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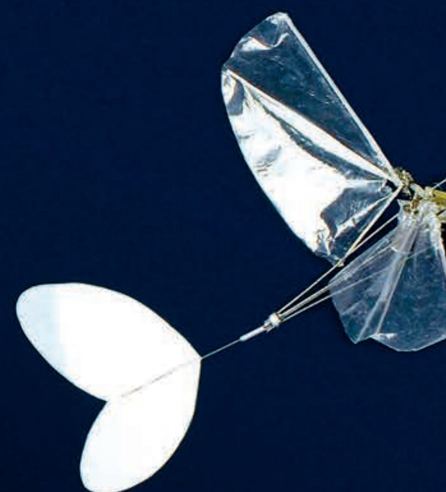
Engineering & Science



Incubating the Future

VOLUME LXXVI, NUMBER 1, SPRING 2013
California Institute *of* Technology

*__FROM BATS TO BATTLING VISION LOSS__ *The "microbat" seen above was invented in 1998 by Caltech electrical engineer Yu-Chong Tai and was the first electrically powered palm-size ornithopter—a type of aircraft that flies by flapping its wings. Since then, the materials and technologies designed to create this tiny creature have been incorporated into a wide range of inventions, including a retinal implant.* *To learn more, go to page 6.*

e&s

Engineering & Science

VOLUME LXXVI, NUMBER 1, SPRING 2013

Caltech on Twitter

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

@dblevy: You know you are at #Caltech when #tedxcaltech starts out with University president recounting #Spock's Brain episode of #StarTrek.

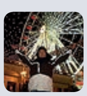
@ChrisPepper616: @Caltech Coursera is the coolest thing out there. Check it out!

@NBCLA: A single #earthquake could simultaneously affect Northern and Southern Calif., @Caltech study finds. 4.nbcla.com/UDShCS

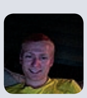
@bad_posture: Excited to perform a Cha-cha w/#Caltech #Salsa Team to the live music of #PonchoSanchez. Rehearsal tonight. ;)

@PlanetDr: Giving a seminar at undergrad alma mater (@Caltech) next week and a little freaked out. They all knew me when was 18yo kid, not scientist.

@NASAKepler: J Johnson: @Caltech has confirmed the very low false positive rate (10%) of the Kepler planet candidates. #aas221

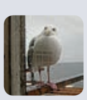


@ArBKR: @Caltech as a dyslexic, your website title bar is fantastic, you can use it to read individual lines, easier not to jump around paragraphs



@joshsherick: Just wrote an essay to @Caltech about Cheez-Its. Yup.

@arjunc12: @Caltech next year is the 100th rose bowl game – i don't think it would be complete w/out a caltech float! i would love to help make one



@onesleepynerd: @Chemjobber @AlexF-Goldberg Pick any sports team at Caltech. We're really funny when we're sleep-deprived AND trying to be athletic.

Engineering & Science

VOLUME LXXVI, NUMBER 1, SPRING 2013

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Special thanks to the Caltech Bookstore, Sonia Chernobieff, Christine Garske, Nancy Kyes, Yang Liu, and Yu-Chong Tai.

The nest on the front cover was inspired by the art of Nancy Kyes.

Culture, Environment, People

I'm often asked how a place as small as Caltech is able to drive so much innovation and entrepreneurship. My answer is simple: it all starts with the Institute's culture, environment, and people.

We focus on high-risk research at Caltech. Students and scientists don't come here to focus on the incremental—that's not our culture. They come because they're comfortable with risk, and because they're the kind of people who look at problems differently and know they'll thrive in an environment that values collaboration over competition. They come because they want the freedom to incubate ideas and to transform the world around them (see "Bridging the Gap," page 26).

At Caltech, we consider our laboratories to be incubators for ideas generated by enterprising individuals who are interested in high-risk, high-impact work and who dedicate an enormous amount of energy, passion, and tenacity to achieve their goals (see "What Is a Quantum Computer?" page 20).

It is because of our commitment to educating and empowering scientific leaders, inventors, and pioneers—and their commitment to Caltech and to science—that this small research university has become such a renowned incubator for ideas and discoveries, and a home to some of the most exceptional scientists and engineers in the world.

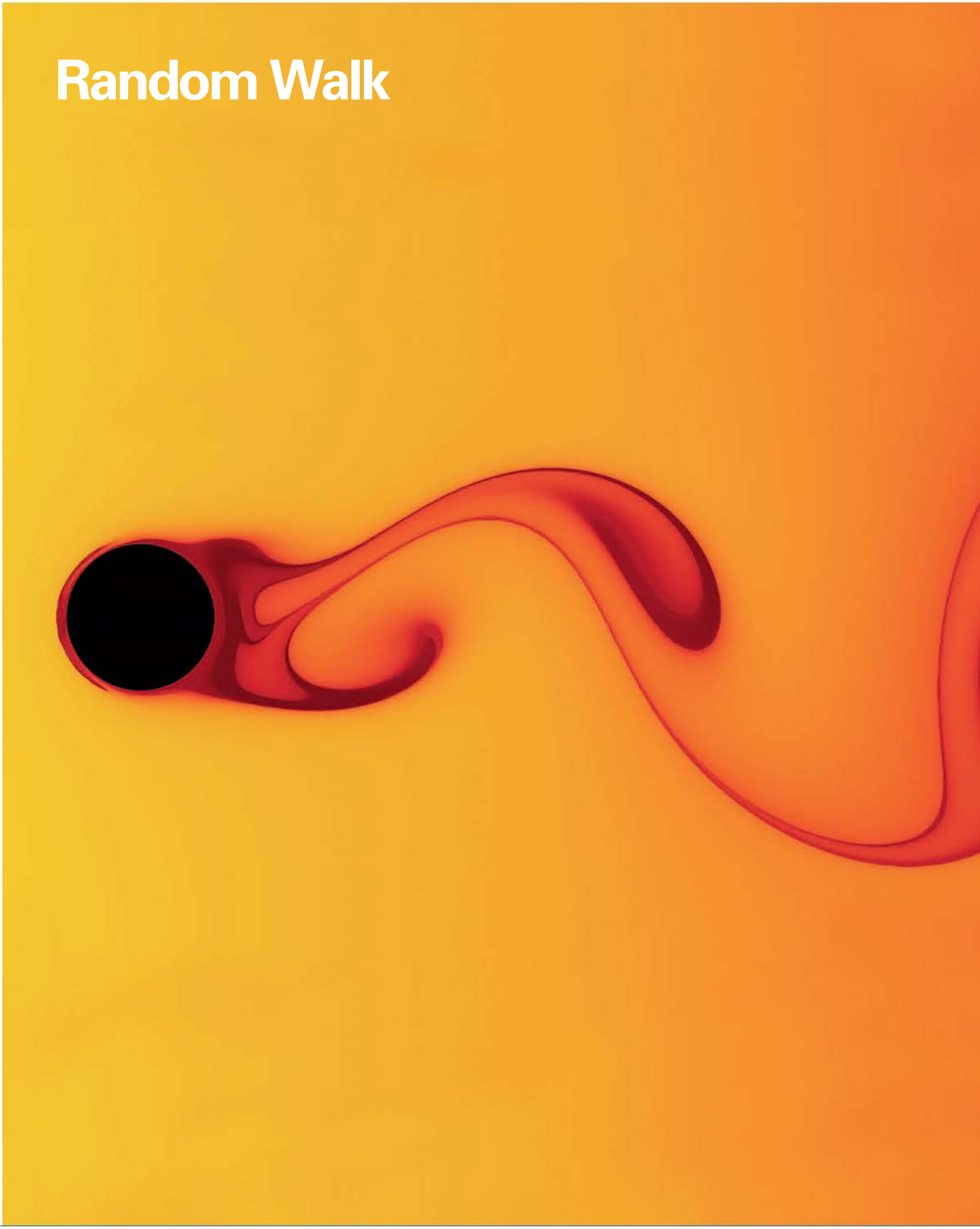
"Students and scientists don't come here to focus on the incremental—that's not our culture. . . . They come because they want the freedom to incubate ideas and to transform the world around them."

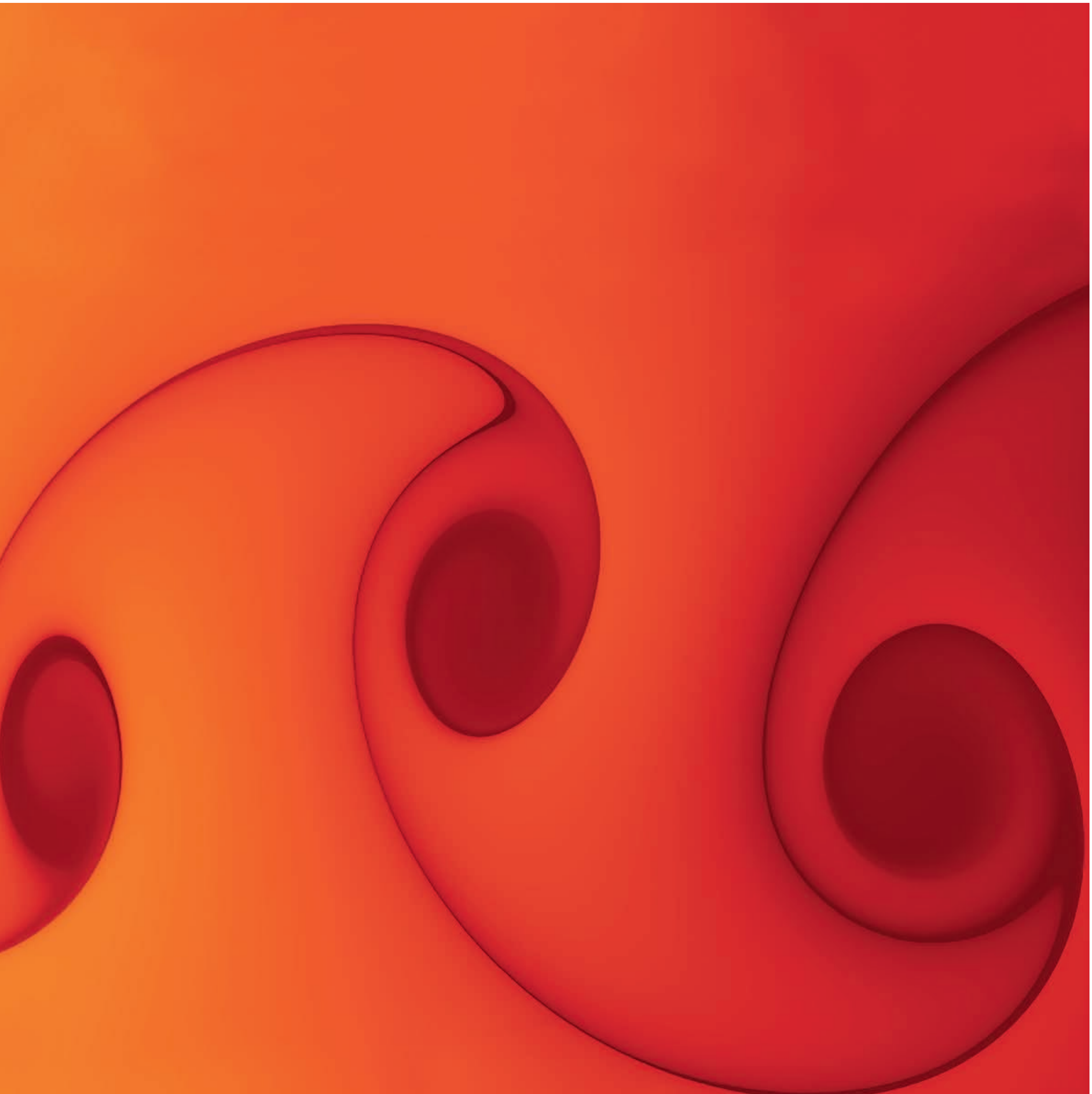
This issue of *E&S* looks at how the Institute's commitment to intellectual and creative autonomy builds a foundation for the movement of new ideas and technologies from initial experiment to real-life application (see "From Lab Bench to Marketplace," page 12). At Caltech, we believe that true innovation comes when people dream with focus and freedom.

And as the articles in this—and every—issue of *E&S* show, the consequences, benefits, and spin-offs of such dreams can be truly spectacular and literally world-changing.

Yours in discovery,

Random Walk





THE VORTEX STREET The image above is known as a Kármán vortex street—a repeating pattern of swirls (vortices) caused by an instability in the flow of a fluid as it passes over an object with a broad, flattened front called a bluff body. The phenomenon is named after Theodore von Kármán, the aerodynamics pioneer who was the founding director of what is now known as the Graduate Aerospace Laboratories at the California Institute of Technology (GALCIT).

Unlike most such images—in which the swirls would have been visualized thanks to dye injected into a stream of fluid—this version was created by computer (and by mechanical engineer Tim Colonius), using numerical data from a simulation that tracked individual particles as they moved and tumbled past one another.

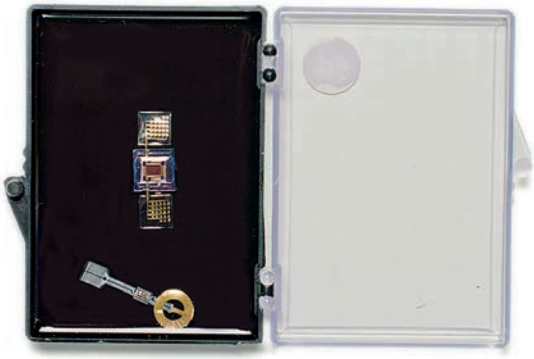
Earle M. Jorgensen Laboratory *Caltech's clean-energy research efforts are now going full throttle, thanks to the renovation of the Earle M. Jorgensen Laboratory, which officially opened on October 19 of last year and was recently given a LEED Platinum rating, the highest level of certification for "green" buildings. Transformed into a cutting-edge facility for energy science, the lab—whose lobby is pictured above—unites two powerhouse programs: the Resnick Sustainability Institute and the Joint Center for Artificial Photosynthesis, or JCAP.*

"Caltech has a central role in the search for dark matter and whatever else lies beyond the Standard Model. It's a never-ending journey, and one that has inspired students at Caltech for decades."

—Harvey Newman, professor of physics

From Bats to Battling Vision Loss

Caltech electrical engineer Yu-Chong Tai invented the "microbat"—seen on the cover—back in 1998 as part of a project focused on building the best wing. Since then, the materials and technologies designed to create that tiny flying creature have been incorporated into a wide range of inventions, including retinal implants (center) aimed at restoring sight to the blind.



The clear material used to make the wings has proven particularly useful for biomedical applications. It's called parylene, and although it was commercialized in the 1950s, Tai and his lab have now exploited it for a number of new uses. Parylene is extremely lightweight and flexible, Tai says, and it doesn't require glue since it is self-adhesive. It's also biocompatible—meaning that the human body does not reject it when it's placed inside the eye.

"NASA's space exploration research resulted in a lot of technology that has since been commercialized—for instance, the material in memory-foam beds," says Tai. "Our efforts were similar. We worked on this little flyer, and only later did we realize that the technology we'd developed was useful for biomedical implants." *—KN*

Not-So-Oozy Oobleck

You might know the stuff pictured below as Oobleck—the elementary-school goop that oozes between your fingers if you gently slide your hand into it, but stiffens up if you stir or poke at it. Truth is, Oobleck—made of nothing more than cornstarch and water—is neither fully liquid nor fully solid. Instead, it's something known as a non-Newtonian fluid, a type of substance that has odd properties. What's Oobleck's odd property? It becomes more viscous—more sticky or gummy—the more briskly you stir it.

Left to their own devices, the particles of cornstarch in Oobleck float freely in the water. But when you apply a force to the mixture—specifically, a shear force, which is a force that causes a kind of interior sliding action—the particles bunch together. "There's no space where they can go, so they jam up together and form very long chains," explains John Brady, the Chevron Professor of Chemical Engineering at Caltech and an expert on complex fluids like Oobleck. "That gives rise to the increase in viscosity."

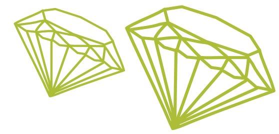
More than 20 years ago, Brady and his colleagues used computer simulations to discover exactly how this so-called shear thickening works; today, Brady teaches his students about shear forces and other physics concepts using a plastic cup of cornstarch that he keeps on hand in his office. All he has to do is add some water to the dried-out mixture and he's ready to go.

Shear-thickening fluids are more than just a neat party trick. Recently, they've been incorporated into Kevlar vests to create a type of experimental liquid armor. The fluid is sandwiched between Kevlar layers, forming a thinner and lighter armor that allows the wearer to move around freely. Faced with an impact, that fluid solidifies—making the armor even more impervious to bullets and flying shrapnel. Score one for Oobleck. —*MW*



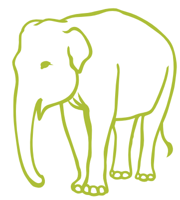
Insider Info

5



Number of rubies George Maltezos made from his titanium-doped sapphire crystal
(See page 13)

9



Number of Ken Pickar's students who rode elephants while in Kerala, India
(See page 26)

59

Number of wires and other bits-n-bobs that make up the nest on our cover

DOLLHOUSE DELUXE

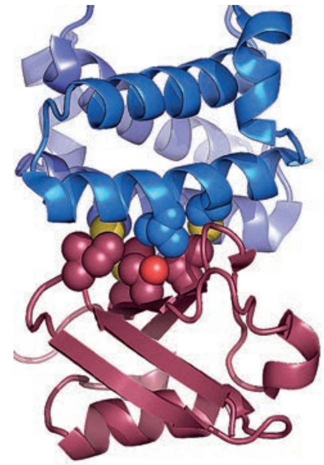
When Caltech alum Bettina Chen (BS '10) met Alice Brooks in graduate school, they quickly bonded over a shared goal of influencing young girls to become interested in science, technology, engineering, and math (STEM).

They realized that an educational toy could be a good introduction to STEM, and Roominate—a fully modular build-your-own dollhouse complete with wiring capabilities—was born. (See Alumni Impact, page 32.) Each kit comes with all the walls, furniture-building pieces, circuit components, and decorations needed to construct a room from scratch. There is no set way to assemble a Roominate room; instead, the girls are encouraged to explore and experiment.

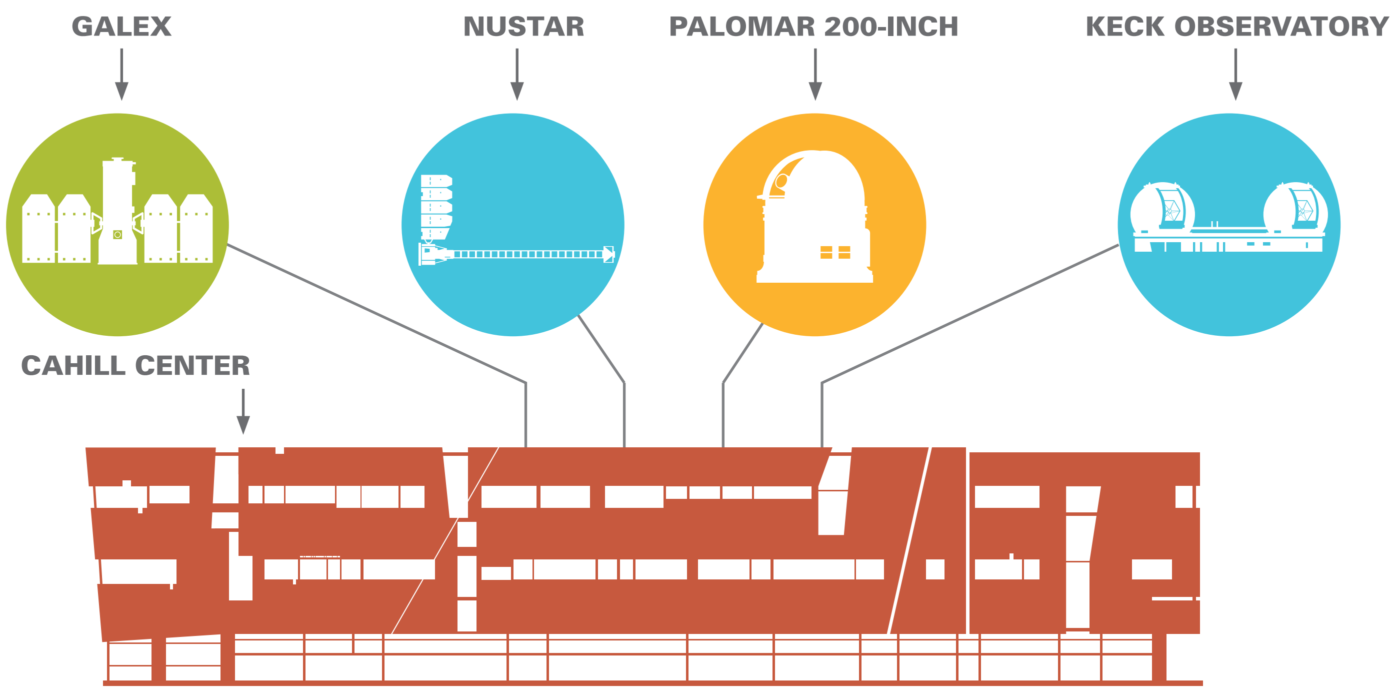
"Girls must use creativity and problem-solving skills—essential skills to develop for STEM—in order to build and wire a room with Roominate," says Chen. "We believe that Roominate is the type of toy that is missing from the market today: a toy that will help girls build up the skills and confidence they need to persevere in more male-dominated fields." —*KN*

GLAMOUR SHOT Although it might appear that a martian was needed to take this photo, this is actually a self-portrait captured by Curiosity's Mars Hand Lens Imager (MAHLI) on October 31, 2012. Sitting at the end of the rover's 2.1-meter-long robotic arm, the scientific camera snapped 55 hi-res images from different angles. The photos were stitched together to produce this mosaic, which includes only part of the robotic arm. Images like this one help mission engineers document the state of the rover.

In the photo, Curiosity is parked at Rocknest, an area in Gale Crater where the rover scooped its first soil samples, as evidenced by the four visible scoop scars. The base of Mount Sharp—the science team's ultimate target—appears in the upper-right corner of the picture. *—KF*



Getting Get *For several years, biochemist Bil Clemons and members of his lab have been picking apart a protein pathway known as the GET pathway, which ushers certain proteins to their proper locations in the membranes of cells. Recently, Clemons and graduate student Justin Chartron used Caltech's nuclear magnetic resonance (NMR) facilities to determine the structure of several previously unknown proteins in the pathway. This cartoon diagram shows a complex that incorporates two of the newly characterized proteins, Sgt2 (blue) and Get5 (maroon).* —KF



Studying the heavens from an observatory atop a remote mountain? That's so 20th century. Nowadays, astronomers can control some of the world's most powerful telescopes—even ones in space—without leaving the comfort of the Caltech campus. In fact, from within the Cahill Center for Astronomy and Astrophysics on California Boulevard, astronomers can operate the twin 10-meter telescopes at Keck Observatory in Hawaii, the 200-inch telescope at Palomar Observatory, and the space telescopes GALEX and NuSTAR—GALEX captures the ultraviolet light produced by the cosmos, while NuSTAR detects high-energy X-rays. —MW

BY THE NUMBERS: Solar Toilet

2.5 BILLION*	*Number of people around the globe without access to sanitary toilets, which results in the spread of deadly diseases*
1.5 MILLION*	*Number of people, mostly under the age of five, who die each year from diarrheal diseases*
$100,000	*Money for additional development of a solar toilet, awarded to James Irvine Professor of Environmental Science Michael Hoffmann and colleagues by the Gates Foundation for winning its Reinvent the Toilet Challenge*
$0.05	*Cost, per user per day, of Hoffmann's solar toilet*
50 GALLONS	*Amount of fake feces (made from soybeans and rice) brought in for the demonstrations that were part of the Gates challenge, held last summer in Seattle*

**Source: The Bill and Melinda Gates Foundation*

The Schrödinger Equation

Devised by physicist Erwin Schrödinger in 1926, the Schrödinger equation is at the heart of quantum physics. Among the profound implications of quantum theory is that you can never simultaneously know both the exact location and the exact velocity of a particle. Instead, it turns out, you can only know the *probability* that a particle is somewhere—a probability defined by what is called the particle's wavefunction, symbolized by the Greek letter psi (ψ). The Schrödinger equation describes how such a wavefunction changes over time—thereby describing the behavior of that particle.

Quantum mechanics may not seem to apply to our macroscopic world; you don't need a wavefunction to represent the location of the magazine you're holding, for instance. But quantum effects can still manifest themselves in our everyday lives. For example, it is thanks to the properties of quantum mechanics that certain materials act as superconductors (which are useful for things like MRI machines and particle accelerators) and other materials act as semiconductors (on which nearly all of our electronics are based). Physicists are even trying to exploit quantum mechanics to create new types of superfast computers. (See "What Is a Quantum Computer?" on page 20.) —*MW*

THE TOTAL ENERGY OF THE PARTICLE

the Laplacian operator ($\nabla^2\psi$) describes how the wavefunction changes in space

"ħ bar" is Planck's constant (6.63×10^{-34} m^2 kg/s) divided by 2π

an imaginary number ($\sqrt{-1}$)

the wavefunction of the particle

$$\frac{-\hbar^2}{2m}\nabla^2\psi + V\psi = i\hbar\frac{\partial}{\partial t}\psi$$

the mass of the particle

THE KINETIC ENERGY OF THE PARTICLE

THE POTENTIAL ENERGY OF THE PARTICLE

HOW THE PARTICLE'S WAVEFUNCTION CHANGES OVER TIME

Snap Judgments

We all make snap judgments about a new face. Perhaps nowhere is this truer than in speed dating, during which one person has to decide on another's romantic potential in just a few seconds. As it turns out, however, that decision doesn't depend only on whether someone is hot or not.

By scanning the brains of speed daters as they looked through pictures of potential dates, a group of Caltech researchers recently showed that as people weigh their romantic options they consider two factors: physical attractiveness and—perhaps less obvious—their own individual preferences regarding compatibility. Moreover, the researchers found that these two factors are related to activity in two distinct parts of the brain.

The first is the paracingulate cortex, an area of the brain known to become active when we're comparing choices. It lit up when participants saw pictures of attractive faces.

The other—the rostromedial prefrontal cortex—was more surprising. It had previously been associated with consideration of other people's thoughts, comparisons of oneself to others, and, in particular, perceptions of similarities with others. In the experiment, it became active when people saw the face of someone they wanted to date but who was not, on average, rated as especially desirable by the rest of the group. Its activation suggests that, in addition to beauty, the speed daters were considering individual compatibility.

And that really is in the eye of the beholder. —*MW*

"Caltech is about more than rocket science and earthquakes … Those of us that are neuroscientists here know that the *brain* is the final frontier."

—David Anderson, Seymour Benzer Professor of Biology, at TEDxCaltech: The Brain

A Martian-to-English Dictionary

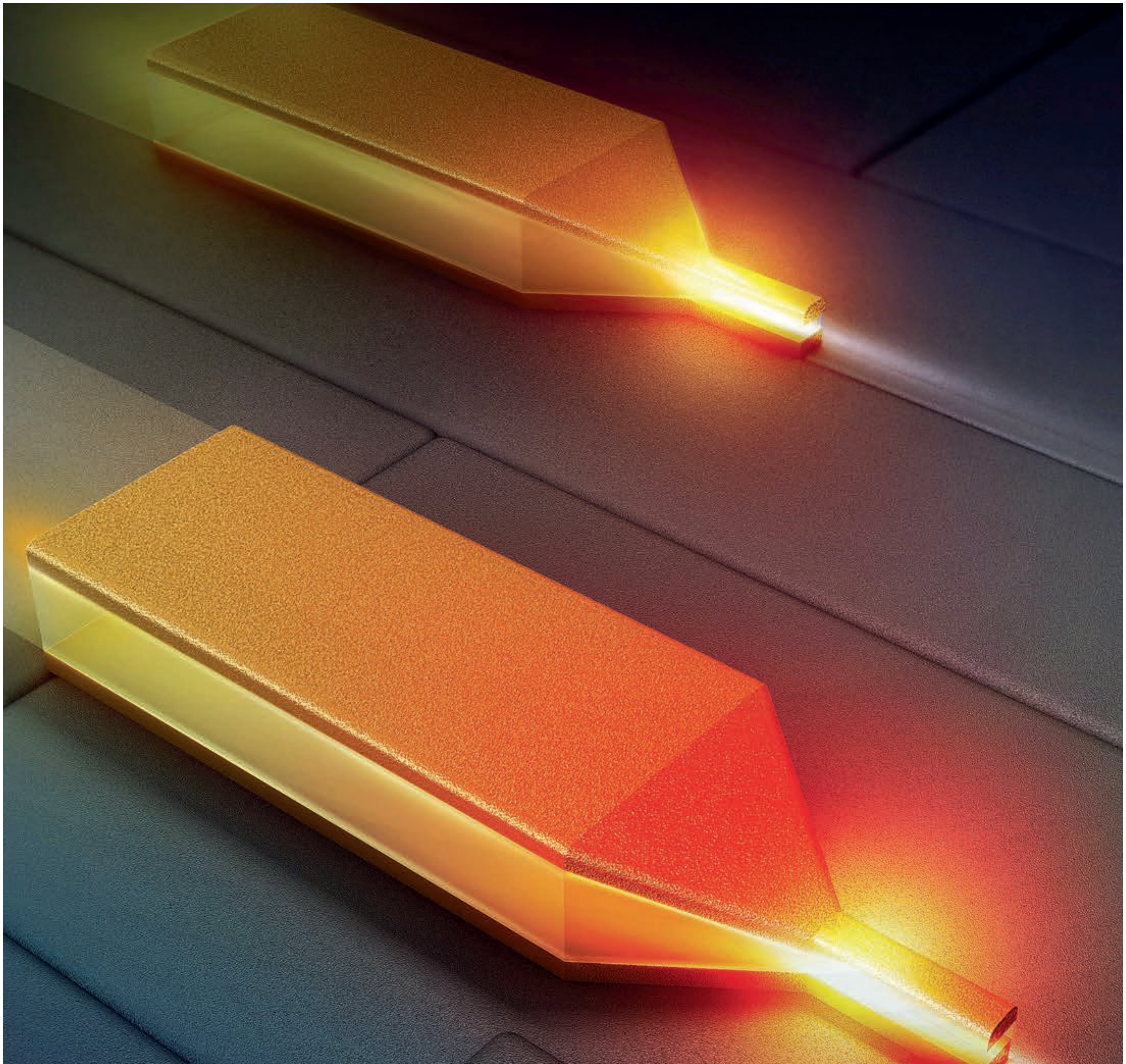
Martian days—called sols—last roughly 24 hours and 40 minutes. For most of us, that's just a fun fact, but it turns into a bit of a logistical headache for anyone working with or operating a rover on the Red Planet while living here on Earth. Although the engineers and scientists of the Mars Science Laboratory mission stopped living on Mars time after the rover's first 90 sols, Curiosity still does most of its work during martian daylight hours. To limit confusion, it's standard to reference sols by number when talking about what the rover is doing when. Still, Curiosity team members are getting plenty of use out of the following terms, some of which were coined during previous Mars missions. —KF

yes-ter-sol [yes-ter-sawl]: *the sol before the present sol on Mars*

to-sol [tuh-sawl]: *the present sol on Mars*

sol-or-row [sawl-ahr-oh]: *the sol after the present sol on Mars*

ALSO USED: MORROWSOL, NEXTERSOL



available now on **CALTECH.EDU**

RAY OF LIGHT

Caltech engineers have created a device that can focus light into a point just a few nanometers (billionths of a meter) across—an achievement they say may lead to next-generation applications in computing, communications, and imaging. Learn more at **www.caltech.edu/news**.

Watch

Improve your gray matter by watching talks from TEDxCaltech: The Brain. Check out the videos at www.youtube.com/caltech.

Read

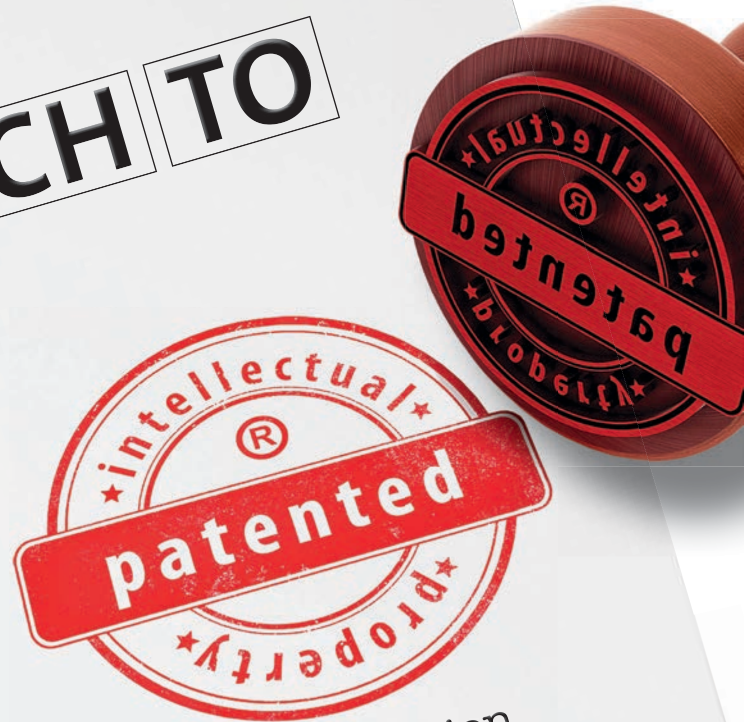
Satisfy your curiosity about Caltech's vision, impact, and community. Flip through the newest version of Caltech's *Overview*, available online at www.caltech.edu/content/viewbook.

Engage

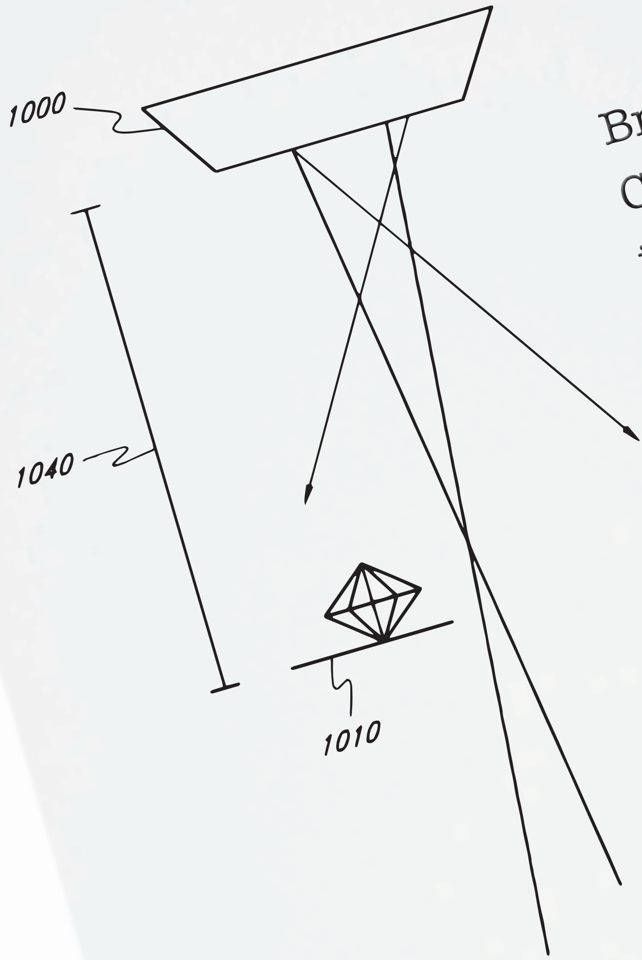
Folk music legend Janis Ian performs on campus Saturday, March 23. Buy tickets and find out more at www.caltech.edu/calendar/public-events.

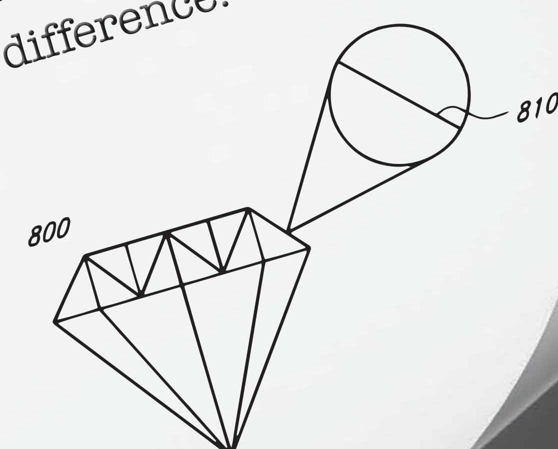
FROM LAB BENCH TO MARKETPLACE

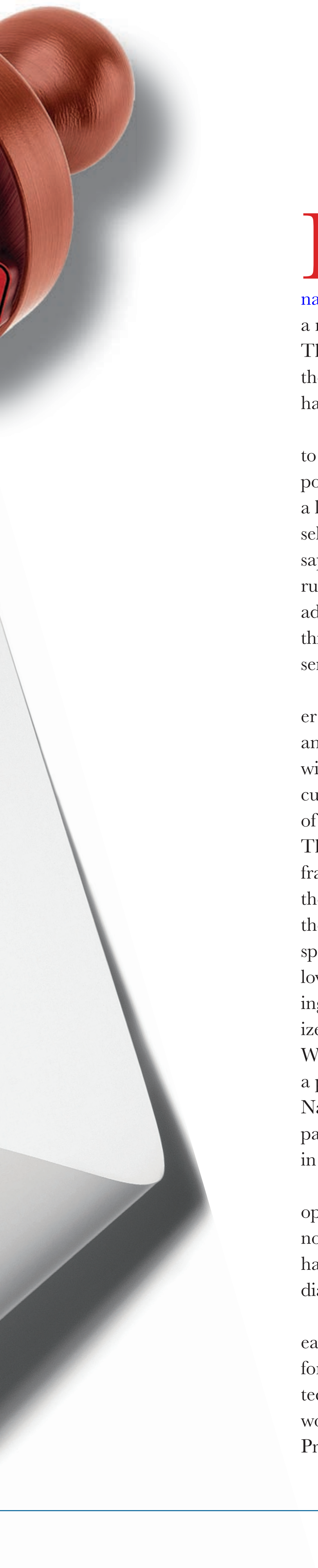
By Kimm Fesenmaier

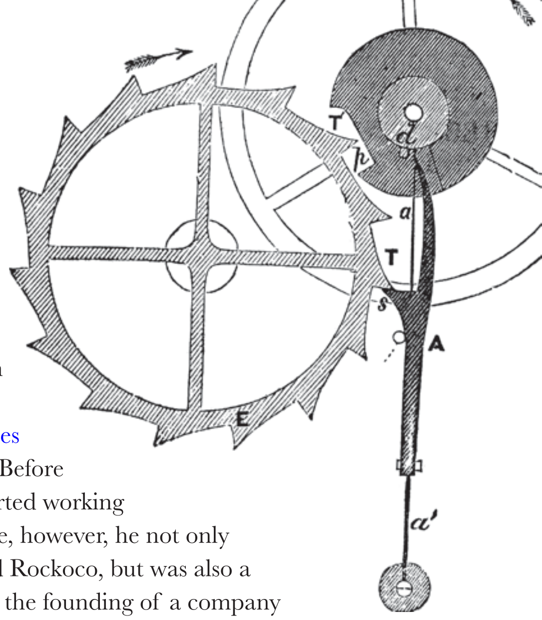


Brimming with innovation, Caltech is more than an institution of thinkers. Its culture and policies also encourage researchers to get their discoveries and inventions out into the world, where they can make a difference.









In 2005, George Maltezos was 11 months away from getting his PhD, working as a graduate student in the lab of nanofabrication expert Axel Scherer—and just a month away from marrying his fiancée, Suzy. The couple wanted to give special gifts to all of the members of their wedding party, but didn't have a lot of money with which to buy them.

What's a poor-but-generous young scientist to do? A little dumpster diving, a little repurposing of some outdated laser equipment (it's a long story), and voilà: Maltezos found himself with a lab-grown rod of titanium-doped sapphire crystal—basically an enormous ruby—to work with, and a Caltech advisor who certainly knew a thing or two about etching semiconductors.

Necessity being the mother of invention, Scherer and Maltezos soon came up with a new way to facet, or cut, crystals using the tools of modern microelectronics. They then etched nanoscale diffraction gratings very precisely onto the bottom of the stones, making grooves in the stone to diffract light and produce fire and sparkle. The outcome? Not only did Maltezos's loved ones get jewelry adorned with breathtaking laser rubies, but he and Scherer also realized they could extend the idea to diamonds. Within a month, the Scherer group had filed a patent on the process, which they now call Nanocut plasma etching, and started a company called Rockoco, which uses the method in the jewelry industry.

"We've changed the paradigm of diamond optics," Maltezos says. "In a hundred years, nobody will think of buying a diamond that hasn't been Nanocut because it just makes diamonds look better."

Today, Maltezos is developing a low-cost, easy-to-use diagnostic device that could transform the way diseases such as HIV are detected and monitored around the globe. He's working on the project with Scherer and Nobel Prize–winning biologist David Baltimore, with funding from the Bill and Melinda Gates Foundation. Before Maltezos started working on this device, however, he not only helped found Rockoco, but was also a key player in the founding of a company called Helixis—which produced a polymerase chain reaction (PCR) device much smaller and much less expensive than the standard machines then available.

AN OBLIGATION TO THE PUBLIC

Although Maltezos's story might be a bit unusual—not every grad student gets to help launch one company, let alone two—it's not entirely surprising either. Caltech researchers are an innovative and productive lot, and while many focus on basic science, a significant number make discoveries or collaborate on projects that go on to be applied to the development of new products, processes, or therapies. As a result, work at Caltech has led to such transformative and practical advances as ultraefficient thin solar cells, high-performance materials for medical products and personal electronics, and environmentally friendly chemical processes. In other words, Caltech research frequently has

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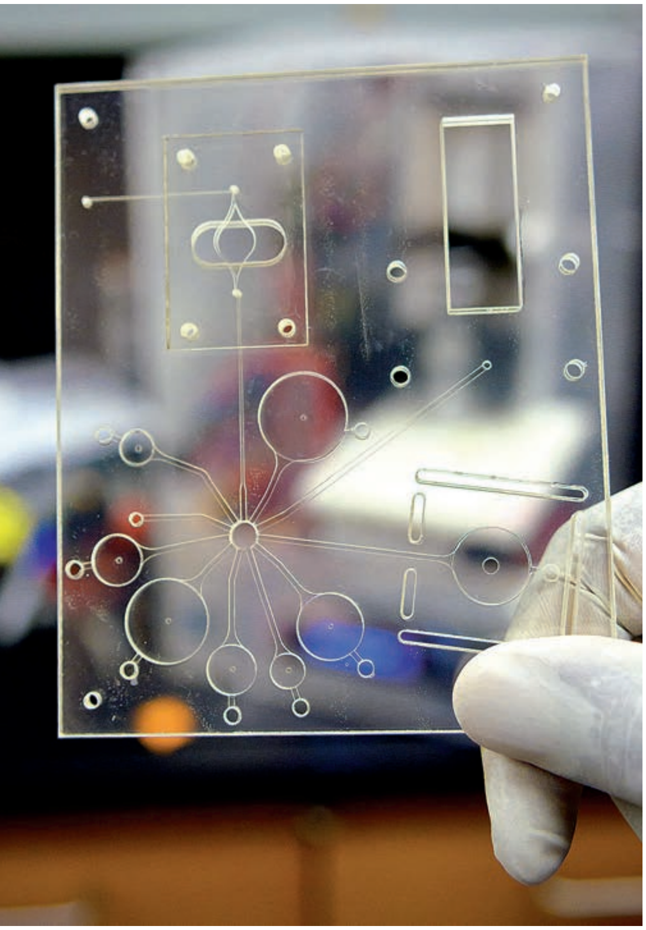
7
COMPANIES STARTED
&
104
PATENTS ISSUED

an impact that extends beyond—or actually knocks down—the walls of the Ivory Tower.

And that's no coincidence, says Fred Farina (MS '92), executive director of Caltech's Office of Technology Transfer (OTT) and Caltech's chief innovation officer. "Taxpayer money is a large portion of Caltech's funding, so we have an obligation to the public," he says. "The public is interested in science to some extent, but they also want to know that there is a return on their investment—that there are things that come out of the research that benefit society."



Above: A piece of the new, inexpensive, backpack-sized PCR device that George Maltezos, Axel Scherer, and David Baltimore are building for the Gates Foundation.

Next page: Chemist Theodor Agapie works with some air-sensitive chemicals in a glove box in his lab.

Since its founding in 1995, OTT has worked to foster a culture on campus that encourages and empowers faculty members to protect their intellectual property and to bring their ideas to the marketplace, where they can make a difference to the world at large.

That work has paid off. Caltech regularly reports a higher number of invention disclosures—initial filings of ideas that have the potential to eventually be patented—per research dollar than any of its peer institutions. During the fiscal year that ended last September, the faculty filed 246 such disclosures; about half of those disclosures will eventually go on to be filed as full patent applications. Over the last five years, Caltech has, on average, been granted more than 115 patents and started five new companies per year.

"I think one of the keys to this level of success is that the faculty trusts our office, and they come to us when they need us," says Farina. "We are here to serve the faculty. We strive to provide them with excellent service, as well as knowledge, experience, and connections that they don't have to go outside to get."

DEVELOPING ENTREPRENEURS

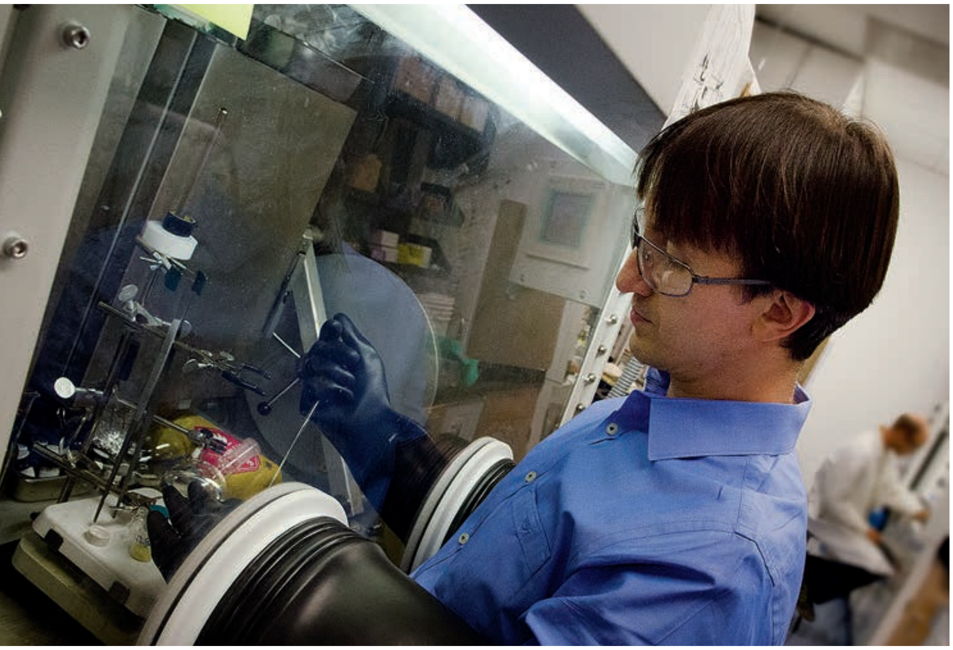
For chemical engineer and biochemist Frances Arnold, one of the most valuable services OTT provides is assistance with licensing deals, which give an individual or a company the right to use a piece of intellectual property, such as a patent. Arnold's patents have been licensed to companies interested in developing her work, and she has started companies of her own based on inventions developed by her group. She, like many other Caltech faculty members, thanks Larry Gilbert, senior director of technology transfer at Caltech, for her success in licensing her patents. "His attitude is, 'Let's make it happen,'" Arnold says.

Indeed, Gilbert was instrumental in getting the Institute and its faculty members to recognize that, in order to be competitive, companies often need exclusive licenses to patented ideas and technologies. Caltech granted its first exclusive license in 1988. "It was a novel philosophy at the time," Arnold says.

As is Caltech's enthusiastic promotion of entrepreneurship. Although the Institute holds the title to patents issued to its employees for inventions made in the course of work or using Caltech facilities, it is also Caltech policy to facilitate the transfer of useful technologies to those who can make them available to the public. Therefore, while some schools charge faculty members up front for use of the intellectual property they developed, Caltech often grants researchers an option agreement, which puts a hold on the intellectual property they intend to license while they develop a business strategy and seek investors. To further help the young start-up, Caltech will defer reimbursement of patent expenses for a period of time, allowing the company to focus its resources on developing, marketing, and selling products. In exchange, the Institute will take a modest equity stake in the fledgling business.

Arnold says this approach makes sense both from her own point of view as a scientist and from the Institute's perspective, given its desire to see Caltech work make its way out into the world. "It's essentially the Institute saying that it will take the risk along with you," she says. After all, what sense does it make to demand cash from a start-up that has yet to make a dime?

Scherer's success as an entrepreneur, like Arnold's, began with one-on-one conversations with OTT employees. Though Scherer has now started three companies, he says he never imagined



as a young professor that he would start even one. "But Caltech has the best tech-transfer office I know of, and they convinced me that my ideas had value," Scherer says. "They are flexible, efficient, and have a knack for matching the needs of the staff, the professors, and the students."

And that knack is important, Scherer notes, because Caltech's diverse faculty members have an equally diverse set of needs. "Some people don't know where to find funding, other people don't know how to write patents. Some people have no concept of the value of their ideas, others just need connections to find a management team. Caltech's OTT has people who can help you navigate all of those challenges."

START AT THE VERY BEGINNING

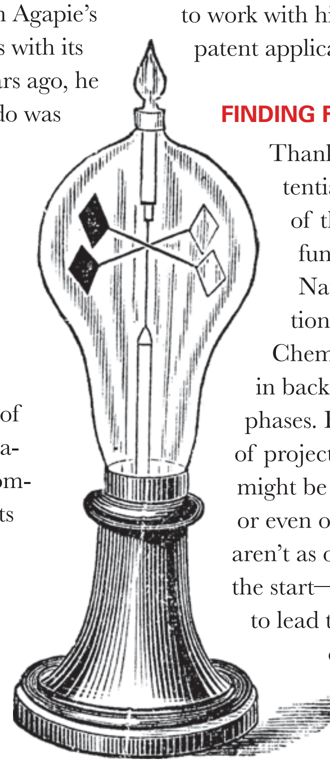
What chemist Theodor Agapie (PhD '07) needed was help navigating the process of filing a patent application. Agapie's lab had recently synthesized a new catalyst that drives the chemical reactions of polymerization—reactions in which chemical monomers (the original reactants) are combined to produce molecular chains, known as plastics, with desired properties such as elasticity and strength. The catalyst Agapie's group designed allows for the incorporation of chemicals with functional groups that had previously been difficult to incorporate in these reactions, opening up new possibilities in terms of the properties the resulting polymers can possess. For example, the new catalyst holds promise for developing polymers with improved adhesive and antimicrobial properties.

When Agapie joined the Caltech faculty in 2009, he had already participated in the patenting process once with his graduate advisor, Caltech chemist John Bercaw. Together they had developed and then patented a catalyst, also for polymerization. So when Agapie's group started having success with its new catalyst a couple of years ago, he knew that the first thing to do was to contact OTT.

"We, as a society, make a lot of plastics for applications as diverse as construction materials, electronics, medical equipment, and packaging," Agapie says. "Catalysts that control the structure and performance of plastics open up new applications, and there's a lot of commercial interest in these sorts of materials."

For instance, Agapie can see using his group's newly developed catalyst to make antimicrobial plastics for use in biomedical applications. After some optimization of the design, he can also imagine using the catalyst to produce building materials, such as PVC piping, under lower-temperature conditions and with more control over the polymer's structure at the molecular level than current fabrication methods allow.

But to commercialize any of those ideas, he would have to begin the patent process. So in 2011, he filed an invention disclosure, a simple form that documents the basics of the discovery. OTT used that disclosure to file a provisional patent application on his behalf with the United States Patent and Trademark Office; this provided a year of protection for his ideas, during which he could continue his research and decide whether the catalyst was truly promising enough to make it worth filing a full patent application. After about 10 months, OTT contacted him to talk about the status of his work and the next steps in the patent process. After he decided that it made sense to continue pursuing the patent, OTT referred him to an outside attorney who had the expertise to work with him to write up the full patent application.



FINDING FUNDING

Thanks to its commercial potential, Agapie's research is of the type that traditional funding sources, such as the National Science Foundation or companies like Dow Chemical, might be interested in backing, even in its earliest phases. But Caltech is chock full of projects whose basic premises might be considered high-risk or even off-the-wall, and which aren't as obviously commercial at the start—but have the potential to lead to some form of technology transfer down the road. For these, Caltech has started a program called the Caltech Innovation Initiative (CI2), with the help of a generous gift from trustee Jim Rothenberg. Steve Mayo (PhD '87)—now William K. Bowes Jr. Foundation Chair of the Division of Biology and then vice provost for research—and his successor in that role, bioinspired engineer and vice provost for research Mory Gharib (PhD '83), worked with OTT to set up the initiative in 2009. Their goal? To encourage innovative thinking. In the less than four years since its inception, CI2 has provided grants ranging from $50,000 to $125,000 per year to more than a dozen projects—enough money to get such early research ideas off the ground.

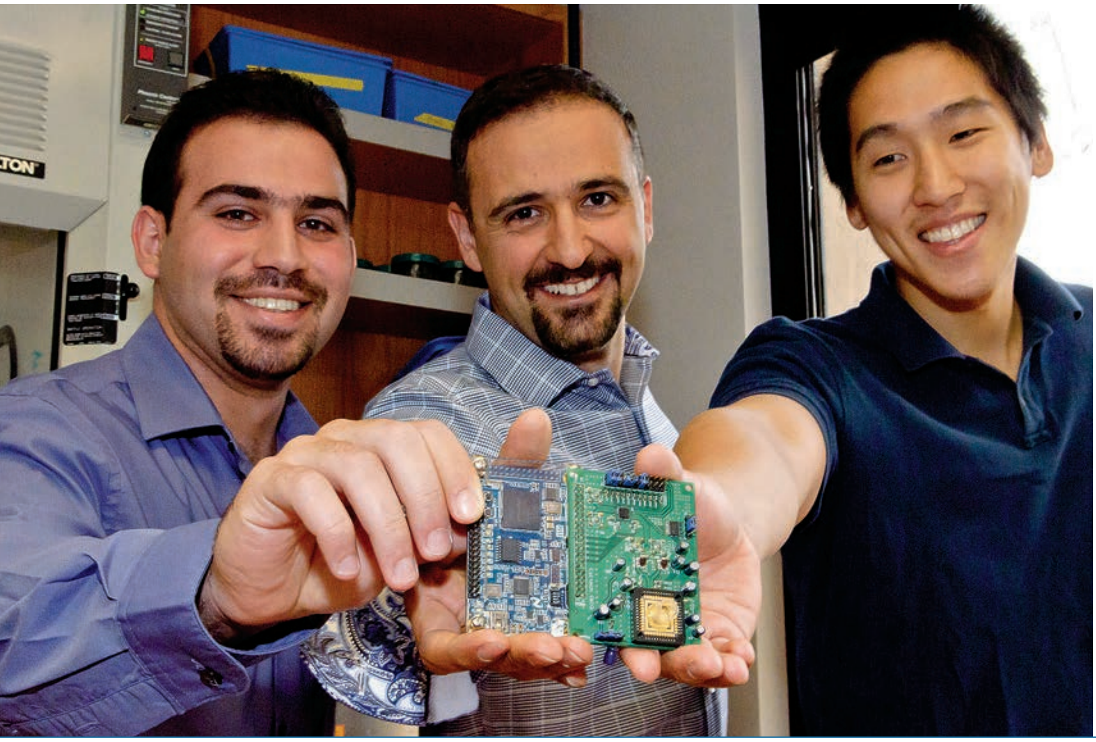
Electrical engineer Ali Hajimiri was among the first recipients of CI2 funding. A promising idea had sprung up in his lab—an approach that he thought could lead his team to develop handheld magnetic biosensors for the detection of diseases in parts of the world where there is little or no access to medical facilities. "When we submitted a proposal, the idea was in a very early stage," Hajimiri says. "The CI2 funding enabled us to take the project to the next level." His group pressed forward, and today they hold several patents based on the work they did, and are considering forming a company based on their technology.

"Before I came to Caltech, I had many inventions that I basically lost because I never protected them. I just published, and industry used my ideas."

Gharib considers Hajimiri's story a perfect example of why the CI2 program was created—to encourage excellent, high-risk research and to boost the technology transfer process at Caltech. Gharib has another reason for his interest in the process, he says—he wants to prevent other Caltech researchers from repeating the mistakes he made earlier in his career.

"Before I came to Caltech, I had many inventions that I basically lost because I never protected them," he explains. "I just published, and industry used my ideas. That's a problem because, at the end of the day, those are the fruits of your labor." Now, after having started several companies of his own, he realizes the information and guidance OTT can provide would have been invaluable back when he was starting out. "We let faculty talk to ventures, but we give them all the data points—what they should look for, what their expectations should be," he says. "If you know from day one what to expect and you have an experienced group backing you, it helps."

Gharib also hopes to dispel the myth that researchers involved in tech transfer spend so much time on their commercial ventures that their research programs suffer. He points to both himself and to chemistry Nobel laureate Bob Grubbs as proof to the contrary. Both, after all, hold dozens of patents and have each started successful companies, and yet both continue to publish prolifically. "You can be an entrepreneur and a dedicated academic researcher if you're in an environment that helps you to cultivate both without interfering with each other," Gharib says. "That's what Caltech provides."



Undergraduate student Aroutin Khachaturian (left), electrical engineer Ali Hajimiri, and grad student Alex Pai (right) show off the integrated circuit at the heart of their handheld diagnostic device.

FOLLOWING AN IDEA TO THE MARKETPLACE

In fact, Caltech also provides rules that prevent the blurring of the line between academic research and entrepreneurial endeavors. For instance, faculty members cannot take on management roles in the companies they start. "You cannot hire, fire, or sign checks," Gharib says. Postdocs who want to work for such companies have to leave the Institute, and students must take a leave of absence.

That's exactly what George Maltezos did when he went to work as chief engineer for Helixis, the company he helped found, along with Scherer and Baltimore, in 2007. As a grad student, he had worked with Scherer and Baltimore to develop a PCR device—a system that can copy and analyze any short sequence of DNA or RNA—that is small enough to sit on a lab bench, less than a quarter the cost of standard PCR devices, and able to provide a more uniform temperature for amplifying genetic materials. Scientists use PCR devices to search samples for evidence of cancer, genetic mutations, and pathogens such as HIV, malaria, tuberculosis, and sexually transmitted diseases, thereby diagnosing these conditions quickly. While typical PCR devices cost more than $50,000, Helixis's first product sold for $13,000 and is now used around the world.

When Maltezos and Scherer first started working on the PCR device, they were responding to the H5N1 bird flu pandemic that had erupted in Asia in late 2003; becoming entrepreneurs was not their initial goal. And yet that's exactly what they became; in 2010, Helixis was acquired by the San Diego–based biotech company Illumina for approximately $105 million. "I never anticipated that," Scherer says.

These days, Maltezos is back on campus. He's working with the Scherer and Baltimore labs and clinical researchers at Dartmouth-Hitchcock Medical Center to take the idea of an inexpensive, small, accessible PCR device to the next level—making the entire sample-to-answer system compact enough to fit in a backpack, and delivering a technology that can operate at a cost of no more than $5 per test.

"We're working toward the goal of making this technology available to places that desperately need it in the developing world," says Maltezos. "Even with Helixis, that *always* was our goal." e&s

Caltech holds

1,700

active U.S. patents

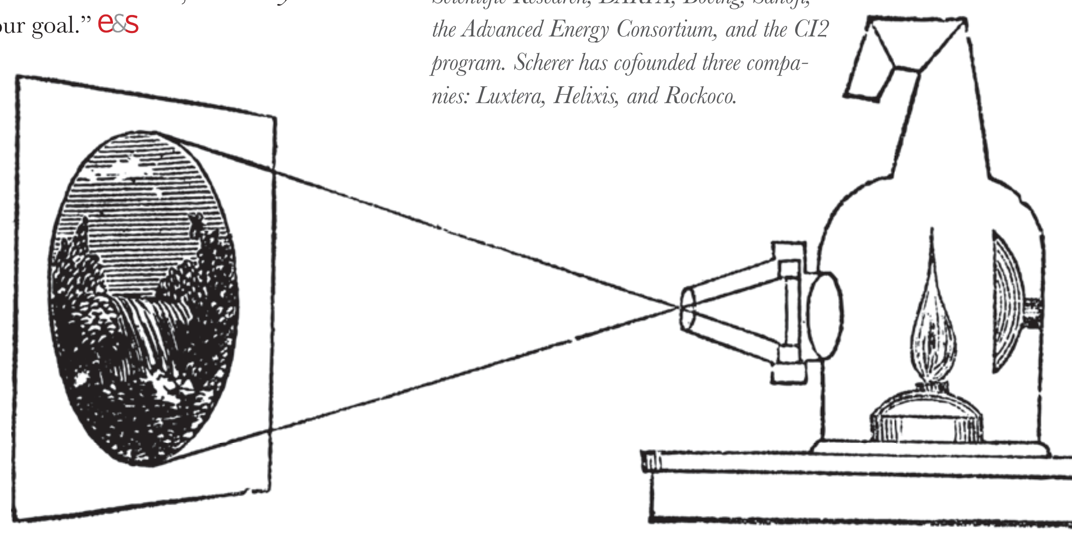
Frances Arnold is the Dick and Barbara Dickinson Professor of Chemical Engineering, Bioengineering and Biochemistry. Her work is funded by the U.S. Army, the Department of Energy, the National Science Foundation, DARPA, and the CI2 program. She cofounded Gevo and was on the founding advisory boards of Maxygen, Fluidigm, and Mascoma.

Theodor Agapie is an assistant professor of chemistry. His work is funded by the Dow Chemical Company, the National Science Foundation, BP, and Caltech faculty start-up funds.

Morteza (Mory) Gharib is the Hans W. Liepmann Professor of Aeronautics and professor of bioinspired engineering. He is also Caltech's vice provost for research and is affiliated with the Kavli Nanoscience Institute. His work is funded by the Office of Naval Research, NASA, Boeing, and Zambon Pharma. He cofounded Arges Imaging.

Ali Hajimiri is the Thomas G. Myers Professor of Electrical Engineering and leads the Caltech High-speed Integrated Circuits group. His work is funded by several government agencies and industry partners, including DARPA and the Air Force Research Laboratory. He cofounded Axiom Microdevices.

Axel Scherer is the Bernard Neches Professor of Electrical Engineering, Applied Physics and Physics. He leads the Caltech Nanofabrication Group and is affiliated with Caltech's Kavli Nanoscience Institute. His work is funded by the Gates Foundation, the Air Force Office of Scientific Research, DARPA, Boeing, Sanofi, the Advanced Energy Consortium, and the CI2 program. Scherer has cofounded three companies: Luxtera, Helixis, and Rockoco.

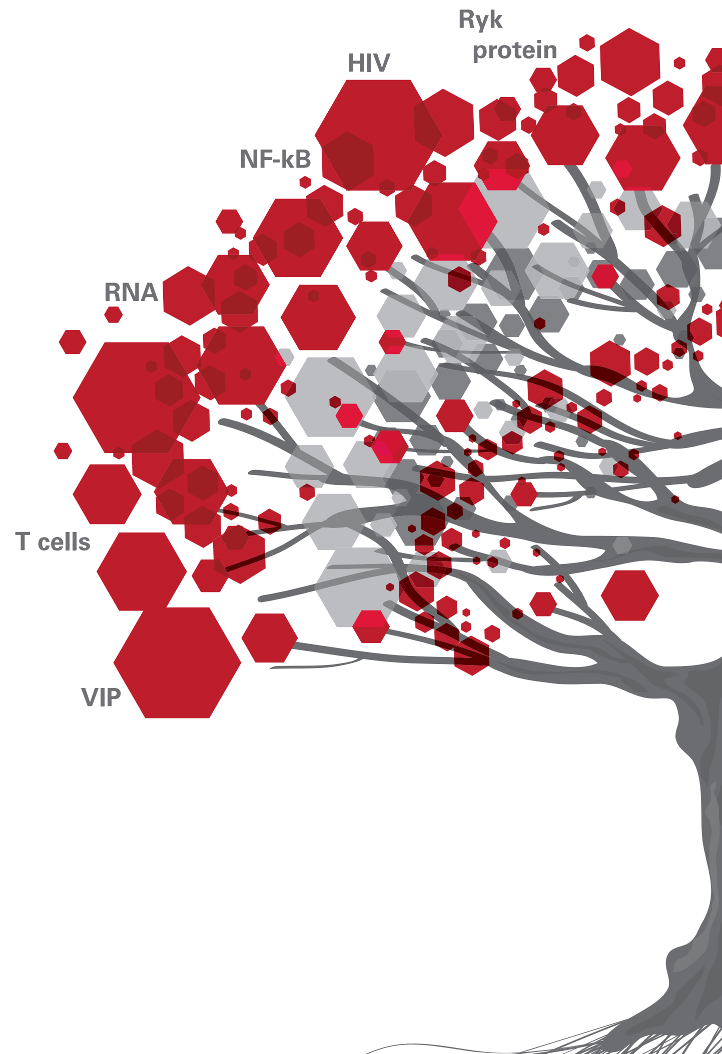


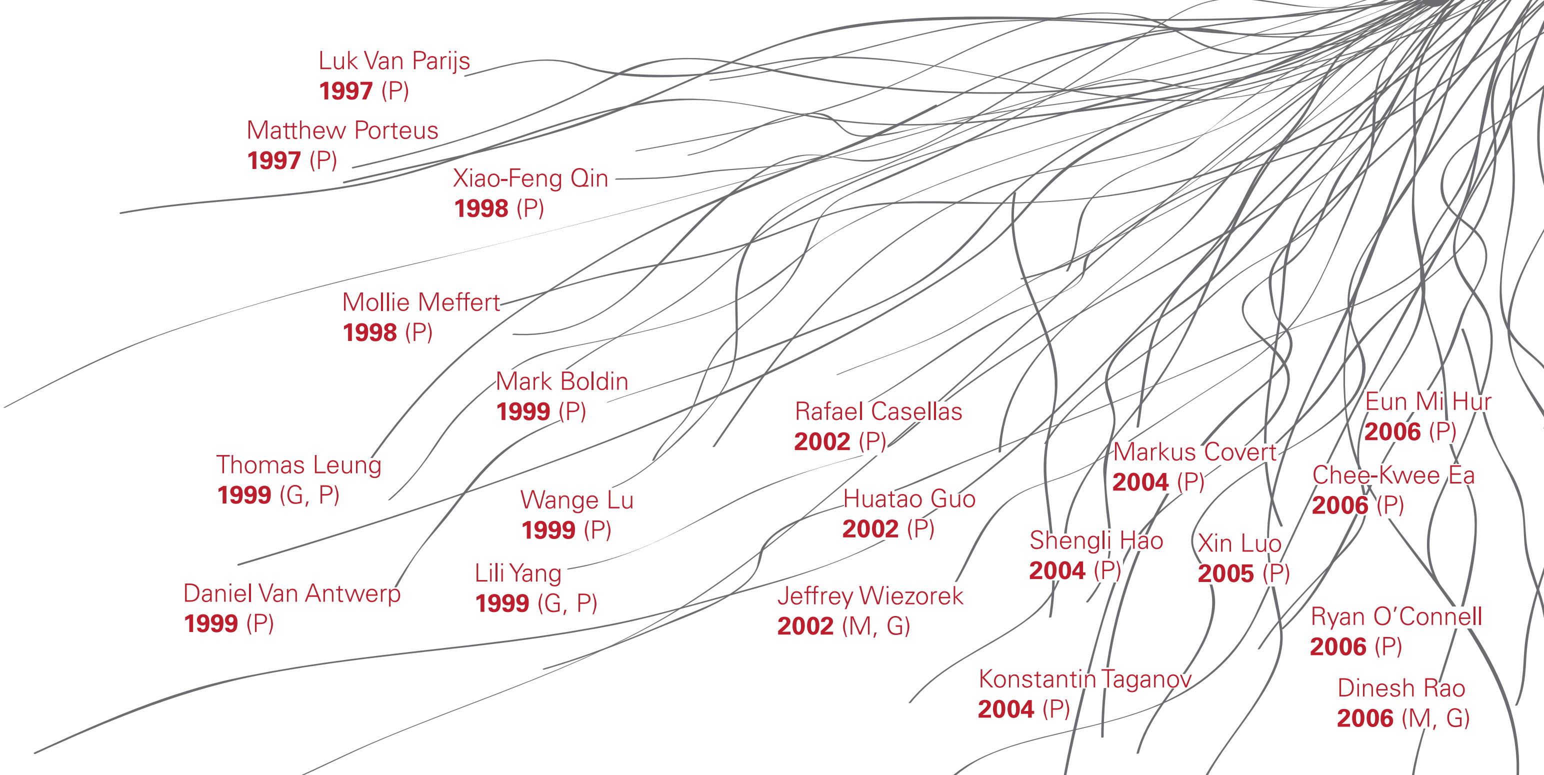
HOW SCIENCE TAKES ROOT:
David Baltimore's Caltech Family Tree

When we talk about Caltech as an incubator for great scientific ideas, we sometimes forget to consider the scientists from whose minds those ideas come. Great science doesn't spring from nowhere; nor, most often, do great scientists.

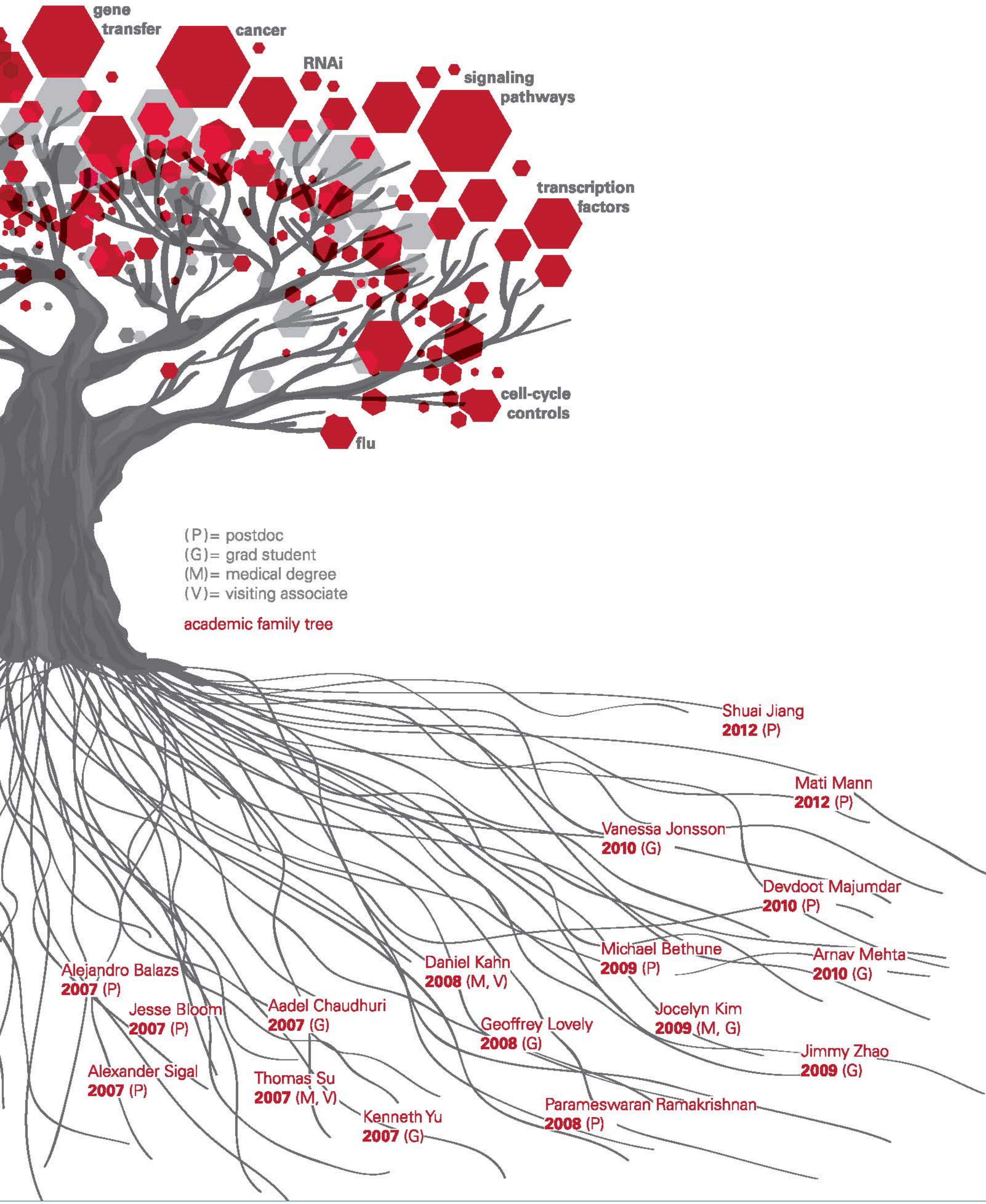
The Caltech laboratory of Nobel Laureate and Robert Andrews Millikan Professor of Biology David Baltimore has, over the past decade and a half, been an incubator for more than three-dozen scientists—graduate students, postdoctoral scholars, and physicians in training. And they, in turn, have driven the lab's thriving research programs aimed at understanding and exploiting signaling pathways, transcription factors, and more, to assist in treating and preventing diseases such as AIDS, influenza, and cancer.

Labs across the Caltech campus foster this same kind of scientific growth. The Institute's scientists and engineers all take the academic portion of its mission—to "educate outstanding students to become creative members of society"—just as seriously as they do any crucial experiment. In the end, the Institute is just as proud of its legacy of educating our country's future leaders, scientific and otherwise, as it is of its legacy of innovation. After all, you can't have one without the other. *—LO*





Source: Baltimore laboratory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WHAT IS A QUAN COMP

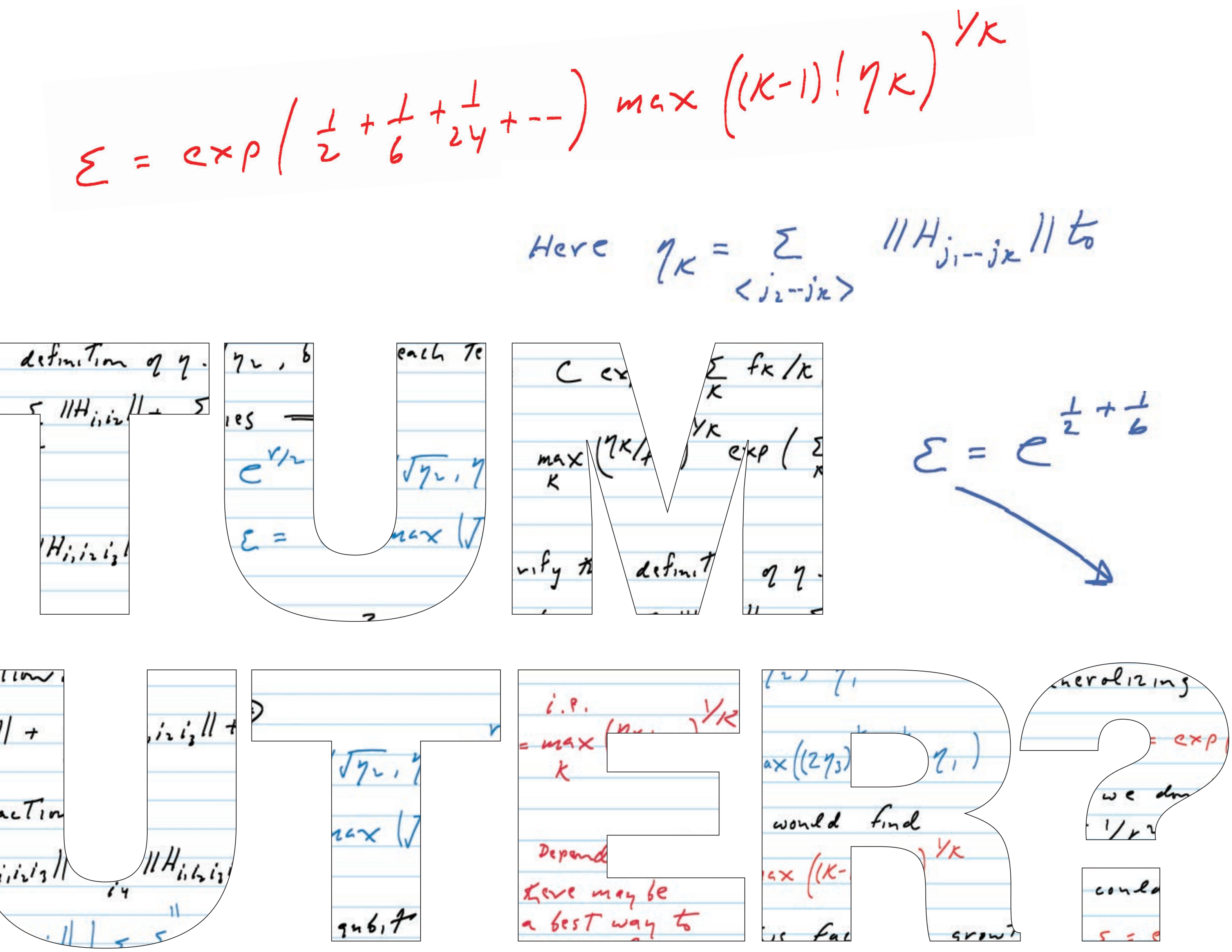
By Marcus Y. Woo

How Caltech physicists are helping to bring us ever closer to our quantum future

The quantum world is bizarre. It's a world where particles are waves and waves are particles, where an electron doesn't have to choose between door number one or door number two but can zip through both *at the same time.*

Still, that weirdness serves a purpose; it has a use. In the last few decades, physicists have come to realize that such scientific eccentricities can be harnessed to create a whole new breed of computers—computers that need only seconds to solve problems that would take thousands of years to crack if fed into a conventional computer. Indeed, quantum computers have been touted as the Next Big Thing: the advance that will usher in a new technological revolution. If you thought the computer age was amazing, experts say, wait until you see the *quantum* computer age.

Thing is, you really are going to have to wait. No one has yet built a truly useful quantum computer, and a lot of the talk about what such machines will be able to do is purely speculative. But it's not all hype. After all, the principles of quantum computing are based on the well-tested laws of quantum mechanics—one of the triumphs of 20th-century physics—which describe the behavior of all things very tiny, a realm unlike anything we encounter in our not-so-tiny everyday lives. Buoyed by their ever-strengthening grasp



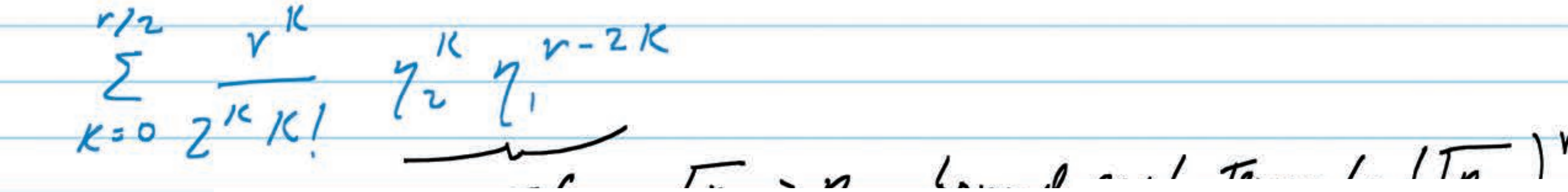
of quantum mechanics, physicists, computer scientists, and engineers from around the world are now racing to be the first to make quantum computing a reality. Even industry giants like IBM and Microsoft have joined the fray.

Thanks to all this effort, the field is progressing rapidly—and the world has taken notice. The 2012 Nobel Prize in Physics was awarded for the experimental techniques that have allowed scientists to manipulate light and matter in the quantum world—tools that are essential for building a quantum computer. And, last summer, Caltech physicist Alexei Kitaev won the first Fundamental Physics Prize (and a record-setting $3 million) for his ideas on how to make quantum computers feasible. Today, he and others at Caltech are working to take those ideas to the next level—to envision just how this technology might work—and thus bring us closer to our quantum future.

WHAT'S SO GREAT ABOUT A QUANTUM COMPUTER ANYWAY?

Many credit legendary Caltech physicist Richard Feynman with being among the first to recognize the potential for quantum computers, suggesting in a well-known 1981 talk that such a computer could be a powerful tool with which to simulate the physics of quantum systems—for example, a collection of electrons. Although today's computers are able to simulate and probe, say, simple chemical reactions between individual molecules, deciphering the quantum details of anything more complex would require an inordinate number of variables—more information than a conventional computer could ever handle.

Indeed, it's our current inability to simulate quantum systems that's behind much of the push to develop a quantum computer. Quantum computers should be able to help biologists and chemists not only design a new drug but understand its chemistry in unprecedented detail; they should also be able to help physicists probe the quantum



secrets of an atom or solve such long-standing mysteries as how high-temperature superconductors work.

But the full potential of quantum computing wasn't apparent until 1994, when theoretical computer scientist Peter Shor (BS '81) developed an algorithm that exploits the laws of quantum mechanics and could be used by a quantum computer to factor enormous numbers that are a thousand digits long. Such a problem would take a regular computer billions of years—literally—to solve.

"That just blew me away," says Caltech physicist John Preskill, who works on ways to make quantum computers not only feasible but reliable. "Factoring a thousand-digit number is so far beyond what we can do now—it's not going to happen. What Shor said was if you just build a quantum computer, then it's a cinch."

The ability to factor huge numbers highlights one major potential application of quantum computing: quantum cryptography. Because it's so monumentally difficult to calculate factors of big numbers, such a task is at the heart of the sorts of encryption algorithms used to secure data and communications. Someone with a quantum computer and Shor's algorithm could thus, in principle, crack such codes and hack into the world's computer and communications systems. To protect against future quantum hackers, researchers are developing new quantum encryption methods. And over the last several years they have been fairly successful, according to Leonard Schulman, a theoretical computer scientist at Caltech who works on quantum cryptography and algorithms.

Physicist Alexei Kitaev (left) talks with physicist John Preskill, whose equations and notes are scattered across these pages.

Perhaps more importantly, however, Shor's breakthrough showed that a quantum computer could be a transformative technology, making the impossible possible.

WHAT MAKES A QUANTUM COMPUTER SO POWERFUL?

Like all things quantum, the question of how a quantum computer could be imbued with such unprecedented computational muscle is hard to pin down.

"There have been actual debates on this question at some of the quantum-computing meetings where everybody in the room knows the math perfectly well and knows exactly what they're talking about," says Schulman. "And still, they manage to argue over the answer."

Understanding quantum computers requires a basic comprehension of the conventional computers from which they are derived. Today's computers rely on electronic transistors that switch on or off—positions that are represented by a zero (off) or one (on). Each on or off value is called a digital bit (short for binary digit) and is the smallest unit of information on a computer. To compute is to process these bits—to rearrange and connect them in various ways—all of which is done on a silicon chip.

A quantum computer is also based on bits: quantum bits, or qubits (pronounced CUE-bits). Instead of being either a zero or a one, however, a qubit—in true quantum fashion—can be both at the same time. This phenomenon, called superposition, allows quantum computers to work much faster than regular computers.

This peculiar property of being in two states at once is an essential and inseparable feature of quantum computing—so much so that most general descriptions of the field usually end there. Still, superposition isn't the whole story.

In fact, the crux of what truly makes quantum computing powerful remains a bit nebulous. "It's hard to put a finger on it exactly," Preskill says. "But the closest I can come to characterizing what makes quantum computing different is that it exploits entanglement."

If you thought superposition was odd, you're going to love entanglement. Quantum entanglement is a phenomenon in which two quantum states—the directions in which two particles can spin, for instance—are inextricably correlated. To simplify: Imagine you have a pair of gloves, and that you put the left-handed glove in one box and the right-handed glove in another. Now imagine you don't know which glove is in which box. By opening one of the boxes, not only will you be able to see which glove is inside that box; you'll also immediately know which glove is in the other box—even without opening it. After all, that box *has to* contain the opposite glove. The "states" (or handedness) of the two gloves are correlated; the information you learn about one gives you information about the other. In quantum mechanical terms, the gloves are entangled.

So, too, can a quantum computer's qubits become entangled with one another. And they don't only pair up one to one; in fact, as you squeeze more qubits into a quantum computer, the correlations between those qubits rise exponentially, becoming so numerous and complex that it's impossible to represent the relationships between them using nonquantum, classical physics.

All of this means simply that, thanks to entanglement, a quantum computer has at its disposal a tremendous amount of complexity and, thus, an ability to store and process information far beyond the reach of a regular computer. This sort of unparalleled complexity is intrinsic to the laws of quantum mechanics, and therefore to nature. "The idea is to exploit this complexity so that nature does the computation for us," Kitaev says.

It's impossible to attribute the power of quantum computing to any single factor. It's not just superposition; it's not just entanglement. Instead, it's the overall weirdness of quantum mechanics—in which both superposition and entanglement play critical roles—that packs such a large amount of complexity and information into qubits, despite the fact they take up only a tiny amount of physical space.

"I can't stress too much how amazing this is," Schulman says. "It doesn't make sense from our classical intuitions."

HOW DO YOU BUILD A QUANTUM COMPUTER?

Qubits. Superposition. Entanglement. It's all very abstract. But a quantum computer would need to be a concrete object, visible and usable. And so, to make the abstract concrete, researchers are trying to figure out the best way to physically represent a qubit, in much the same way a regular bit is embodied in an electronic switch.

They've come up with a myriad of possibilities. Some have built qubits out of charged atoms, whose individual spin states—whether that particular atom is spinning clockwise or counterclockwise—represent the qubit's zero-one or on-off states. The process by which these ions can be trapped in a vacuum by lasers and electromagnetic fields is what won David Wineland his half of this year's physics Nobel. Another idea involves tiny loops of superconducting wires with electrical currents flowing through them. The two directions of the current—whether it flows clockwise or counterclockwise—create the qubit. Yet another proposal is to use the spin states of electrons inside semiconductors as qubits.

Using these ideas as their basis, researchers have been able to build working quantum computers with around a dozen or so qubits—not enough to calculate anything a regular computer can't, but still an impressive feat. Scaling up to a truly powerful version, however, isn't going to be as simple as it might seem.

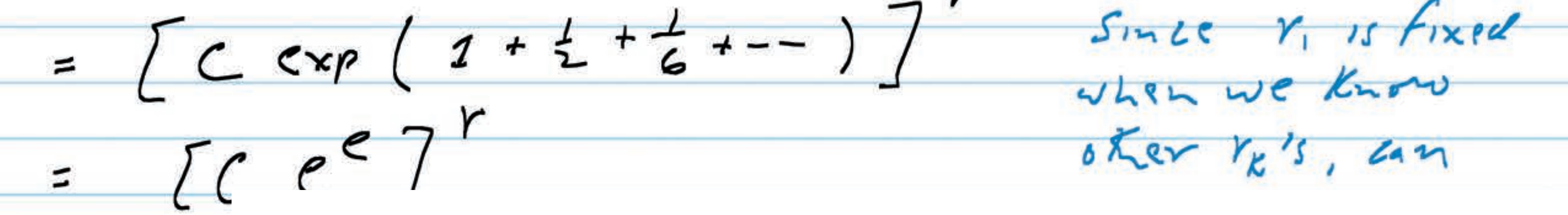
The problem? Quantum systems are exquisitely delicate. If some foreign, stray particle—like an atom or photon—bumps into or otherwise interacts with the qubits, it can change or disturb the quibits' quantum state, ruining whatever calculation the computer might be doing. Since it's impossible to completely shield such a computer from the rest of the universe, these disturbances—and the errors they cause—are inevitable. "If we don't do anything, the errors will accumulate throughout the computation and destroy everything very quickly," Kitaev says.

One way to solve this problem is to design algorithms that fix the errors—and indeed, developing this kind of error-correcting code is a major effort in quantum-computing research. But they're not easy to write, says Kitaev. And, besides, wouldn't it be better to just devise a computer that is error-proof—or at least error tolerant—instead?

Kitaev thinks so. Which is why he's worked to come up with a plan for a quantum computer based on an exotic type of particle called an anyon. Unlike electrons or protons—which can exist in isolation—anyons can only exist inside exotic quantum systems, in certain kinds of materials under certain conditions.

As a result of the particle's strange properties, a pair of anyons share a single quantum state—that on-off, zero-one property that is normally the hallmark of a single particle. And since the two anyons share a quantum state, that means the pair can act as a single qubit.

Now, here's the key point: it turns out that an anyon pair can still act as a qubit even if you separate the two quasiparticles. For the qubit to be disturbed—by that stray photon or electron we talked about earlier—the photon or electron would have to interfere with *both* anyons. But if you keep the anyons far enough apart—say,



a micron or so, which is a long, long distance in the quantum world—that stray particle would impact only one of the anyons, meaning that the qubit as a whole would remain safe and error free.

"This is a beautiful, elegant way of doing quantum computing," Preskill says. "It is an illustration of the type of thing we might do to get quantum hardware to work reliably."

While a conventional computer works by turning bits on and off, a quantum computer processes qubits by changing their quantum state. In Kitaev's computer, that change happens by physically moving the anyons around—for example, by making the anyons swap places with one another.

It was for coming up with the concept behind this kind of computer—called a topological quantum computer—that Kitaev won the Fundamental Physics Prize. Indeed, his insights into this type of error prevention essentially created a new field of research when they were first published in 1997.

"It's pretty amazing how ahead of the game he was," says Caltech physicist Jason Alicea. "He really laid the groundwork for what everybody is doing today in this field—including me."

What Alicea—along with Caltech theoretical physicist Gil Refael and their colleagues—has been doing is drawing the theoretical blueprints by which one could turn Kitaev's ideas into a physical computer.

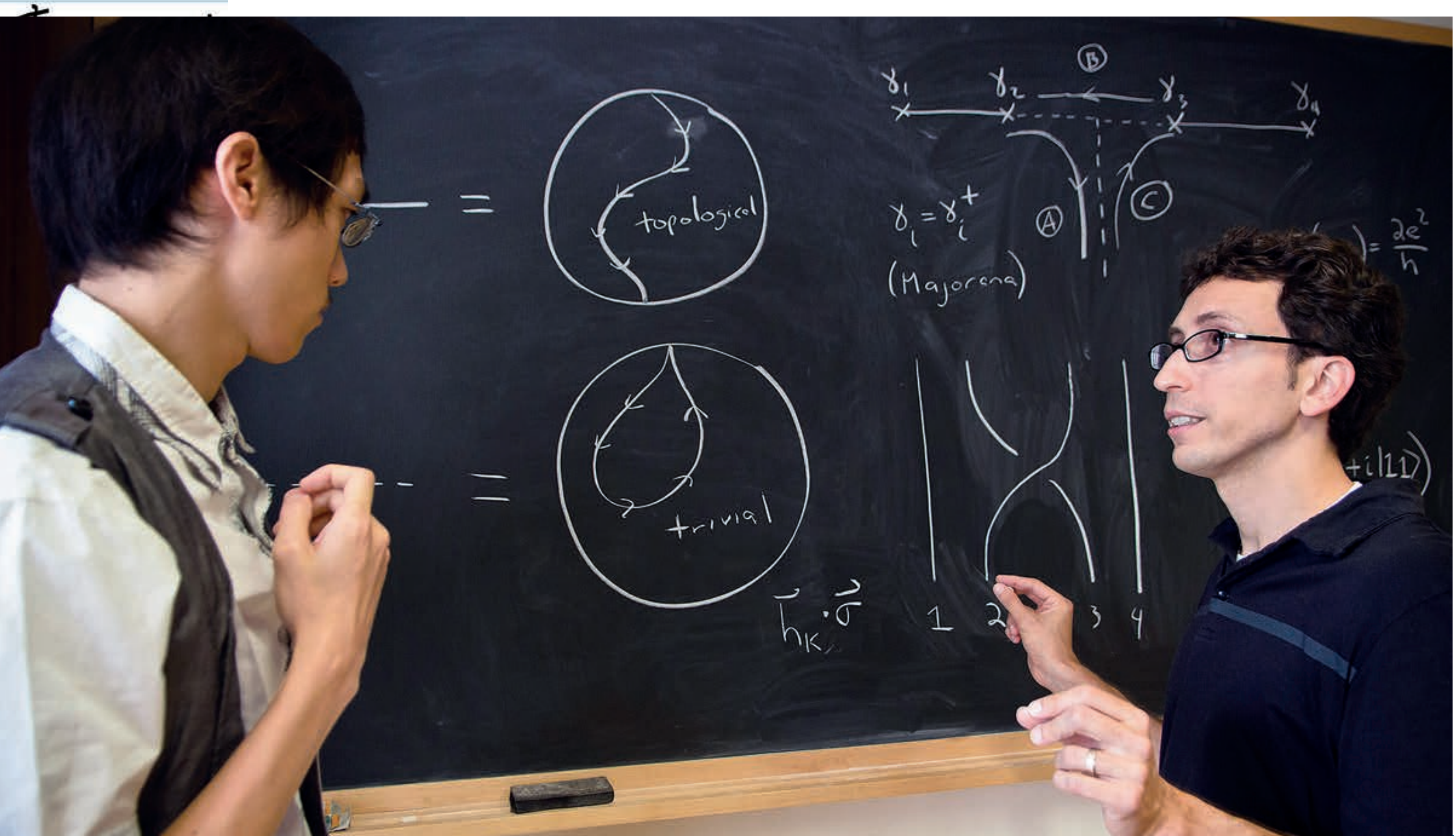
Their proposal starts with a network of quantum wires, each only tens of nanometers thick. The wires are designed so that at each of their two ends is an anyon that traps a hypothesized object called a Majorana mode, which has long been theorized to exist in certain exotic states of matter. Two of these modes can form a qubit.

In keeping with Kitaev's theories, the modes at each end of the quantum wire will be protected against outside disturbances as long as they remain sufficiently separated—in this case, about a micron apart. And just as in Kitaev's original idea—in which the computer processes data by moving the anyons around—the quantum-wire computer processes its qubits by using capacitors to adjust the voltage along the wires, which then moves the modes around.

Quantum wires, says Alicea, could be built out of fairly common superconductors and semiconductors surrounded by a magnetic field. "That's the beauty of it," Alicea says. "These are extremely rudimentary building blocks that one can combine in a way that lets you get something extraordinarily exotic out."

SO WHEN CAN I BUY A QUANTUM COMPUTER?

What we can do and what we have done are two very different things in the field of quantum computing, its practitioners admit. Kitaev's envisaged topological computers may have the most potential for scaling up to a workable machine containing hundreds or even thousands of qubits, but to date



no one has built a single quantum-wire qubit. "We're a long way off—decades, probably—from using these things to actually build hardware in a computer," Alicea admits. "But the research is advancing rapidly. The experimental pace has just been fantastic."

Other types of quantum computers—those based on the spin states of single atoms, for example—may be developed sooner. In fact, primitive quantum computers already exist—such as the handful of photon-based qubits that researchers in the United Kingdom used this past year to factor the number 21 with the help of Shor's algorithm. But while some researchers claim that useful quantum computers will exist within the next decade, most experts think otherwise. "When I started working on quantum computing around 1995, I gave an estimate of 30 years," says Kitaev. "Now I'm more cautious."

To create a true quantum computer—one that can outcompute a conventional computer—however, you'd need at least 50 qubits, says Preskill. But even that—even *double* that—might not be powerful enough to solve the problems that today's machines can't even begin to fathom. In order to factor large numbers, he says, you'd probably need a few thousand qubits. And to implement the necessary error-correcting algorithms if you're not using a topological quantum computer? Well, then the count goes up to a few hundred thousand.

Still, Preskill and his colleagues say, the question isn't if, but when. "Quantum computers will be built in the 21st century," he says. "And the technology will have an impact on society in ways we can't fully anticipate. I think most people who work on quantum computing will agree with that."

Left: Graduate student Shu-Ping Lee (left) and physicist Jason Alicea

Above, right: Theoretical physicist Gil Refael

A QPHONE ANYONE?

Although quantum computing may indeed lead to a science-fiction future, the truth is that scientists are still in the early stages of even creating the *field* of quantum computing. Their first full-power quantum computers will likely rely on huge cooling systems, and will probably resemble the fledgling electronic computers of the mid-20th century, which weighed a ton and filled entire rooms.

In fact, researchers say, even later and more advanced quantum computers will likely be too large, expensive, and complex to ever replace our desktops and laptops. "It's hard to envision doing your email on a quantum computer," Preskill says. The expectation is that they'll be used for specialized, computationally intensive tasks—just like today's supercomputers. Scientists will likely send their most difficult problems to quantum-computing centers distributed around the world, in the hopes that they can be calculated, simulated, and solved.

But many physicists are excited about quantum computing for an even deeper reason: they hope that it may help them gain insight into nature itself. "Quantum mechanics is kind of preposterous—outlandish may be a better word," Schulman says. Bring quantum computing into the mix, he adds, and you may have a direct test of quantum mechanics, with quantum computing providing the ability to probe how quantum physics gives way to classical physics as you go from the microscopic to the macroscopic.

Of course, no one truly knows what the quantum future will hold. After all, in the early days of mainstream computers, no one had any inkling of how ubiquitous they would one day become. "I think we've just scratched the surface of understanding what quantum computers will be good for," Preskill says. "Maybe we're not being visionary

enough. Maybe everyone's going to want to play quantum games. Quantum games might be pretty cool." E&S

Jason Alicea is an associate professor of theoretical physics whose quantum computing work is supported by the Sloan Foundation and the National Science Foundation (NSF).

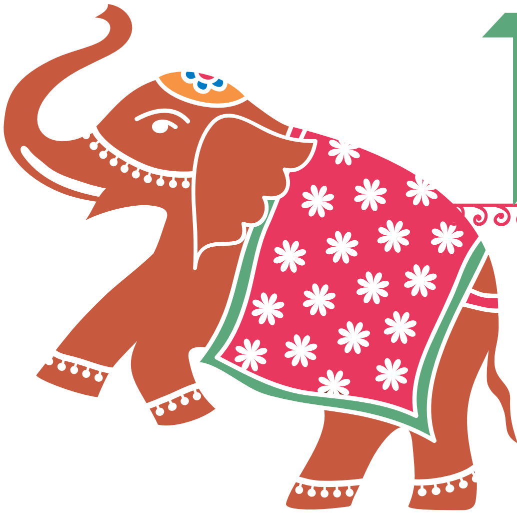
Alexei Kitaev is a professor of theoretical physics, computer science, and mathematics. In addition to the Fundamental Physics Prize funding, his work is supported by the NSF and the Air Force Office of Scientific Research (AFOSR).

John Preskill is the Richard P. Feynman Professor of Theoretical Physics. His research is funded by the NSF, the AFOSR, the Army Research Office (ARO), and the Intelligence Advanced Research Projects Activity.

Gil Refael is a professor of theoretical physics. His work in the field is funded by the Packard Foundation.

Leonard Schulman is a professor of computer science. His research is supported by the NSF and the ARO.

All of the researchers are members of Caltech's Institute for Quantum Information and Matter, an NSF Physics Frontiers Center with support from the Gordon and Betty Moore Foundation.



bridging

Students engineer innovative pr

By Katie Neith

For most college students, the final weeks of summer are spent wringing out the last few drops of freedom and warm weather before the chill winds and tedious school days of autumn. But for a group of adventurous Caltech undergrads, those final days of break this year were spent touring smoke-filled factories, visiting dilapidated hospitals, and learning how to use every single part of a coconut. And all this in preparation for an engineering class that had yet to begin.

When one thinks of feats of engineering, modern and grand structures often come to mind: the Dubai Tower, the Large Hadron Collider, the International Space Station. But the primary objective of the field has more to do with utility than grandeur; it's about taking basic mechanical principles and drawing upon them to make tools and objects that will enhance people's lives.

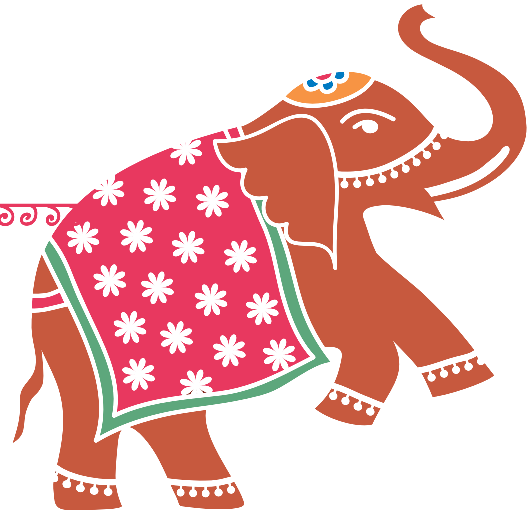
It was this concept that inspired nine of the students who were about to enter Caltech's E/ME 105 course to travel halfway around the world to India to learn firsthand about the needs of certain populations in rural areas of this vast and complicated country. They went knowing that their charge would be to return to Caltech and exploit the knowledge they'd gathered to develop useful and innovative products from scratch, with the help of the dedicated faculty and students who are part of a unique class that aims to tackle one of the greatest challenges of the developing world—lack of resources due to poverty.

"Product design has always been the most interesting part of engineering to me; the ability to create something that has never existed before is an exciting opportunity," says Blaine Matulevich, a senior with a double major in mechanical engineering and history. "The fact that this class allows me to do this while helping improve

A woman at the Akhil Rubber Mat Works cuts excess rubber from a mat. Each of the approximately 150 holes in the mat must be chiseled out by hand, causing pain and strain for the workers.

the gap

oducts for the developing world



the lives of less-fortunate individuals made enrolling in the course an obvious choice."

Aptly named "Product Design for the Developing World," this most practical of mechanical engineering courses—created and taught by Caltech visiting professor Ken Pickar—is part product design and development and part anthropological survey, giving students the opportunity to get up close and personal with the populations they seek to serve. The ultimate goal of the class is to teach the students how to take a product from the initial spark of an idea all the way to its implementation—and possibly even to gauge the success of the product once it's out in the market.

Through Pickar's collaboration with engineering faculty at the Saint Gregorios Institutes of Technology and Sciences (called Saintgits)—located in a rural area of the Kerala, a state at the southern tip of India—his Caltech students are not only assigned Indian student partners for the duration of the class, but a number of his students actually visit India just before the start of the school year, during which time they get a chance to meet and work with those partners.

"I think it's a great educational experience, allowing students to learn how the world works outside of their own neighborhoods and getting them to think about what people really need when they work on their designs, rather than designing what they *think* someone else might need," says Pickar. "I want students to develop a product that they feel strongly about."

Pickar—who worked at Bell Labs, GE Corporate R&D, and Honeywell before coming to Caltech in 1998—started his Developing World class in 2004. At the time, he says, his ideas for the curriculum were considered a bit "out there."

"Many of the classes at Caltech did not focus on teams or teamwork, and tended to use formal methods, like writing software codes to simulate what things should do," says Pickar. "That is all really cool stuff, but it also is removed from reality."

"This is possibly the most real hands-on class and one of the most unique classes we have here at Caltech," agrees Trisha Guchait, a Caltech junior in Pickar's class who started her studies as a chemical engineer but switched to mechanical engineering after a friend told her about the Developing World course.

During the first two years of the course's existence, students focused on an in-need population from anywhere in the world, and there were no trips or partner institutions. Then, in 2006, Pickar formed a partnership with a faculty member at Rafael Landivar University in Guatemala City, Guatemala: students from both institutions then worked together to find cheap, technological solutions for problems plaguing the rural populations in that Central American country.

The partnership—which also included students from the Art Center College of Design in Pasadena, in the hopes that the technologies developed would be aesthetically pleasing as well as useful—was a success, says Pickar. Such a success, in fact, that two of the members of the Caltech class, Rudy Roy (BS '07) and Ben Sexson (BS '07), went on to form a nonprofit called Intelligent Mobility International (IMI), which now provides to needy populations across Guatemala the safe, durable wheelchairs they first envisioned in Pickar's course. (See "Engineering for the Bottom of the Pyramid," in Random Walk, *E&S* 2007, No. 3.) The students exhibited their wheelchair at the Smithsonian Institute and won a Breakthrough Award from *Popular Mechanics*.

Three years ago, Pickar decided to shake things up, and he shifted the focus to India. The first Caltech trip to Kerala was in 2011. It was, says Pickar, "an inspirational and magical mystery tour."

STREET SMARTS

The nine Caltech undergrads who made the second trip to Kerala in September 2012 were welcomed to Saintgits by students and faculty

At Haven Homes for the Disabled—where resources are scarce—a table is strewn with rudimentary prostheses and the tools that will help build new prostheses out of existing parts.

members who had organized an expedition that would allow the students to get a firsthand look at the lives of local factory workers and hospital patients.

"The most rewarding experiences on the trip were the interactions we had with our fellow students, and with the many other Indian people who we got to know," says Matulevich. "I was really inspired by seeing how resourceful and innovative the Indian workers and entrepreneurs could be."

For nine days, Matulevich and his fellow students toured businesses in the area. They watched as women cracked cashews by hand using tools that could easily maim them with one false move; they looked on as other women working at construction sites used machinery clearly meant for much larger men. They toured factories filled with smoke and visited water sources choked with weeds. And they spent time at hospitals and homes for the disabled where resources like wheelchairs, prosthetic limbs, and rehabilitation equipment were severely lacking.

The group also met with the leaders of local nonprofit organizations that have unparalleled insight into the issues in the region. In fact, by the end of the trip, the students had visited or met with representatives from over 20 local companies and organizations. Only then, says Pickar, were they ready to even think about beginning the actual design process.

"We saw the problems, we framed them, but we did not try to come up with a solution on the trip," he said when he spoke with *E&S* in October of last year. "Now that the class has begun, we've begun going through a brainstorming process, coming up with possible solutions, and will soon build some prototypes."

"The trip is essential to make the eventual product development meaningful," adds Katja Luxem, a junior studying chemistry who took the class in 2011 and was so changed by the experience that she returned as a teaching assistant for the 2012 class, even traveling with the students and Pickar to Kerala. "It gives you a much better context for what the problem you're trying to solve actually is."

Guchait adds that she chose to go on the trip not only for the firsthand market research, but because she knew she would be able to see an India that most student-tourists never even glimpse.

"Knowing that I could go and see India with the students who live and study in Kerala really made me want to travel there," she says.

"I had the best time with the students from Saintgits, seeing how enthusiastic they were about all of the tours that we took to find issues to research for the class. Being with them and learning their culture was a lot of fun."

PRACTICAL PROJECTS

Once back in the States, the students who traveled to India recounted their experiences to the rest of the class; together, the entire class participated in brainstorming sessions, narrowing the list of possible projects down to eight. The students were then asked to list their top choices, after which Pickar assigned them to teams based on that ordered list. Each of the eight working groups includes at least one student who went on the Kerala trip, as well as two students from Saintgits, with whom the rest of the team often interacts during class lecture time via video-conferencing, Skype, and email.

Matulevich and his team are working to engineer a better wheelchair for the disabled people of Kerala, in much the same way that the Intelligent Mobility founders did for Guatemala. Wheelchairs are expensive and have a myriad of problems relating to comfort and reliability, he points out, so the team is strategizing to come up with economically and technically viable solutions to at least a couple of these problems.

"We are focusing on taking the wheelchair created by IMI and adapting it to fit the problems of rural India, as well as manufacturing it in India as cheaply as possible," says Matulevich. "To make the wheelchair affordable, being in India is actually a huge advantage due to their huge number of production facilities and a good infrastructure. At this stage, we believe that we will be able to reduce the cost of the wheelchair to less than a fifth of what it cost IMI to build it in Guatemala.

"My goals for this class," he adds, "are not only to solve the problem we've selected in a unique and successful way, but also to enjoy the process and learn new things about working with international teams and new approaches to design."

Guchait and her team are working on a problem she was made aware of during a visit to a rubber-mat factory where the employees—most of them women—manually punch holes in thick mats used in the shipping industry and as household products.

"Their company gets these mats from a larger rubber-mat factory that isn't set up to put in all the holes that are needed," explains Guchait. "So they ship them out to these women, who literally take a chisel and hammer and punch out each hole by hand, one after another."

Hammering and chiseling away at rubber all day is an ergonomic nightmare; that's why Guchait's team's goal is to create a hole-punching tool that will eliminate some of that strain on the women. They would also like to make the punching process faster so that the women can make more mats and, in turn, more money, she explains.

Students at Caltech hope new tools will make the job easier for rubber-mat workers like the woman above.

> "We are focusing on taking the wheelchair created by IMI and adapting it to fit the problems of rural India."

"I think our project is perfectly scaled so that we'll have a product by the end of the class that we can actually implement," she says. "That's my ideal goal—a finished tool that we can send to the women and that they will find useful."

Matulevich's search for a better wheelchair and Guchait's for a better hole puncher will be joined by similar efforts, including one aimed at devising a method to clear local lakes and ponds of a notorious weed that causes water loss, kills fish, and infests rice paddies. Another of the class's teams is working to design better face masks for employees who work in dust- or smoke-filled locations. And then there's the group that's working to convert organic

A woman begins to weave a screw-pine mat. Handicrafts are the source of income for many rural women in India.

waste, such as kitchen scraps, into biogas as a low-cost alternative fuel source for homes and businesses.

To achieve its goal, each team will have to work within the very specific parameters Pickar has set. The students cannot use imported materials; everything they build with has to be found indigenously in India. Recycled or repurposed materials are even better. The product must also be strong; Pickar says he doesn't want anyone to compromise on quality. But most of all, it needs to be really, really cheap.

"If you were to design a product in the U.S., you would probably want the return on investment to be significant so that you get your initial investment back in a year or two," says Pickar. "With these products, we're talking about a month or two."

In other words, the product should be so useful and immediately productive that—even if you have to spend a little bit of money to make it—you would earn that money back quickly. For example, the biogas project team is looking at pricing its product to match the fuel costs for an Indian family over a month or two. Then, the team will drive the cost down even further by trying different, more affordable materials or recycled goods.

"Even though the technology in all of our projects is very simple, that doesn't mean they're not complex ideas," says Pickar. "The students need to really and truly understand the people who need their products, the human interactions involved, and the concept of building it at an insanely low cost. The challenges are very real and the designs reflect a lot of thought even though they may seem to be very simple."

Taking even a simple idea and bringing it to fruition, however, requires time. Which is why, this school year, Pickar's Developing World course was expanded to two quarters from just one. The idea, he says, is to allow students time to do a second iteration of their initial designs, as well as to focus on marketing—including hearing from guest lecturers who have seen success in commercial development.

"I am hopeful that we will have enough time to actually transfer some of our innovations to India," says Pickar. "I would be very disappointed if we didn't move some of these projects from idea to a usable product—maybe not all eight, but I'd like to see a couple go out into the world. The ones we've done in the past, we just didn't have enough time to do anything more than relatively crude prototypes. This is an engineering class, so we'd like to engineer something."

ENDURING IMPRESSIONS

Regardless of project success or final grades, Pickar and his students all agree that E/ME 105 is much more than a simple academic exercise.

"Most of the people who come to Caltech are not coming from poverty," says Luxem, the class TA. "For the most part, we are people who have been cushioned our entire lives, and it's important for us to realize that people who *haven't* been cushioned aren't any less smart, or any less talented. I recently heard a quote that said something like 'Talent is universal, but opportunity is not.' This class really puts that phrase into perspective. There are a lot of smart people out there living in poverty who just haven't been given the opportunity to get an education like we have, or to get the money they need to start a company."

For Guchait the core value of the class is the insight it's provided into how best to interact with people of a different culture.

"I really enjoy working with the students in India—they are so hardworking and possibly even more invested than we are since these products that we are making will affect them more directly," she explains. "They see the problems we are trying to address every day, so I think they really want solutions. And they know how and whether our products are likely to be accepted in India, from a cultural standpoint.

"The experience also made me realize that while other people may do things very differently, it's *their way* of doing it—that's what they are used to, so you can't just impose your ideas on them. Whenever you are making a product or trying to implement a solution, you have to make sure it will be acceptable to your target population."

Caltech students Katja Luxem (left) and Anish Agarwal (second from left), along with Abel Christina from Saintgits (second from right), inspect a waterway that has become clogged with weeds.

For Matulevich, the class is important because of how it encourages students like himself to approach engineering problems in new and interesting ways.

"Most classes at Caltech teach you math; this class teaches you to innovate. To me, that is one of the most useful skills anyone can develop," he says. "It also forces students to develop a global perspective, which is very important as technology and the increasingly global economy begin to blur the lines between different nations and cultures."

Even Pickar, a seasoned world traveler, finds that the trips continue to have an impact on him and play a role in the way his class has evolved. He spent some extra time in India this past year, walking the streets and speaking with people in some of the poorest neighborhoods in Ahmedabad—a city in northwest India—while visiting a school there.

"You take a superficial look and think, 'How can these people live under these conditions?'" he says. "But then you find that people who are very poor are not necessarily unhappy. You get the feeling, though, that if you could do things to make these people's lives better—create products that they could use and enjoy—it would ease some of the pain they experience.

"But," he urges, "don't assume for a second that everyone is desperately waiting around for you to go do some cool thing to please yourself. You have to make sure what you do is really going to benefit other people."

And, in the end, that's what Product Design for the Developing World is all about: helping to bring others the tools they need to build a better world—a developing world—for themselves. e&s

Ken Pickar is a visiting professor of mechanical and civil engineering. His "Product Design for the Developing World" class was funded in 2012 by the George W. Housner Student Discovery Fund and by donors Rainer Schaaf, Paul Ouyang, and Rajiv Sahney (BS '85).

FOR THE LONG HAUL

ROOMINATE

Bettina Chen (BS ’10), *Cofounder*

While in a graduate program at Stanford, Bettina Chen and a fellow student lamented that there weren’t more women in the sciences. “It even goes back to childhood,” Chen says. “Nearly all science-based toys, like Erector sets, are geared toward boys.”

Their solution: Roominate, a simple kit that allows girls to construct—from layout to furniture to electrical outlets—their own dollhouse. (For more on Roominate, see “Dollhouse Deluxe,” page 7.)

The initial signs are promising—girls like playing with the kits. But Chen will have to wait to test her larger goal. “Success for us would be to inspire more girls to pursue science as women,” she says.

BIONANO GENOMICS

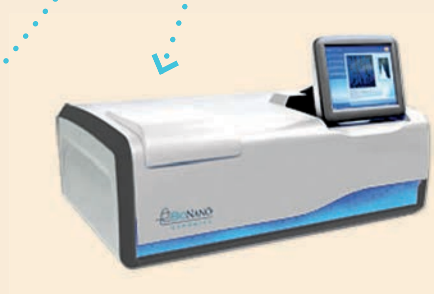
Erik Holmlin (PhD ’98), *President & CEO*

Erik Holmlin says President Clinton’s announcement, in 2000, that the human genome had been successfully sequenced for the first time ushered in “a momentous time period”—one he wanted to be part of. “I felt that the private sector afforded tremendous opportunity to have impact,” he says.

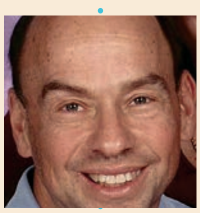
In 2001, Holmlin joined Caltech chemist Jacqueline Barton—in whose lab he had done his graduate work—to start GeneOhm, a company that created cost-effective, rapid molecular and chromogenic testing.

In 2011, he was named CEO of BioNano Genomics, a company developing a platform to provide rapid, high-resolution genome maps.

On starting a company, Holmlin says: “Believe in yourself and your idea, then work to get others to believe as well.”



C8 MEDISENSORS



Paul S. Zygielbaum (BS ’72, MS ’73)
Cofounder, President, & CEO [top left]

Robert McNamara (BS ’73, MS ’73, PhD ’78), *Cofounder, Vice President [middle left]*

Jan Lipson (BS ’72), *Cofounder* (deceased) *[bottom left]*

For years, Jan Lipson watched his son—who was diagnosed with type I diabetes at the age of 10—struggle to keep track of his glucose levels. An expert in optical technology and spectroscopy, Lipson wondered if he could use light to measure glucose without drawing blood. And so he reached out to two of his oldest friends: Caltech classmates Robert “Mac” McNamara and Paul Zygielbaum, each of whom had decades of experience in technology companies.

Solving the science piece of the puzzle was hard enough, says Zygielbaum. “The greater challenge,” he says, “is convincing others to back you.”

Their product—the C8 MediSensors device—is the size of a smartphone and provides noninvasive measurements every five minutes. This fall, it was cleared for trials in Europe; the team expects a 2013 product launch in Europe, with U.S. trials to begin thereafter.

Regrettably, Lipson was killed in a car accident in 2010, before the prototype went into production.

“There isn’t a day that goes by that we don’t think about Jan,” says McNamara. “We believe his inspiration and passion will lead to better, healthier lives for millions.”

"Caltech has rich history of making discoveries that lead to new industries or dramatically transform existing ones," says Vice Provost Morteza Gharib (PhD '83). Here, five Caltech alumni talk about how they've nurtured start-ups and brought them to five very different stages of development.

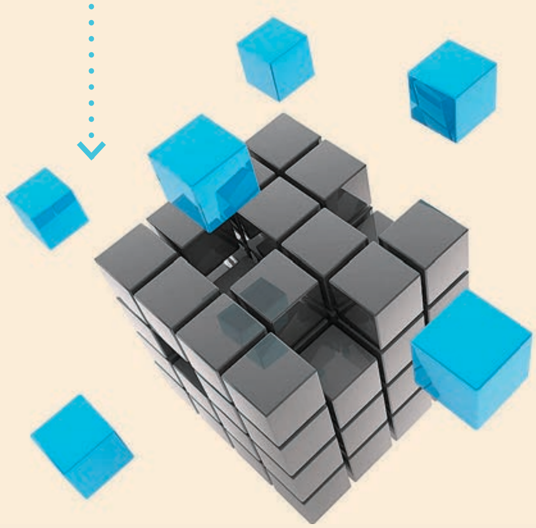
MYRICOM

Nanette Boden (MS '88, PhD '93), *President & CEO*

When Nanette Boden was earning her doctorate at Caltech as part of computer scientist Charles Seitz's research group, supercomputers were still large, custom-built machines. "Our group enhanced supercomputer performance by networking together smaller computers," she recalls.

Boden joined Seitz and other researchers from Caltech in 1994 to found Myricom. "Within a few years, the entire culture changed," she says. "Cluster computing became dominant in the '90s and 2000s."

Today, products made possible by Myricom's breakthroughs can be found throughout the wired world. And when hiring, the company frequently turns to graduates from Caltech. "The interdisciplinary way that Caltech teaches you to problem-solve is unique," says Boden, who became Myricom's CEO in 2010. "Whatever the issue, we know that Techers will examine a problem from all sides."



IDEALAB

Bill Gross (BS '81), *CEO*

While in high school, Bill Gross started a business making kits to build simple, solar-powered engines. In three years, he sold 10,000, thus paying his way through Caltech.

"Back then, the normal route was to go work for big companies like JPL or Ford Aerospace," Gross says. "I took a different path."

Gross went on to start—and sell—a series of successful software firms. In 1996, he founded Idealab, a business incubator that has launched close to 100 companies, including renewable-energy firms such as eSolar, and web companies such as Picasa and Citysearch.

Gross says success depends not just on an idea, but on building a team with the ability to execute. "Every business needs four types of people: a visionary, a producer, an administrator, and then someone to integrate them all together," he says, adding, "I believe that this is the absolute best time to be an entrepreneur. And Techers are perfectly positioned to do it."

Wallace "Wal" Sargent,
1935–2012

Wallace "Wal" Sargent passed away October 29, 2012, at the age of 77. The Ira S. Bowen Professor of Astronomy, Emeritus, at Caltech, he began his career at the Institute as a research fellow, working from 1959 to 1962. He returned as an assistant professor in 1966, becoming full professor in 1971 and Bowen Professor in 1981. Sargent served as Caltech's executive officer of astronomy from 1975 to 1981 and again from 1996 to 1997.

An astrophysicist, Sargent was a principal investigator on the second Palomar Observatory Sky Survey, a photographic survey of the entire northern sky that was converted to a digital image format so that it could be analyzed via computers. This process produced a catalog of over 50 million galaxies and half a billion stars, including tens of thousands of quasars. Sargent was director of the Palomar Observatory from 1997 to 2000.

Sargent is known for his analysis of quasar absorption lines, and surveys of active galactic nuclei and remote clusters and superclusters of galaxies. He determined the relative abundances of several elements in the early universe. For his work, Sargent was named a fellow of the American Academy of Arts and Sciences in 1977, and a fellow of the Royal Society in 1981. He received the Bruce Medal of the Astronomical Society of the Pacific in 1994, was elected to the National Academy of Sciences in 2005, and was the Henry Norris Russell Lecturer of the American Astronomical Society in 2001.

Sargent is survived by his wife and fellow astronomer, Anneila Sargent, vice president for student affairs and the Benjamin M. Rosen Professor of Astronomy at Caltech; and two daughters, Lindsay Eleanor Berg and Allison Clare Hubbs.

To learn more about Wal Sargent's life and work, visit "Caltech Mourns the Passing of Wallace L. W. Sargent" at http://www.caltech.edu/content/caltech-mourns-passing-wallace-l-w-sargent.

Robert F. Christy
1916–2012

Robert F. Christy, one of the last people alive to have worked on the Manhattan Project—which created the atomic bomb during World War II—and whose later research in astrophysics contributed to our understanding of the size of the universe, passed away on October 3, 2012, at his home in Pasadena. The former provost and acting president of the Caltech, where he was a longtime professor, was 96 years old.

One of the early recruits to Los Alamos, he was credited with designing the explosive core of the first atomic bomb.

At Caltech, Christy worked in theoretical physics and nuclear physics, including the study of cosmic rays. He later moved into astrophysics, turning his attention to Cepheid variable stars, which had long been used to measure distances to other galaxies because their pulsation rate varies with their intrinsic brightness. The mathematical model that Christy developed helped explain why the stars vibrate, and it earned him the Royal Astronomical Society's Eddington Medal. He was elected to the National Academy of Sciences in 1965.

Because of his wartime experience, Christy became an opponent of the further development of nuclear weapons. In the mid-1980s, he joined the National Research Council's Committee on Dosimetry, which studied the radiation effects of the Hiroshima and Nagasaki bombs.

Christy is survived by Juliana, his second wife; two daughters, Ilia Juliana Christy and Alexandra Roberta Christy; two sons from his first marriage to Dagmar Elizabeth von Lieven, Thomas Edward "Ted" Christy and Peter Robert Christy; and five grandchildren.

Robert Christy's life and work are memorialized in "Noted Physicist Robert F. Christy Dies" at http://www.caltech.edu/content/noted-physicist-robert-f-christy-dies.

WHAT MAKES CALTECH SPECIAL? After Caltech was named the top university in the world by *Times Higher Education* for the second year running, we asked alums what they think makes the Institute a standout. Here's what they had to say.

THE HONOR CODE: It provides autonomy and responsibility—ideal training for personal integrity.

Caltech did not just teach me how to solve problems, it taught me how to **FIGURE OUT** how to solve problems.

THE PAIN.

Caltech is a very special experience for undergrads. The "introductory" classes are taught by the **GEEK EQUIVALENTS OF ROCK STARS**, and they are full-throttle and exciting. There are opportunities to jump into real research very early on and get a sense for what life in research is like.

Caltech is special because it is a **MERITOCRACY**, **PURE** and **SIMPLE**.

Everyone you encounter there is **INCREDIBLY SMART** and **INTELLECTUALLY CURIOUS**.

Caltech is unique for the combination of three things: its **SMALL SIZE**, the **HONOR CODE**, and the **HOUSE SYSTEM**.

It is the best place to **CHALLENGE** one's own limits.

An unapologetic appreciation of all aspects of scientific **UNDERSTANDING FOR ITS OWN SAKE**.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Financial Challenge
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Inside Money
RF
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