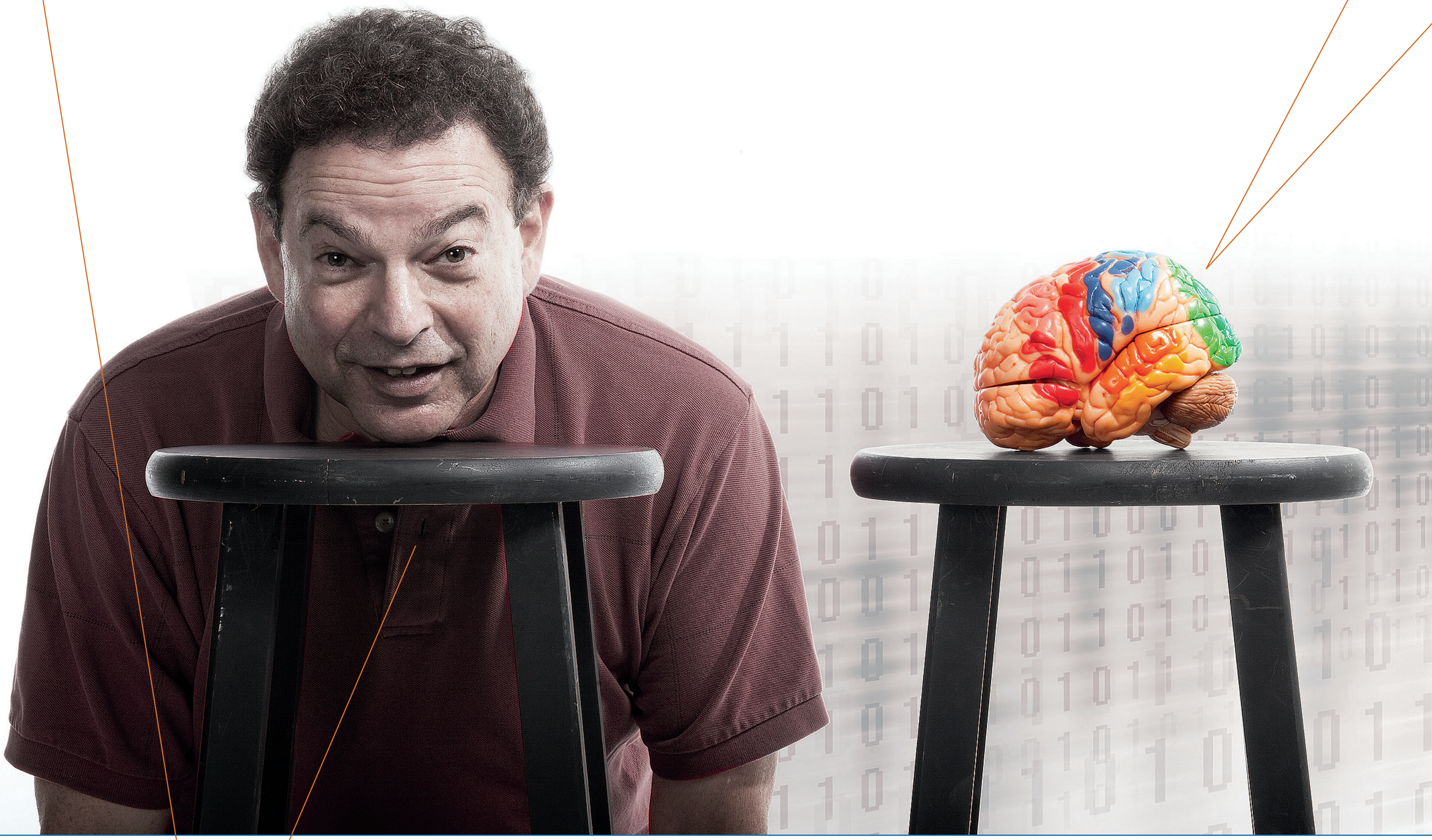
We're not quite there yet, says Bruck—on either the theoretical or the technical front. But we're already taking the first steps, he says, by developing flash memory technology, the ubiquitous technology now inside almost every portable electronic device. Conventional hard drives are magnetic disks on which data must be read or written in sequence. With flash, however, the computer can access the data in any order—more akin to how your brain works—giving it increased speed and efficiency.

But what's most promising about flash, Bruck says, is that this memory device is based on silicon—the same material from which computer processors are made. In current computers, the processor and the information storage are separate components—unlike the brain, which thinks *and* stores memory. And so, with flash memory, Bruck and his colleagues could one day create a more brainlike machine that integrates storage and computing in a single silicon device.

One limitation of current flash memory technology is that information can only be written and erased a few thousand times, and although that's good enough for your camera or phone, it won't work for the large-scale computing that's becoming increasingly necessary in industry and government. But that's changing. Bruck has been designing new methods to improve the capacity, speed, and reliability of flash memory. He's also chairman and a cofounder of XtremIO—a start-up company recently acquired by EMC Corp.—that has developed the first all-flash storage system capable of large-scale use.

Meanwhile, Bruck continues his endeavor to understand the brain and to improve information systems. Biology, he says, can inform computer science and technology—and vice versa. "Those walls between disciplines are going down," he says. "It's a very exciting time." e&s

***Jehoshua "Shuki" Bruck** is the Gordon and Betty Moore Professor of Computation and Neural Systems and Electrical Engineering. His research is supported by the National Science Foundation and Caltech's Lee Center for Advanced Networking.*



THE PATH TO SCIENTIFIC FRE

By Katie Neith

"Had I stayed in Russia, in a profession called molecular biology, it would have been tantamount to a death sentence," says Caltech molecular biologist Alexander Varshavsky, who was born in Moscow and began his research career in the former Soviet Union, a country under totalitarian Communist rule. Which is why, in the late 1970s, he undertook great risk for the opportunity to explore science on his own terms, escaping the Soviet Union and starting fresh in America.

It paid off. Thirty-five years later, he is known for a number of major contributions to biochemistry and genetics, most particularly for discovery of the biological functions of the proteolytic (protein-destroying) cellular machinery called the ubiquitin system, and for the discovery of primary degradation signals in short-lived proteins. Ubiquitin, a small protein, is a key part of a highly complex system that underlies just about everything that living cells do. Ubiquitin-dependent protein-destroying pathways play major roles in cell growth and differentiation, DNA repair and replication, the regulation of gene expression, and many other biological processes, including immune responses and the functioning of the brain. For his groundbreaking work, which cofounded the field of ubiquitin and regulated protein degradation, Varshavsky has received numerous awards and honors.

But the path to scientific success was neither clear nor easy for a young molecular biologist coming of age in Moscow during the Cold War. Growing up with a scientist father and a physician mother, he had familial support for his love of science and interest in research. However, there were few opportunities for doing fundamental biology in the Soviet Union of those days, largely because the conditions for scientific work were simply awful—a combination of nearly absent funding, the impossibility of traveling abroad, and the lack of freedoms that are taken for granted in the West.

"What kept me working was my youth, love for science, ambition, and the unrealistic hope that things might improve."

"My dreams and the reality I had to face were on different planets," says Varshavsky of his early academic years. As he went on to study biology and chemistry at Moscow University, it became increasingly obvious that attempting molecular biological research in the Soviet Union would be unlikely to succeed, in part because the country was destitute when it came to lab equipment and reagents good enough for sophisticated experiments.

"What kept me working was my youth, love for science, ambition, and the unrealistic hope that things might improve," says Varshavsky, who received his PhD in 1973 and then continued to work at the Institute of Molecular Biology (IMB), where he had done his graduate research.

It was in 1976, after receiving an invitation to speak at a symposium in England, that Varshavsky got his first taste of freedom. Against all odds, he was allowed to travel, with an escort—the director of the IMB—who had obtained permission for both of them from the KGB.

"I have no idea how he was able to convince them to let me travel to London with him, especially because I had no hostages," says Varshavsky. (In those days, a person would virtually never be allowed to travel abroad unless the government knew there was a "valuable" family member waiting at home, acting as a kind of collateral; Varshavsky knew the KGB did not consider parents to be viable hostages.) "The weeklong trip to London was over before I knew it. I returned to Moscow dejected, thinking that I had squandered my first and only chance for escape."

Ironically, it was a totally unexpected phone call from the KGB and a follow-up meeting with its officers shortly after his England trip that reignited Varshavsky's hope for emigrating to the West.

"They wanted me to gather intelligence on genetic engineering, a concept that both baffled and worried them," he says. "I told the two 'counter-intelligence' officers whom I dealt with that I would be able to assist them in gathering the required information. But to do so, I would need to travel to where genetic engineering was being developed—the West." Before long, he was on his way to a conference in Finland, where he hatched an escape plan with the help of an American friend.

Varshavsky says the actual getaway was uneventful: he simply boarded a ferry from Helsinki to Stockholm, Sweden. The guard at the ferry barely glanced at his ticket, and no visa was

EDOM

required to enter Sweden. From the dock, he drove to the U.S. embassy and was then sent to Frankfurt, Germany, where the U.S. consulate suggested he go to Rome to wait for a visa. Eager to get his research started in America, Varshavsky took a gamble by calling overseas to an acquaintance he had made at a USA-USSR science symposium in Kiev two years earlier—the Nobel laureate (and future Caltech president) David Baltimore, who was at MIT at the time.

"Amazingly, David remembered me. He was gracious and supportive," recalls Varshavsky. "He suggested that I stay in Frankfurt while he looked into getting the necessary paperwork for a visa. Within a few days, I was flying to New York with U.S. visa in hand."

Varshavsky's gifts as a scientist were quickly appreciated in the States. He became an assistant professor at MIT in 1977, within two months of his arrival in America. By 1982, he had tenure and was pioneering the field of ubiquitin research. Ten years later, he moved the laboratory to Caltech, where his science has continued to prosper.

"Not unexpectedly, MIT and Caltech are very similar places, first and foremost in their shared standards of excellence," he says. "But there is little similarity in climates between Boston and Pasadena, and I don't have to tell you which of two campuses is a greater pleasure to behold."

In describing his lifelong dedication to gaining new understanding in the field that he loves, Varshavsky cites the late experimental physicist Percy Bridgman: "The scientific method is doing your damnedest, no holds barred." It seems a fitting mantra for a man whose passion for science beat the hammer and sickle.

Alexander Varshavsky is the Howard and Gwen Laurie Smits Professor of Cell Biology at Caltech. He is a member of the National Academy of Sciences and has received the Lasker Basic Medical Research Award, the Canada Gairdner International Award, the General Motors Sloan Prize, the Wolf Prize, the Horwitz Prize, the Wilson Medal, and the King Faisal International Prize for Science, among many others.

ALUMNI IMPACT

Whether processing radar signals in Norway or assessing rock properties in Nigeria, Calte

Dublin, Ireland, David McConnell, PhD '71, Biochemistry

David McConnell is a molecular geneticist whose studies of how gene expression is controlled played a key role in the development of genetic engineering in Ireland; he helped establish the Smurfit Institute of Genetics in 1998, where he is a professor today. He is also writing a book on the role of science in Ireland from 1800 to the present day. "It will show why science should be important in modern Ireland for political and intellectual as well as economic reasons," he says. McConnell calls Caltech in the 1960s "a mecca" for geneticists, saying, "Caltech showed me how science was done at the leading edge and opened doors all over the world."

London, England, Sarah Ferguson, BS '08, Engineering & Applied Science (CNS)

Sarah Ferguson is a trader at Ronin Capital, where she develops financial models and uses them to pinpoint mispricings in the European bond market. Ferguson says being away from Caltech makes her value her experiences here even more. "Being out in the 'real world,' I can better appreciate how special the Caltech community is, from the friends I made as a student to the invaluable alumni network," she says.

Sao Paolo, Brazil, Ozires Silva, MS '66, Aeronautics

Ozires Silva says Caltech prepared him for the challenges in founding Embraer, a Brazilian aircraft manufacturer. Silva went on to run a large petroleum company, as well as an international airline. These days, he is the dean of Unimonte, a private university in Brazil. He says that Caltech enabled his international career to take off. "The period of time I spent at Caltech was one of the most valuable of my life," Silva says.

ch alumni are making an impact around the globe.

Oslo, Norway, José Navarro, PhD ’94, Astronomy
José Navarro has worked as an astronomer, a geophysicist, and a radar scientist, and his work has taken him across the globe. As chief scientist and head of the signal processing department at Kongsberg Norcontrol IT, Navarro integrates radar into systems for maritime traffic services. Since radar installations are usually located in remote unmanned sites, the systems need to be robust and resilient. He says Caltech gave him the training, the tools, and the discipline to tackle different jobs successfully, whether they are purely technical or involve managing and working with a variety of people.

Bombay, India, Rajiv Sahney, BS ’85, Physics
Rajiv Sahney is the managing partner of NV Capital Services in Bombay; his focus is on looking for and analyzing anomalies in the prices of various financial products as compared to what his company thinks they should be worth. “This is fun because you are often working on new problems,” Sahney says, “and are trying to both understand the value, but also to improve the process.” He credits Caltech with teaching him how to understand boundary conditions. “The biggest problems arise when we try to fit a solution that has worked in a set of circumstances and then apply them elsewhere without really understanding the fundamentals of why and under what circumstances it worked in the first place,” says Sahney.

Lagos, Nigeria, Bob Kieckhefer, BS ’74, Geophysics
Bob Kieckhefer is a geophysical specialist with Chevron Nigeria who uses seismic reflection data to figure out what is inside rocks. He says that Nigeria is a great place to apply this kind of analysis, since its geology and geophysics allow the scientists to directly image hydrocarbons just a few kilometers underground. Kieckhefer says he quickly learned at Caltech how to delve deeply into basic physics to solve problems.

Melbourne, Australia, Teresa Engelhard, BS ’92, Engineering & Applied Science
Teresa Engelhard is a venture capitalist who serves on numerous boards and helps Australian technology companies raise capital, recruit management teams, and tailor products to succeed in U.S. and global markets. “I consider myself incredibly fortunate to have attended a university where meritocracy, hard work, and tough challenges were the norm,” says Engelhard, “and where collaborative, nonhierarchical problem solving was encouraged; that is also an ideal culture for building successful companies.”

Read travel tips from some of our international alumni at www.alumni.caltech.edu/travel.

ENDNOTES

WE ASKED ALUMS TO TELL US WHAT INTELLECTUAL OR LITERAL BOUNDARY THEIR TIME AT CALTECH ALLOWED THEM TO CROSS. HERE'S WHAT THEY HAD TO SAY:

Caltech opened another avenue for creative energies as a combination of intellectual effort and spirited adventurousness.

The ability to think through to a solution to a problem, regardless of whether or not I have prior expertise, was the most obvious intellectual boundary. This proved exceedingly useful when, after getting my PhD in physics, I was able to do research in biochemistry.

physics

bio

chemistry

Crossed the Mississippi for the first time.

The recognition that time management—rather than skill—can sometimes be the key factor to success.

Tho not on the swim team, I learned from Coach Webb Emery how to work out as an athlete: i.e., seriously.

As an undergraduate, I majored in geophysics but was allowed to take many courses in various fields without interference. When it came time to graduate (1960), I went for the first time to my advisor, C. H. Dix. He got out my transcript, looked it over and said, "You've taken a lot of mathematics. Which do you like best, mathematics or geophysics?" After a moment's thought, I answered, "mathematics." Dix scribbled something on a piece of paper and handed it to me. It said, "BS Mathematics."

After a long academic career in mathematics, I still can't imagine such an important piece of advising happening so quickly and with so few words interchanged. That's Caltech for you.

geo

physics

mathematical

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