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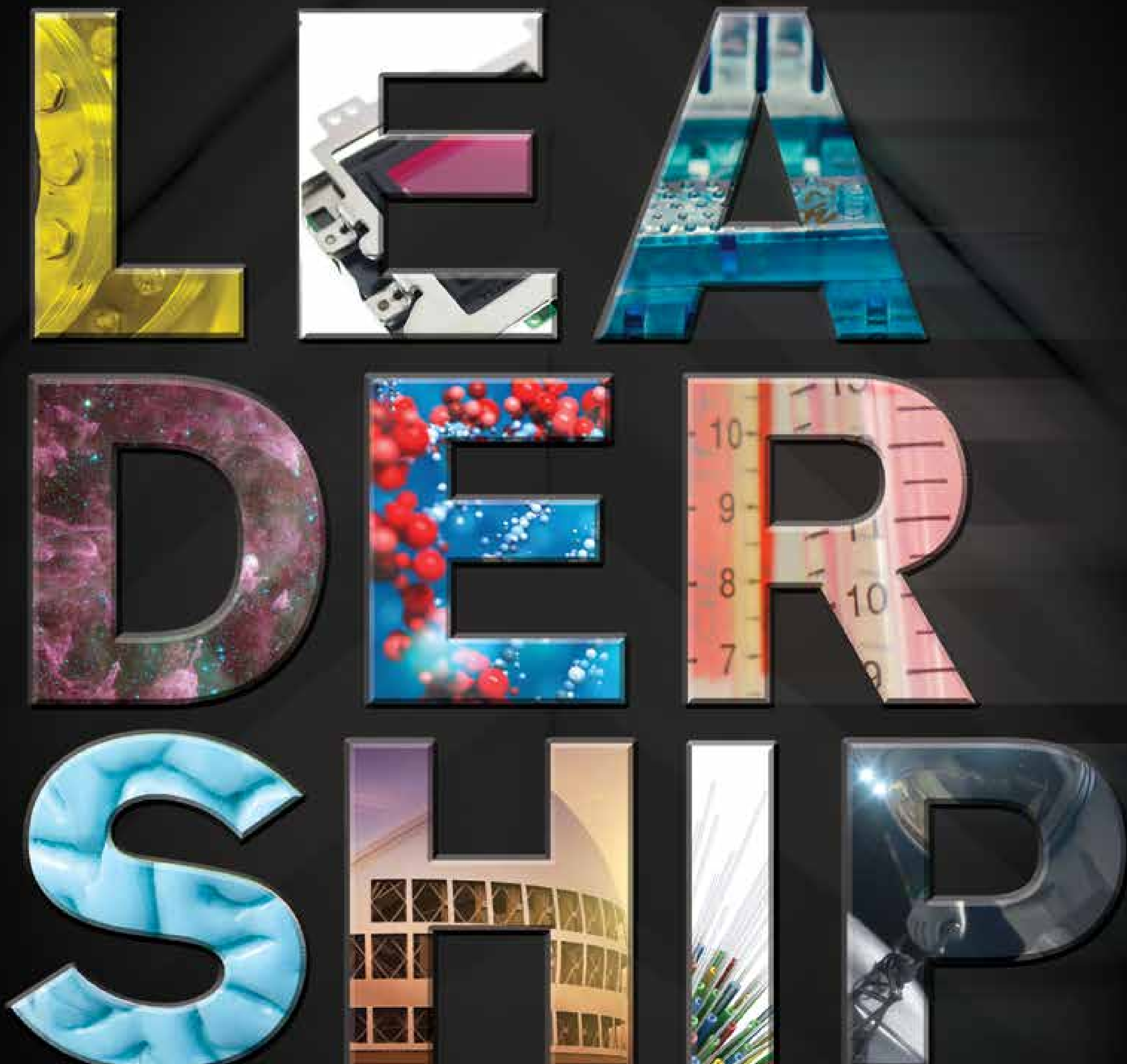
Engineering & Science



Caltech

VOLUME LXXVII, NUMBER 4, WINTER 2014

e&s
Engineering & Science

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Caltech on Twitter

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

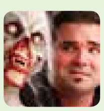
@andrea_wulf: Wish I would be 20 and clever enough to study engineering at Caltech. Such a beautiful campus.

@YangTerrence: Had a @caltech day. Found my dad's Ph.D. thesis online. Dinner w/ a Caltech Ph.D. disciple. & just learned The Feynman Lectures are online.

@plutokiller: It was cute to watch the Modern Family episode filmed at @caltech tonight, no? Look! The pond! Look! the colonnades. Nice to see home on TV

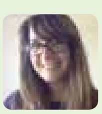
@EnjoyPasadena: Taking a night stroll through Caltech's campus it's a Pasadena MUST!

@joshsusser: As a Caltech alum, I can attest that there's more than one way to get a vehicle onto a roof

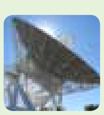


@bradleyvoytek: Talking brains at Caltech today. First time here. This place fails to suck.

@gravitate_to_me: Today I ordered a new computer, attended an excellent PMA party at @Caltech, then went to a women mentoring women mixer and met awesome ppl!



@gravitate_to_me: All in all, today was one of the best days I've had at @Caltech



@shareastronomy: At the RedDoor Cafe on the Caltech campus. Surrounded by people who do what I'd like to do.

Tweets may have been edited for context, spelling, and grammar.

Caltech
Engineering & Science

VOLUME LXXVII, NUMBER 4, WINTER 2014

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Lead On

On October 24, Caltech formally and officially welcomed its newest leader, President Thomas F. Rosenbaum, in a ceremony that celebrated both leadership and tradition as well as the possibilities that arise during times of transition. “It is a time,” Rosenbaum said during his inaugural address, “to ensure that Caltech’s fundamental identity comes from within and that it is never imposed from without.”

It’s no wonder, then, that leadership—both as a concept and as an active role—has been much on our minds of late. And so we’ve chosen to use this issue of Caltech’s *E&S* to explore that concept, that role, in its myriad guises.

In these pages, we consider how Caltech’s tradition of leadership in the building and operation of the world’s most advanced telescopes has influenced the development of—and technology behind—the Thirty Meter Telescope (see page 20). We look at how Caltech-bred technologies have led to the smartphones that are nearly ubiquitous in today’s society (see page 16). We also eavesdrop a bit on the workshops created by the Keck Institute for Space Studies (see page 10) to find out how their innovative and unusual techniques are leading scientists and engineers from across the globe to think differently about how space science is done.

“It is a time to ensure that Caltech’s fundamental identity comes from within and that it is never imposed from without.”

—President Thomas F. Rosenbaum

Then we look, most literally, at the leaders who have come from the ranks of Caltech’s alumni. Specifically, we talk with those men and women who spent some portion of their years as students at Caltech and who are, today, in leadership positions at institutes of higher education ranging from Dartmouth to Washington University in St. Louis to the University of Minnesota, and from Worcester Polytechnic Institute to Olin College of Engineering—and who are helping to shape the next generation of leaders.

Other schools encourage their students and alumni to “fight on”—but that’s not the Caltech way.

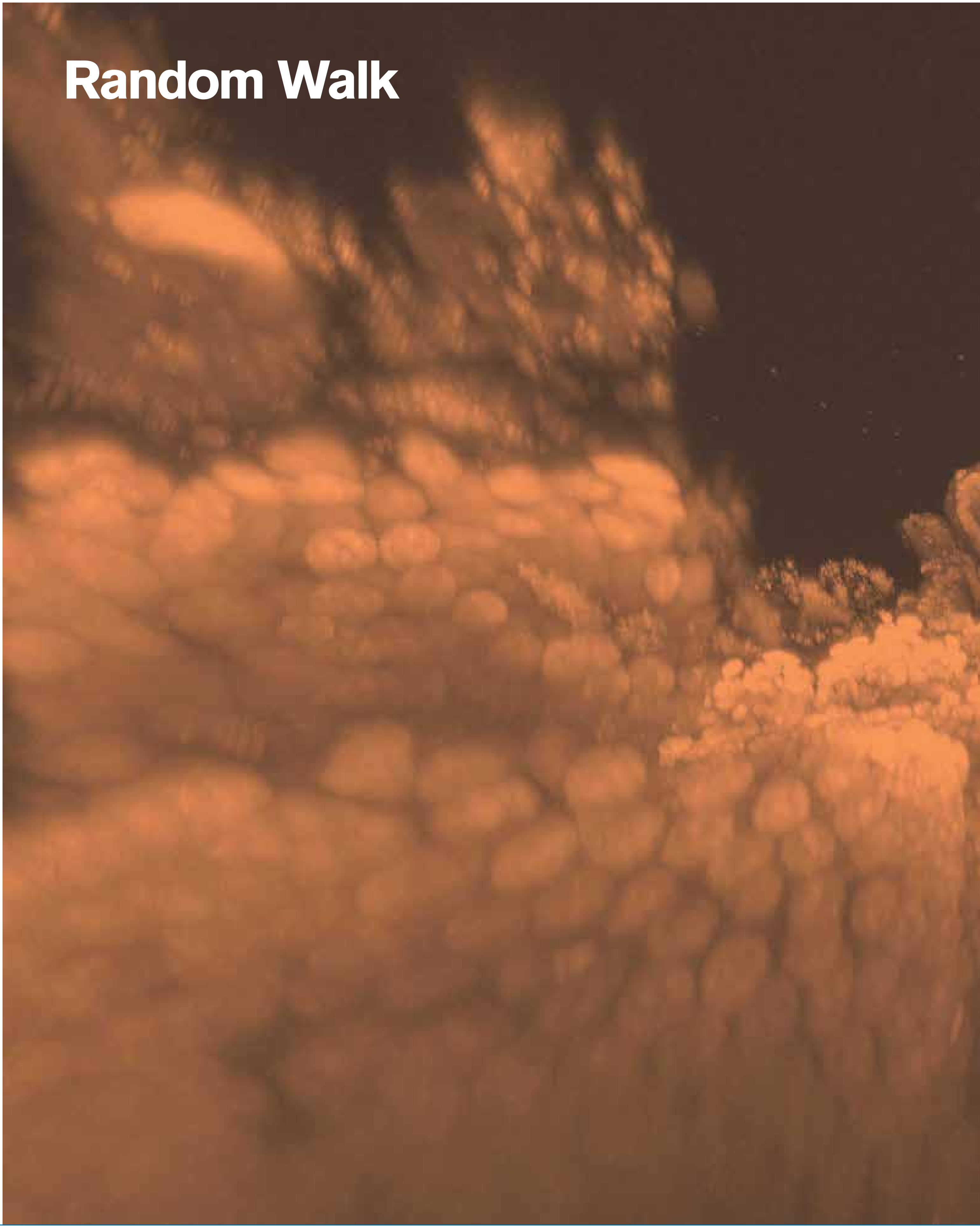
What we say is simply what we do: *lead* on.

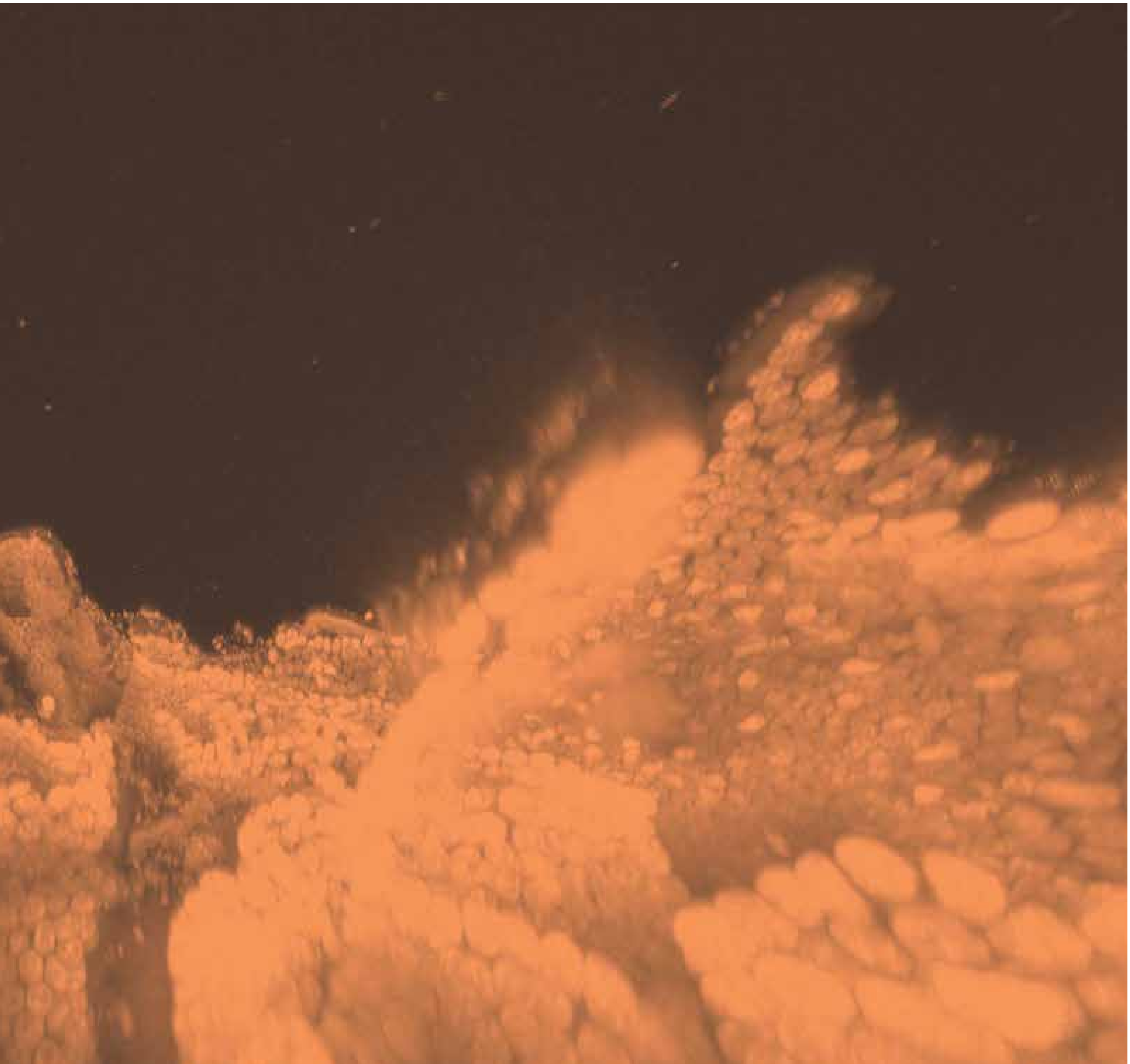
Go Caltech.

Lori Oliwenstein

—Lori Oliwenstein, Editor

Random Walk





SEEING CLEAR THROUGH

Although the formation seen here could easily pass for a sepia-toned collection of clouds, you won't be seeing these structures up in the sky anytime soon. The pink wisps are, in fact, fluorescently labeled intestine cells that were imaged within an intact mouse intestine—a feat made possible by a new technique developed by researchers in the lab of Viviana Gradinaru (BS '05), assistant professor of biology. With this method, researchers can now make thick masses of tissue samples—such as organs and even entire organisms—almost completely see-through, a capability that has numerous research and clinical applications. Rather than having to physically slice through tissue, image each thin slice, and then digitally reconstruct the images into a 3-D visualization of the cells in an organ, researchers using Gradinaru's technique can bypass these time-consuming steps by applying a solution of detergents to whole organs or organisms. The detergents dissolve light-blocking lipids in the cells, while the structures remain intact thanks to a supporting hydrogel that the researchers embed throughout the tissue—meaning that it becomes possible to look directly through and locate specific cells.

"That's one of the lovely things about being a theorist: you can dip into a huge number of different areas."

—Kip Thorne (BS '62), Richard P. Feynman Professor of Theoretical Physics, Emeritus, who has studied gravitational waves, wormholes, and black hole cosmology, among other things. Thorne continues to do research and recently served as an executive producer of the sci-fi film Interstellar, *which was released this fall and is based in part on his science.*

Web of Knowledge

In September, Caltech and JPL offered an unusual take on the massive open online course (MOOC) model: a two-week-long "virtual summer school" class, providing advanced instruction by experts at Caltech and JPL on the computational skills and methods used in the analysis of complex data sets—also known as "big data."

The Caltech-JPL Summer School on Big Data Analytics was the first professional summer class offered by the online learning platform Coursera. At the end of the two-week term, all of the developed content was migrated to Coursera's new on-demand course platform, so now you, too, can take a stab at learning to analyze complex collections of information from the comfort of your home.

Speaking of big data, Caltech has posted some impressive numbers since the Institute started offering online courses two years ago:

242,400
online students have participated in Caltech's MOOCs offered through Coursera and edX

>1.1 million
is the number of views of Caltech MOOC content offered on YouTube and iTunes U

~550 **Caltech students have taken Caltech courses using MOOCs as a component of the flipped-classroom model**

(500 = **average hours spent creating each new MOOC offering**)

20 hours **is the amount of time it takes to prepare the same MOOC for a second offering**

For more information on the online courses offered by Caltech, visit online.caltech.edu.

NEW MATTER
FOR THE MASSES

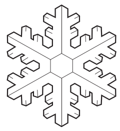
Imagine you have an idea for a new object—say, a custom phone case that perfectly molds to your hand or a cupholder that attaches to your laptop. Then, an hour later, a tangible plastic version of that item materializes just a few feet away, right in your living room. This scenario might sound a bit futuristic, but New Matter, a company founded by Caltech alum Steve Schell (BS '01), is determined to make affordable, at-home 3-D printing a reality in the present.

Schell was introduced to 3-D printing—a process that uses melted plastic to "print" three-dimensional objects—as a way to make quick industrial prototypes in his first job after graduating from Caltech with a degree in mechanical engineering. The technology has been gaining popularity in recent years, but consumer 3-D printers cost over $1,000 and require computer-programming knowledge to turn an idea into an object.

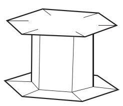
To reduce these barriers, Schell and his colleagues at New Matter came up with the MOD-t printer. By decreasing the number of components and moving parts, the company was able to dramatically cut costs; the MOD-t printer is now available for preorder from the company's website for only $279. The printer also features user-friendly software and a marketplace where programming novices can buy and print premade designs from more experienced users.

Although at-home 3-D printing is often associated with making jewelry or decorative items, Schell says that it could also be used for more practical tasks—like making a replacement part for your dishwasher. He says the MOD-t printers should start shipping to homes in the spring of 2015. *—JSC*

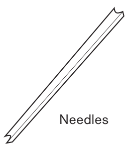
No Two Alike, But How Different?



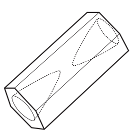
Stellar dendrites



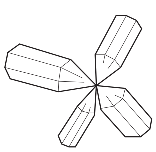
Capped columns



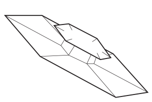
Needles



Hollow columns



Bullet rosettes



Double plates

When you think of a snowflake, you probably picture something like a stellar dendrite—the classic six-armed branching snow crystal that shows up as a decoration everywhere this time of year. But depending on the classification scheme, there are as many as 80 different types of snow crystals, or snowflakes, out there—and you can begin a basic snowflake search to investigate this in snowy regions with little more than a magnifying glass.

In fact, that's how Caltech physicist and snowflake guru Ken Libbrecht started his hunt, which has turned into the focus of his research. After happening across a journal article that described a type of snow crystal called a capped column, he wondered why he had never noticed one of the miniature icy thread bobbins falling from the sky in his native North Dakota. The next time he was back home, he grabbed a magnifying glass and went outside to take a closer look. "I saw capped columns. I saw all these different snowflakes," he says. "It's very easy. It's just that I had never looked."

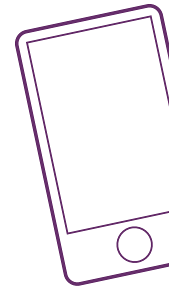
Since that first foray into snowflake hunting in the late 1990s, Libbrecht has published seven books of snowflake photographs and has spent years in the lab trying to understand the molecular dynamics that dictate how ice crystals grow. For example, snowflakes go from forming in thin, flat plates to growing in long, slender needles when the temperature changes by just a few degrees. You can see this change clearly in the laboratory, yet no one knows exactly why it happens.

Among the less recognizable snowflakes on the chart that Libbrecht uses are hollow columns, which are tiny hexagonal columns with hollow spaces at either end; bullet rosettes, which form when multiple crystals grow columns at various angles from a single ice grain; and double plates, which are similar to capped columns but feature one plate that is much larger than the other. —*KF*

For more about snowflake shapes, visit Ken Libbrecht's website, www.snowcrystals.com.

Insider Info

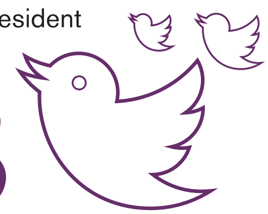
More than



1 billion

smartphones were sold in 2013 alone, and each one has pieces of Caltech history inside (see page 16).

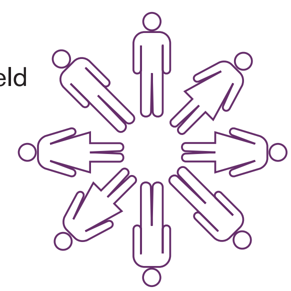
Last time we checked, University of Minnesota president Eric Kaler (BS '78) had



7,603

Twitter followers. Read more about Kaler and other leaders in education on page 26. Then find him tweeting as @PrezKaler.

The Keck Institute for Space Studies has held



60

innovative workshops on new space mission concepts and technology since its inception (see page 10).

On the Grounds

This sculpture, featuring a propeller centered over a set of spread wings, adorns the top of a doorway somewhere on campus. Enter the door to find labs and facilities that are very much in line with the artwork, more than 80 years after the completion of the building. Although the laboratory's original wind tunnel and water channel have been replaced and updated, researchers in the building still focus on aeronautics. Given the sculpture's depiction of the progression from a bird's wings to a flying machine, the artwork is also appropriately situated on the building that is home to the Center for Bioinspired Engineering. Where can you find this carving?

Answer: The sculpture is perched above the service door on the south side of Guggenheim Laboratory.

"Five hundred years after the Copernican revolution, we are marshaling deep scientific insight and ingenious technological accomplishment to search for the signatures of life on planets orbiting distant suns. If life is found elsewhere in the universe, our understanding of the place of human beings in the natural world will undergo another revolution. It is pure and applied science. It is poetry. It is Caltech."

— President Thomas Rosenbaum, talking about the Thirty Meter Telescope (see page 20) during his inauguration speech on October 24, 2014

Celebrating a New President

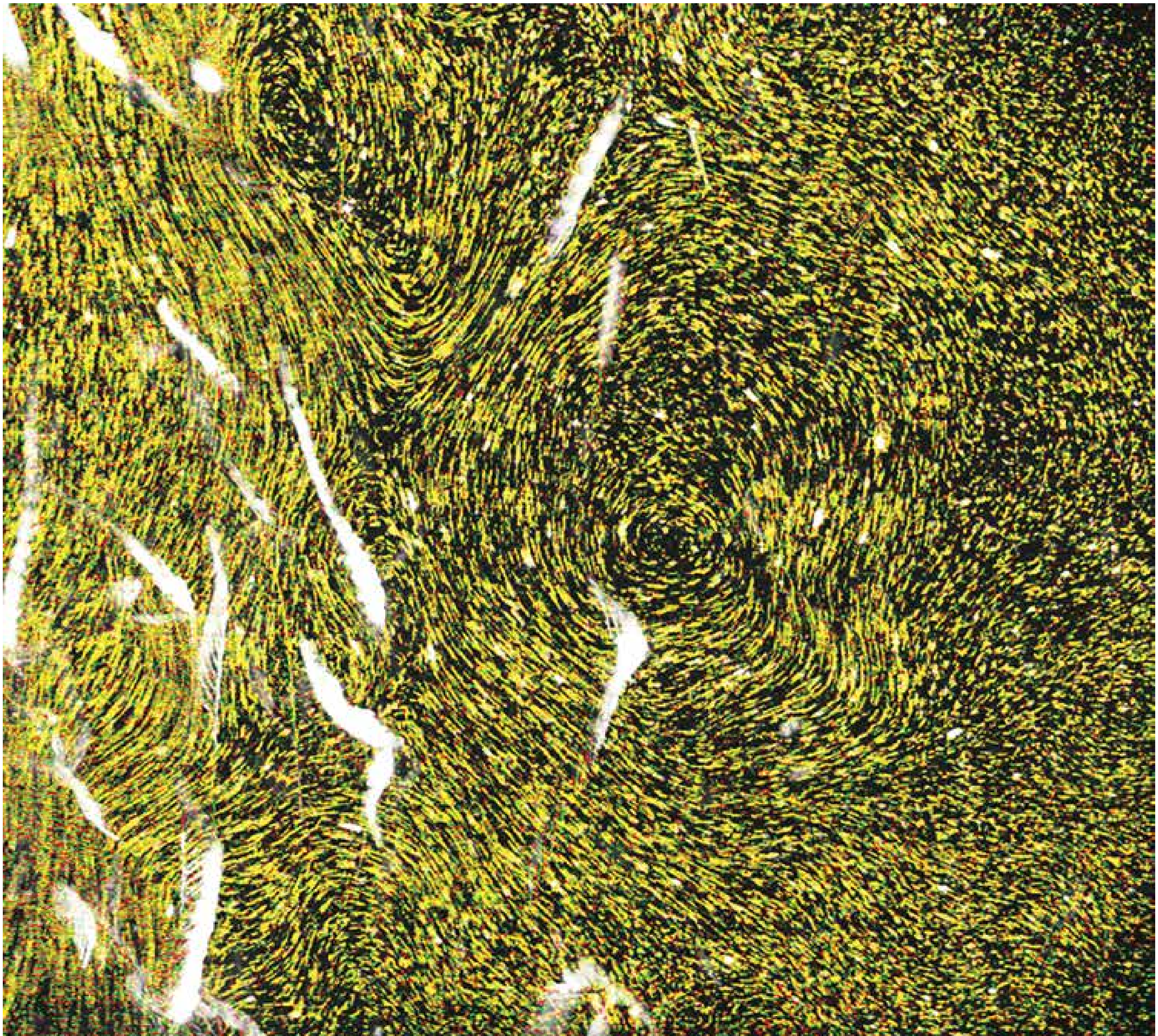
As he formally took his place as Caltech's ninth president, Thomas Rosenbaum focused on transition and the ways in which "the past envelops you as the future beckons."

President Rosenbaum's investiture—during which he was presented with Robert A. Millikan's academic hood, a Caltech tradition—was followed by his inaugural address, in which he reflected on important moments in the history of Caltech. The Institute has always played a significant role in advancing knowledge and then applying those advances to the benefit of society, Rosenbaum said—a focus that is as important today as it has ever been.

To succeed in its pursuits, the president said, Caltech will need to continue its commitment to a combination of excellence, ambition, focus, intimacy, and perspective—five elements that he deemed "difficult to achieve, and perhaps even more challenging to maintain in changing times, but taken together they yield intellectual magic."

The ceremony ended with a festive blast of ribbon confetti over the crowd (below) and was followed by an all-campus reception on the Olive Walk.

For more information on the inauguration of Thomas Rosenbaum, go to caltech.edu/content/inauguration. *And stay tuned for more coverage in the next issue of* E&S.



available now on **CALTECH.EDU**

SMALL BUT MIGHTY

A Caltech research team has discovered that the collective swimming motions of brine shrimp may be able to generate enough energy to affect the circulation of water in the ocean. Learn more at **caltech.edu/news**.

Watch

Want to learn—or remember—what it's like to be a Techer? Two Caltech students take you on a tour of our campus and its culture in a series of videos from Caltech Admissions at **youtube.com/caltech**.

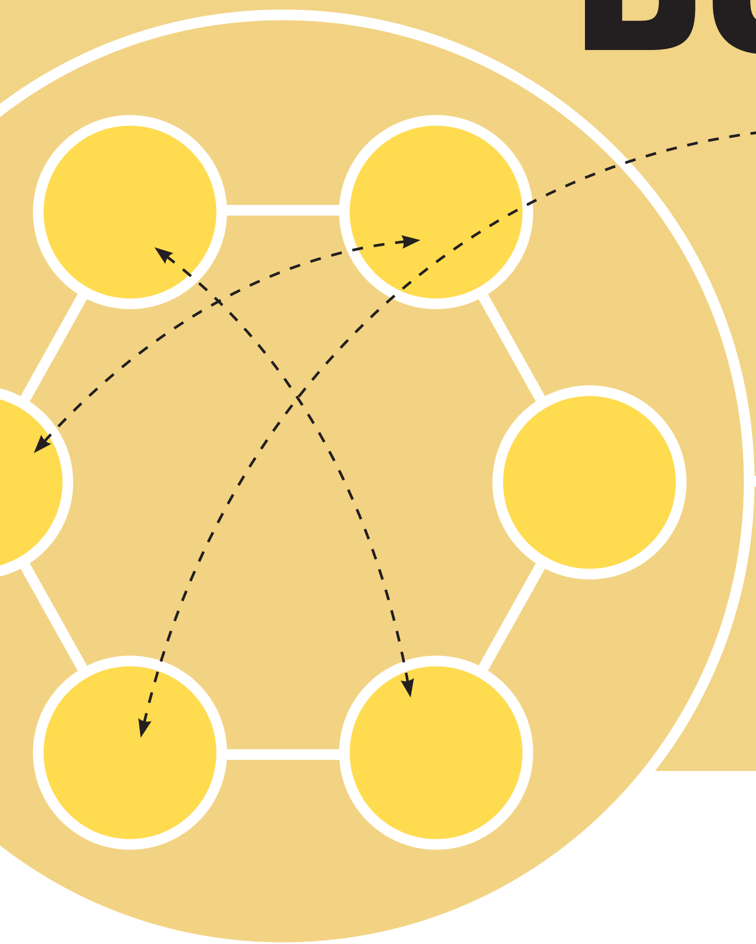
Read

Even if you're not on campus, you can patent an invention, launch a start-up, or protect your intellectual property by partnering with Caltech's Office of Technology Transfer and Corporate Partnerships. Check out its new website at **ottcp.caltech.edu**.

Engage

The acclaimed Vienna Boys' Choir comes to Beckman Auditorium for an evening of waltzes and polkas on Saturday, February 21, 2015, at 8 p.m. Find out more at **caltech.edu/calendar/public-events**.

RISKY BUSINESS



By encouraging unfettered brainstorming and the seeding of ideas that traditional funding sources might deem too bold, the Keck Institute for Space Studies at Caltech is helping space scientists and engineers get transformative concepts off the ground.

by Kimm Fesenmaier

In April 2013, NASA announced that it was in the early phases of planning a robotic mission to snag an asteroid and haul it into lunar orbit for study. At the time, NASA chief Charles Bolden said that such an asteroid redirect mission represented "an unprecedented technological feat that will lead to new scientific discoveries and technological capabilities and help protect our home planet."

To many, the plan sounded farfetched—like something from a Bruce Willis movie. But to those scientists and engineers who had been working out the feasibility of just such a plan since 2011—as part of a study funded by the Keck Institute for Space Studies (KISS) at Caltech—the idea was already old-hat and anything but Hollywood fluff.

And it was just the kind of thing that KISS is designed to do. Established in 2008 with funding for eight years from the W. M. Keck Foundation and additional support from JPL, KISS was designed to bring together diverse groups of scientists and engineers to develop revolutionary concepts and technology for future space missions—like one that would lasso an asteroid.

That's not to say that the asteroid concept seemed eminently doable when KISS first reviewed it as a proposed workshop topic in 2010. In fact, KISS director Tom Prince recalls that several members of the steering committee that reviews such proposals thought the concept was rather unlikely to lead to an actual space mission.

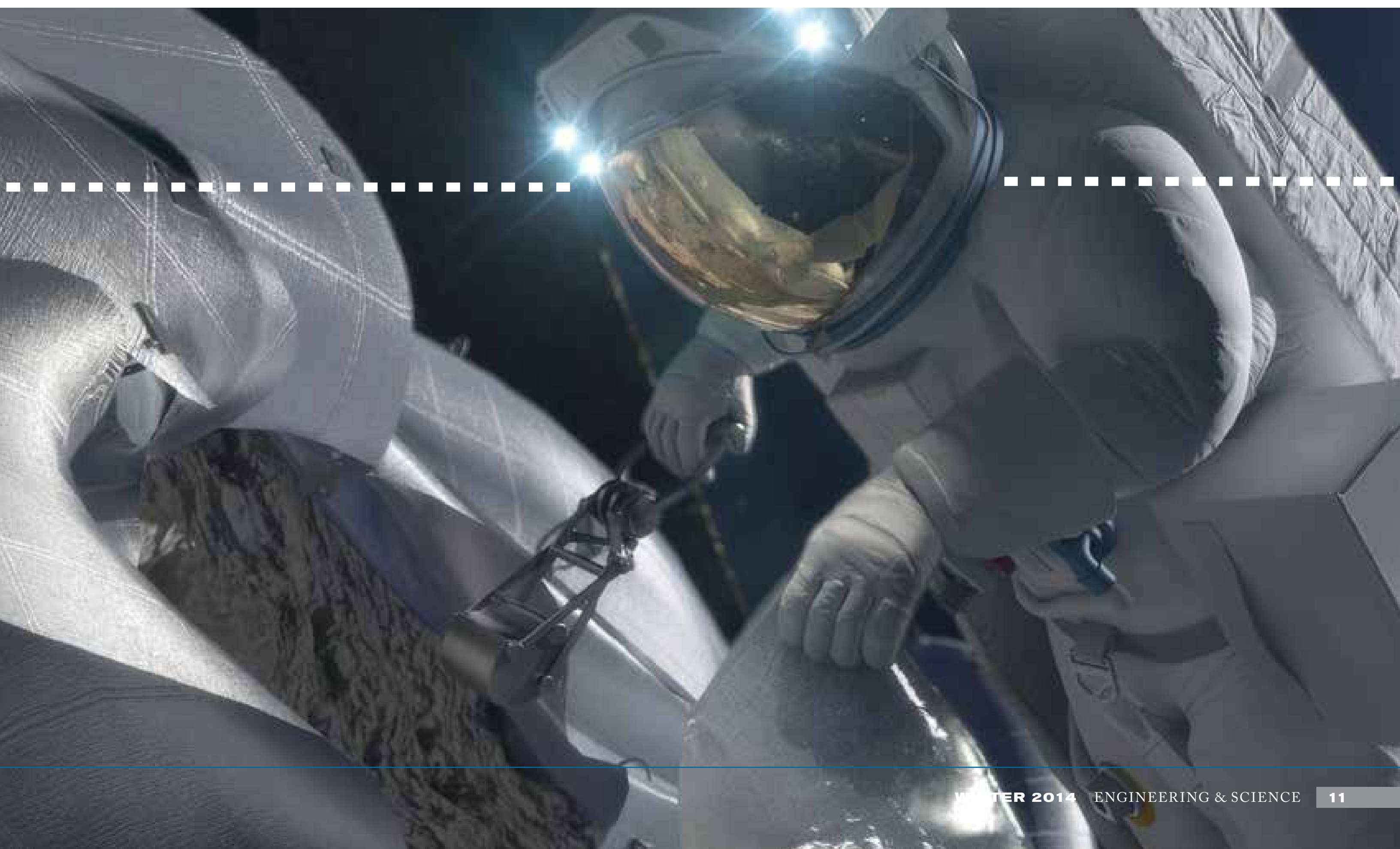
"But we're here to take on risky possibilities and see if they work out," says Prince.

"My view is that we need to be a little bit out on the edge. If every single topic that we pick works, then we aren't being bold and aggressive enough."

Since most of the steering committee agreed with that sentiment, the first KISS-sponsored workshop on asteroid retrieval took place on campus in September 2011. A second followed in February 2012. By April of that year, the participants were able to publish a report suggesting that a spacecraft using solar-electric propulsion could reach and capture a 500,000-kilogram near-Earth asteroid—essentially by putting an enormous bag around it—and then haul it into high lunar orbit. And, they added, all of this could be done by around 2025 for a total cost of about $2.6 billion.

That report caught NASA's eye. In late 2012 and early 2013, the space agency had JPL conduct an additional feasibility study in collaboration with the Glenn Research Center and supported by several other NASA centers. They found that the KISS-described mission and timeline was indeed doable, even suggesting that the mission could be accomplished for less than KISS's original estimate.

NASA's plans to capture an asteroid and put it into orbit around the moon—where it could be studied more easily by future robotic and manned missions—was a concept first discussed at a KISS workshop in 2011.



> "We're here to take on risky possibilities and see if they work out."
>
> —Tom Prince, director of the Keck Institute for Space Studies

Recently, the *New York Times* highlighted another KISS study: one that explored the possible development and use of stratospheric airships for astronomical and Earth-monitoring observations. Airships have been around for more than 200 years, but typically have been flown at altitudes of less than 10,000 feet. The KISS study brought experts together to discuss higher-flying ships, which could soar 65,000 feet above Earth, driving down the cost of space observations while making more science possible. The KISS study noted that a one- or two-meter optical telescope with excellent pointing stability on such a high-altitude airship would have superior viewing conditions night after night as compared to any optical ground-based telescope. It also suggested that airships, with their ability to be deployed quickly and to move as needed, could enable measurements of dynamic events such as wildfires, as well as observations of regions of Earth that have been difficult to study at length but that are critical to our understanding of climate change, such as the Amazon rain forest and the Arctic sea ice.

"KISS encourages work at the interface of science, exploration, and engineering, where something may not be doable, but if it is, there would be the possibility of a key new discovery or capability," says Bethany Ehlmann, a planetary scientist who participated in her first KISS workshop a few years ago and is now a member of KISS's steering committee. While many traditional funding sources require that scientists and engineers demonstrate that a project has a high likelihood of success before it gets funded, she says that KISS takes more of a risk. "KISS occupies an interesting niche, seeking to fund not the 'clearly doable' nor the 'totally crazy,' but the space somewhere in between."

A THINK AND DO TANK

It was actually a biologist, then-Caltech-president David Baltimore, who initially got KISS's ball rolling. Following the successful landings of the Mars Exploration Rovers and the Cassini orbiter's insertion into Saturn's orbit, Baltimore tasked a faculty committee with looking at ways to increase Caltech-JPL collaborations. Chemistry professor Jack Beauchamp was on that committee and first articulated what became KISS's organizing concept: bring experts together to brainstorm a particular space-related topic and to do technical thinking, then fund the initial work on any promising innovation or idea they come up with. Following such a seemingly simple protocol, the institute would serve as a "think and do tank."

"We were really looking to create something that would, in as many ways as possible, benefit collaborative interactions between Caltech and JPL," says Beauchamp. "JPL has enormous capabilities for instrument and spacecraft design, as well as testing and construction. We wanted to tie that together with the science and engineering at Caltech in a synergistic way so that we all benefited. And it seemed that following this model was the best way to do that."

Once a year, KISS solicits proposals for new workshops—in 2014, they funded seven topics ranging from detecting changing landscapes on Earth and other bodies from space to technologies that will enable scientists to explore the interstellar medium. Proposals typically come from teams of three researchers, including someone from the Caltech campus, someone from JPL, and someone from the external community. These team members go on to lead the workshop if the proposal is selected. Over the course of the year, the co-leads then schedule one or two multiple-day workshops in which experts in the field come together for intense brainstorming sessions focused on the proposed topic. That's the *think* part of the model. Following the workshop phase, participants are then given the opportunity to propose two years of technical follow-up work to pursue any great ideas that came out of the workshop brainstorming. That's the *do*.

"KISS allows us to look beyond what is being done to what is possible," says planetary scientist

Dave Stevenson. "It enables us to look at innovative approaches to planetary science—especially those things that we're not going to be able to do immediately or even may not be able to do at all. It goes beyond the current mission set."

In 2010, Stevenson led a workshop in which the group fleshed out novel ideas for using a seismometer to study the interior of a planet like Venus or Mars. At the time, there was no immediate need for the work. But now NASA has selected a mission for its next Mars lander, called InSight, which is to be launched in 2016 and will use some of the seismology techniques that were initially discussed at the workshop. The mission's principal investigator, Bruce Banerdt of JPL, attended the KISS workshop and says he believes it helped pave the way for the mission's selection. "The workshop…helped a lot in my approach to writing the science section of the proposal," Banerdt explains. "I also believe, without any direct evidence, that the higher profile for planetary seismology that came from the activities that were initiated through the contacts and discussions at the workshop helped us in the evaluation."

To try to enhance opportunities for close interaction, KISS asks that no more than 24 researchers and an additional six students or postdocs attend each workshop. They also ask leaders to allot at least half of a workshop's time for unstructured conversation.

To help get that conversation flowing, a robotic helium-filled shark sometimes "swims" around the large meeting room known as the Think Tank, where KISS now holds its workshops; it's a great ice-breaker. And during one recent workshop, a well-known senior scientist volunteered to serve as the target of a Koosh ball attack by other attendees, as a way to remove any existing barriers between junior and senior researchers.

"Workshops should be all about interaction," says Prince. "In our workshops, talks are only a vehicle for getting people to interact, which is very different from what you see at most conferences. The people who speak are discussion leaders, not lecturers. There needs to be a free flow of information."

The approach seems to be paying off. Astronomer Tony Readhead co-led KISS's very first workshop—one focused on designing and building new array receivers for cosmology and astrophysics—because he was interested in the science the devices might enable. But during one of the workshop's breakout sessions, he got to talking with other attendees, and it became clear that Caltech needed a lab to develop these receivers. Even though he had never been a device instrumentalist, Readhead eventually took on the task of running such a lab, which is now known as the Cahill Radio Astronomy Lab (CRAL).

Until the advent of these new receivers, called monolithic microwave integrated circuits (MMICs), nearly all radio telescopes were single-pixel devices, meaning they had just one beam on the sky at any one time. The new, highly integrated circuits make it possible for telescopes to employ arrays of detectors. "They're doing for radio astronomy what CCDs did for optical astronomy 30 or 40 years ago, allowing us to use multiple detectors to go after very, very faint signals," says Readhead. He and his colleagues have already produced a 90-pixel array for the QU Imaging ExperimenT (QUIET) in Chile, are building a 16-pixel array for the Greenbank Telescope in West Virginia, and have provided MMICs to other observatories around the world, including the National Radio Astronomy Observatory. The devices have already improved the sensitivity of ground-based measurements of the cosmic microwave background, and Readhead expects them to be real game changers in studies of star formation. "I'm quite sure that a decade from now, most radio telescopes will have arrays of receivers," says Readhead. "And that was completely enabled by the work that KISS supported."

Planetary scientist Bethany Ehlmann (bottom of previous page) participates in a workshop discussion. John Brophy (above), a principal engineer at JPL, is "Kooshed" by participants at a KISS workshop on an asteroid redirect mission.

In 2009, when KISS provided technical development funding to start the CRAL, researchers in the field had been trying without success for about seven years to secure funding from federal agencies to develop MMICs. Add to that the fact that KISS started up right after the economic downturn and, Readhead says, “there is no way that we would be getting these devices out there now without KISS. This revolution that’s coming in radio astronomy is probably arriving a decade or so earlier than it would have because of KISS’s foresight.”

SEEDING ADVANCES

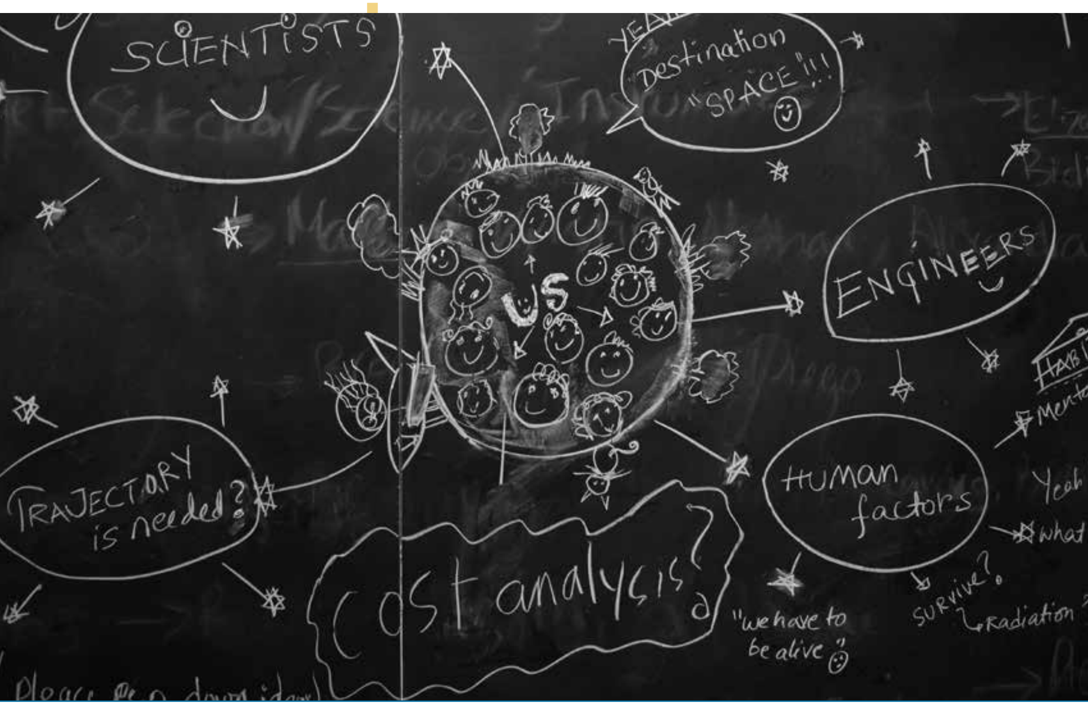
Geochemist Ken Farley’s participation in a KISS workshop led not only to new research ideas but also to a major shift in personal focus. When Farley signed up to attend a workshop about methods for studying Martian stratigraphy, or rock layers, he had never given much thought to space studies. His work had largely focused on determining the histories of rock masses on Earth. But he was intrigued by a KISS write-up about the problem of doing geochronology—rock dating—on other planetary bodies. At the workshop, he interacted with a number of people from JPL who had expertise in developing mass spectrometers, the analytical instruments used to do many geochronology experiments on Earth.

“I could imagine that some of the things that I was doing in my lab could be applied to dating elsewhere,” Farley says. “As the workshop proceeded, it seemed like we might be able to do something special that would help solve this problem of dating on other bodies.”

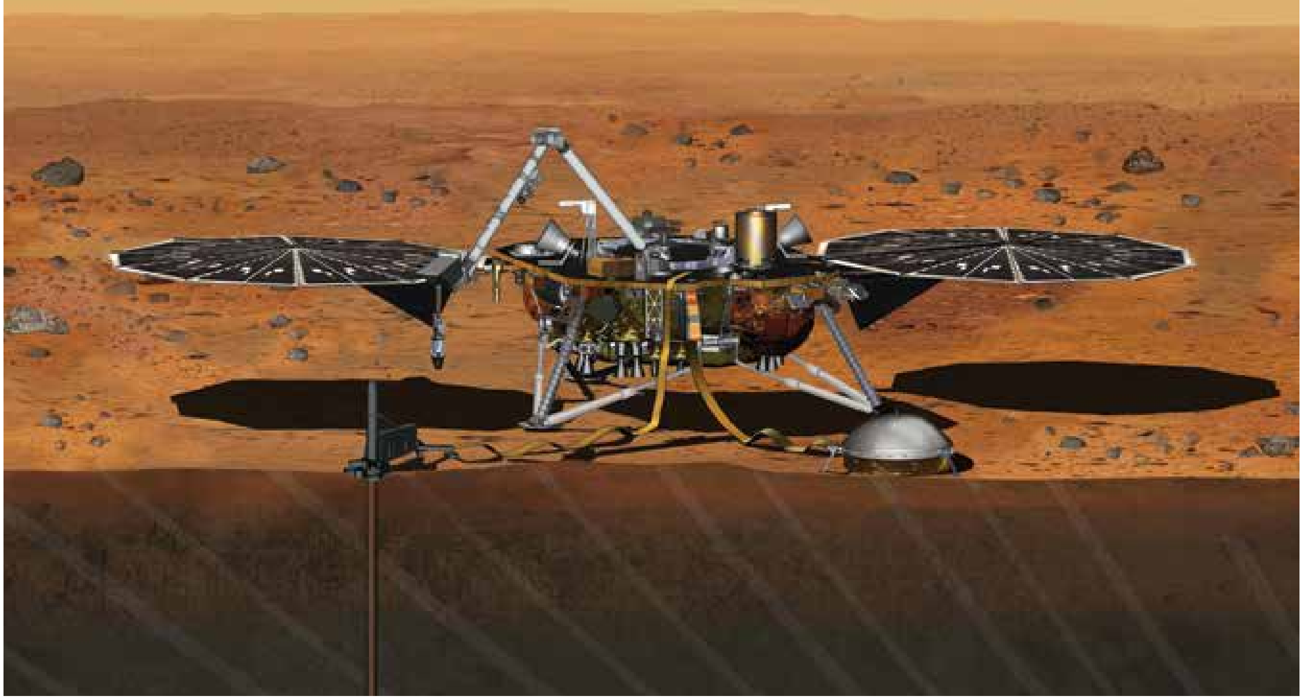
Following the workshop, Farley and his colleagues applied for and received funding for the technical development of their idea to design a new way to measure the age of rocks and soil samples on Mars.

It’s this “do” part that truly sets KISS apart, says Farley. “I don’t think there’s anything that you could even compare it to,” he says. “There are lots of venues where you can go and talk about things, but then what? Nothing. Maybe you can submit a proposal. But there’s nothing more frustrating than having a great idea and realizing that it’s going to take a year to get the money to even start. Here, it was pretty clear that a solid proposal would be funded quickly.”

As the geochronology group started working on its dating technique for martian rocks, NASA put out a call for scientists interested in participating in the Mars Science Laboratory (MSL) mission. Realizing that the mass spectrometer onboard MSL might be able to do some of the dating work he and his colleagues had been thinking about, Farley submitted a proposal and became part of MSL’s science team. He and his colleagues used Curiosity’s Sample Analysis at Mars (SAM) instrument to make the



Brainstorming notes (left) from one of two teams that participated in the first KISS Caltech Space Challenge in 2011. Thirty-two students from around the world, including Nathan Parrish and Kristin Nichols (both seen in photo above), competed in the week-long challenge. NASA’s InSight Mars lander (top opposite) will employ techniques discussed at a KISS workshop on planetary seismology in 2010.



first measurement of the age of a rock on Mars, and Farley is now serving as the project scientist for Curiosity's successor—another robotic rover called Mars 2020.

"None of that would have happened if I hadn't participated in that first workshop," Farley says. "There's no way I would have been doing science with a rover on Mars—it was totally outside of anything I had been doing." Farley is just one of many researchers whose own work has been influenced by KISS's work. So far, more than 70 Caltech faculty members have participated in KISS studies. The think and do tank has also attracted nine postdoctoral fellows, and KISS has worked to engage the broader public through open lectures, as well as Caltech students through a variety of student-led projects meant to give both undergrads and graduate students the chance to pursue their own risky space-related ideas. To date, they've funded five such projects.

Prince says the idea for such projects began when he was walking down the Olive Walk on campus, saw the student houses on either side, and thought, "We have all of this machinery to do workshops and brainstorming. Why don't we hand it over to the students and see what they do with it?"

Notable among those student projects was the KISS Caltech Space Challenge—a project dreamed up by graduate student Prakhar Mehrotra (who received his engineer's degree in aeronautics in 2013). In 2011, 32 scholars from around the world came together for a weeklong workshop and competition on campus to design the best space mission to a near-Earth asteroid. Two years later, a new group of undergraduate and graduate students gathered to plan a mission to one of the moons of Mars. Participants attended lectures throughout the week and had mentors from JPL and elsewhere on hand to help them as they considered the myriad details of their potential missions. The Space Challenge was an overwhelming success, Prince says, and brought together leaders from academia and industry while providing the next generation of mission designers with invaluable experience and access to expertise.

Prince says at every step he has been pleasantly surprised by KISS's success.

"Little did I think that—with the asteroid redirect mission, if that goes, and the 2016 Mars lander—we'd have an impact as great and as quickly as we have," he says. "It just shows how powerful it can be to get two dozen people from different backgrounds together to think about new ways of approaching a given subject. If you do that well and get those people really working together, it can supercharge everybody's research." E&S

Jack Beauchamp is the Mary and Charles Ferkel Professor of Chemistry and sits on the KISS steering committee.

Bethany Ehlmann is an assistant professor of planetary science at Caltech and a research scientist at JPL. She is also a member of the KISS steering committee.

Ken Farley is the W. M. Keck Foundation Professor of Geochemistry and former chair of the Division of Geological and Planetary Sciences.

Thomas Prince is director of the W. M. Keck Institute for Space Studies. He is a professor of physics and the deputy executive officer for astronomy at Caltech. He is also a senior research scientist and the former chief scientist at JPL.

Tony Readhead is the Robinson Professor of Astronomy at Caltech, a senior research scientist at JPL, and director of the Owens Valley Radio Observatory.

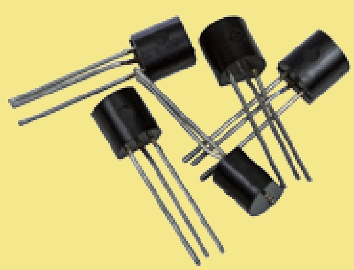
Dave Stevenson is the Marvin L. Goldberger Professor of Planetary Science.

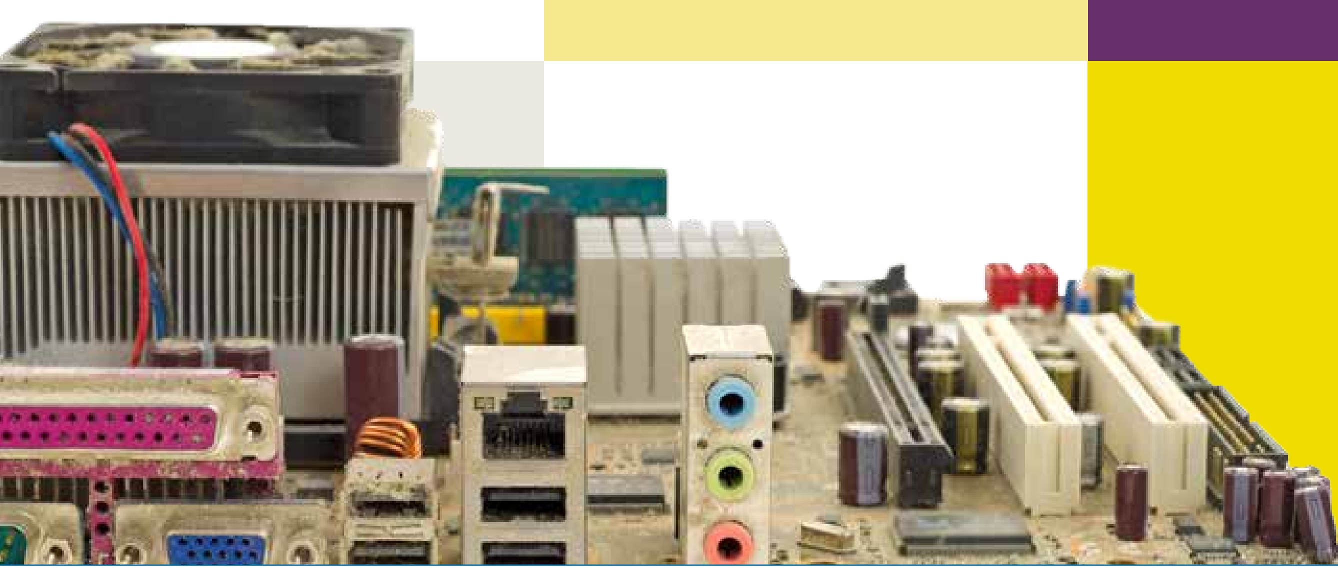
The Keck Institute for Space Studies was established with a $24 million grant over eight years from the W. M. Keck Foundation. It is a collaborative venture with JPL, which supports its participation in KISS programs with significant funding from its Research and Technology Development program.

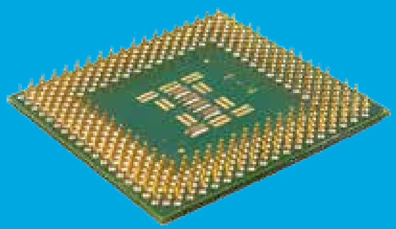
BUILDING BLOCKS

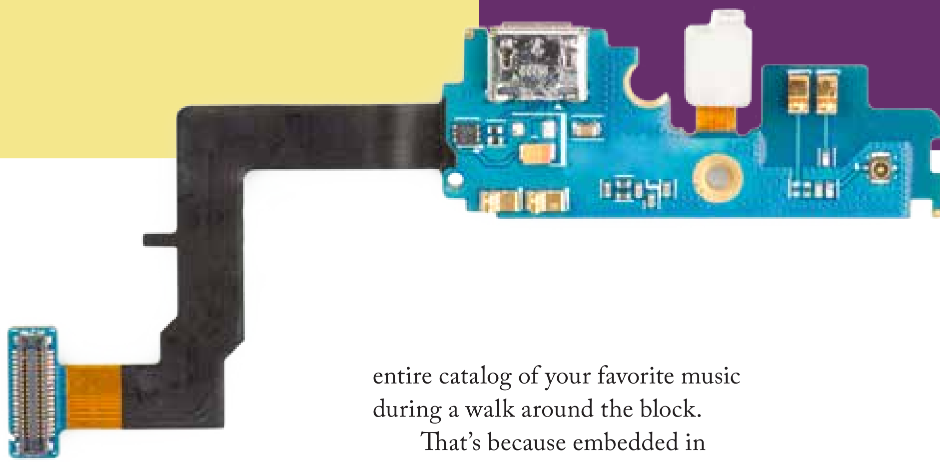
How Caltech breakthroughs in technology have led to advanced communications for the world's use.

by Cynthia Eller & Katie Neith









In today's world, cell phones—and, in particular, their multifaceted brethren, smartphones—are nearly ubiquitous. In no small part, these palm-sized computers have revolutionized the way we communicate, learn, and live in the 21st century, replacing not only our landlines but our alarm clocks, books, cameras, calendars, and more. And that pocket full of powerful technology that most folks can't leave home without—and may even be reading this magazine on—is chock full of Caltech innovations.

"Caltech has always played a role in cutting-edge technologies that are game-changers," says Vice Provost for Research Morteza Gharib (PhD '83), who has served on the Institute's faculty since 1993. "The work that's been done here has taken those room-sized original computers and turned them into an iPhone."

PIONEERING THE BASICS

The smartphone is a marvel of miniaturized engineering. And at its most fundamental level lives the integrated circuit—or chip—which acts as a central hub that connects with and feeds power to all the other components in the phone.

Behind that chip, says Gharib, is Caltech alum Gordon Moore (PhD '54). "Gordon Moore is responsible—more than any other single individual—for putting a silicon chip in every personal computer worldwide," Gharib says.

It began when Moore cofounded Intel in 1968, where he led the development of the chips that began powering microcomputers in the early 1970s. This set of electronic circuits on a tiny piece of silicon is still the central technology that enables you to download and save a book for a subway ride or pull up an entire catalog of your favorite music during a walk around the block.

That's because embedded in the circuits of each chip are a bunch of transistors, coinvented by another Caltech alum, William Shockley (BS '32), who went on to win the 1956 Nobel Prize in Physics with his co-creators for their innovation. These devices are used to manipulate electronic signals and are essential to modern electronics. They provide the power a smartphone needs to perform the calculations that enable a quick check of the weekend weather forecast or the ability to find the best route home during rush hour.

Transistor technology grew by leaps and bounds in the post-WWII era so that, as predicted by Moore in his eponymous law, the number of transistors in an integrated circuit have indeed doubled approximately every two years over the past four decades.

It was Caltech's Carver Mead (BS '56, MS '57, PhD '60)—now the Gordon and Betty Moore Professor of Engineering and Applied Science, Emeritus—who kept Moore's law on track during those boom days by pioneering what is called the very-large-scale integration (VLSI) design methodology in the 1980s. Mead's set of tools and standards enabled scientists to place at first thousands and, today, literally billions of transistors on a single chip. He also shared those tools with the world, coauthoring a VLSI textbook and thus helping to build an industry where others could learn the technique quickly and design even more powerful chips.

"Suppose I had the magical power to go back and remove Carver Mead's work on VLSI from history," says Gharib. "This smartphone in my hand would not be here."

CAPTURING A MOMENT

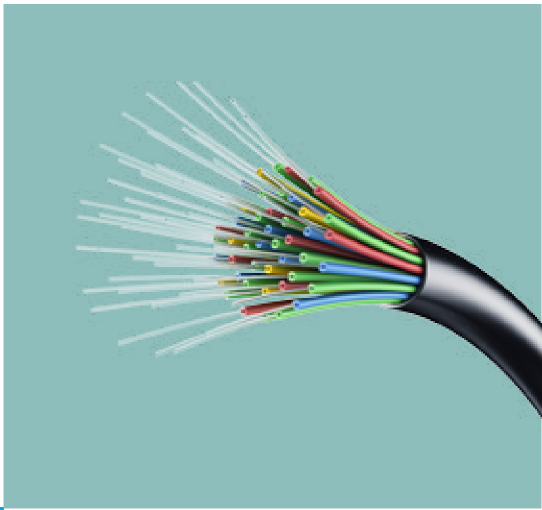
When JPL's engineers first developed its so-called camera-on-a-chip technology, they were clearly not aiming at a proliferation of "selfies" posted to Instagram and Facebook. Instead, the Lab's Center for Space Microelectronic Technology was charged with miniaturizing the camera systems located onboard interplanetary spacecraft.

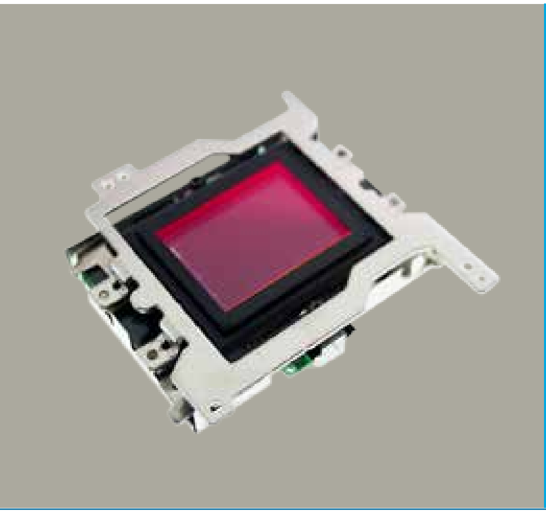
Originally, the plan was to take existing digital camera technology and find ways to make it smaller. But Eric Fossum, JPL physicist and engineer, had a better idea: he invented the active pixel sensor (APS), the camera-on-a-chip technology that could be integrated onto a complementary metal oxide semiconductor (CMOS) chip along with the other circuits required by a cell phone.

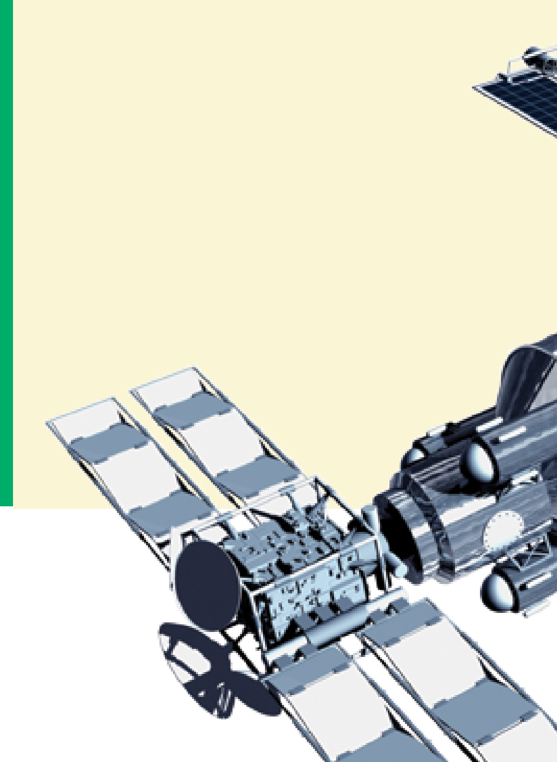
Not only are Fossum's cameras smaller, but they're higher quality, use less power—the CMOS APS uses one-hundredth the power that previous digital camera technology required—and are cheaper than those that came before. Today Fossum and JPL's CMOS APS technology is found in everything from high-end cameras and webcams to automotive safety systems and video games.

"But it's not just a good camera," says Gharib. "It's a culture-changing technology. If you look at many events in recent years from around the world—for example in the Middle East during the Arab Spring—it has been crucial that some ordinary person who was there had a smartphone and took pictures. Easy access to cameras in phones has made societies more open. Everybody is now a journalist."

In the early 2000s, Ali Hajimiri, the Thomas G. Myers Professor of Electrical Engineering, used inexpensive CMOS technology to develop a low-cost power amplifier that improves voice quality and increases the amount of talk time a user can get from a single battery charge. This amplifier has made possible the creation of single-chip cell phones and has cut the cost, size, and weight of the circuitry in all cell phones. Hajimiri and his research team have also combined CMOS chips with silicon chips to create an imaging system capable of seeing through objects—a system that can be used in both security programs and medical diagnostics. And they recently reported on their invention of a self-healing chip that can repair itself inside your smartphone, therby combating extreme environmental conditions, aging, and damage.







MAKING CONNECTIONS

While the functionality of smartphones alone is impressive, speed is really the key when it comes to meeting consumer demands. For the on-the-fly information your phone provides in mere seconds or less, thanks should go to Amnon Yariv, Caltech's Martin and Eileen Summerfield Professor of Applied Physics and professor of electrical engineering. Yariv's distributed feedback (DFB) semiconductor lasers, developed in the 1970s, are still being used today to convert electrical data signals into optical lightwave signals. This allows the signals to travel swiftly through fiber-optic cables, greatly accelerating cable and high-speed Internet transmission.

In the mid-2000s, Caltech computer scientist and electrical engineer Steven Low and John Doyle, the Jean-Lou Chameau Professor of Control and Dynamical Systems, Electrical Engineering, and Bioengineering, created a method—an algorithm called FastTCP—to speed up data transmission over the Internet even more by measuring and controlling its traffic. Computers employing the algorithm can make smarter decisions based on the data they gather, managing and unsnarling congestion so that packets of information can be sent across the network at unprecedented speeds.

As Gharib points out, such high-speed Internet communications are no longer a marvel confined to wealthier countries. With the help of sophisticated components that use Caltech innovations like Yariv's DFB, developing countries can leapfrog over earlier technologies and move directly into the 21st century.

"In Nigeria, for example, they have decided not to put in telephone lines, since most people there now have cell phones," he says. "Their country has saved billions of dollars that they would have had to put into infrastructure; they've bypassed it entirely."

TRAVEL PLANNING

Those of us who rely on the accuracy of global positioning systems, also known as GPS—the travelers, runners, and geocachers among us, for instance—are taking advantage of the work of JPL engineer Yoaz Bar-Sever, who heads NASA's Global Differential GPS System at JPL, where a team of nearly 60 researchers work on advanced GPS applications. Among their innovations is a technique that processes cell phone data to enhance the accuracy of GPS in handheld devices.

David Rutledge, Caltech's Kiyo and Eiko Tomiyasu Professor of Engineering, is one of the researchers who have made it possible for those of us out at sea or flying cross-country to connect with friends via email or surf the Web. In 2000, Rutledge and his graduate students developed an improved transmission system for ground-to-satellite communications, an effort since commercialized through his start-up company, Wavestream. The high-power solid-state amplifiers he created provide a reliable means for bringing communication technologies to remote areas.

In fact, they have already been licensed to Southwest Airlines and deployed by the United States Army for operations in Iraq and Afghanistan. And they even provide satellite news coverage to those traveling the peaks of the Himalayas and other far-flung locations.

"Advances like these," Gharib says, "have made information available to an extent that, in the history of mankind, is unprecedented." e&s

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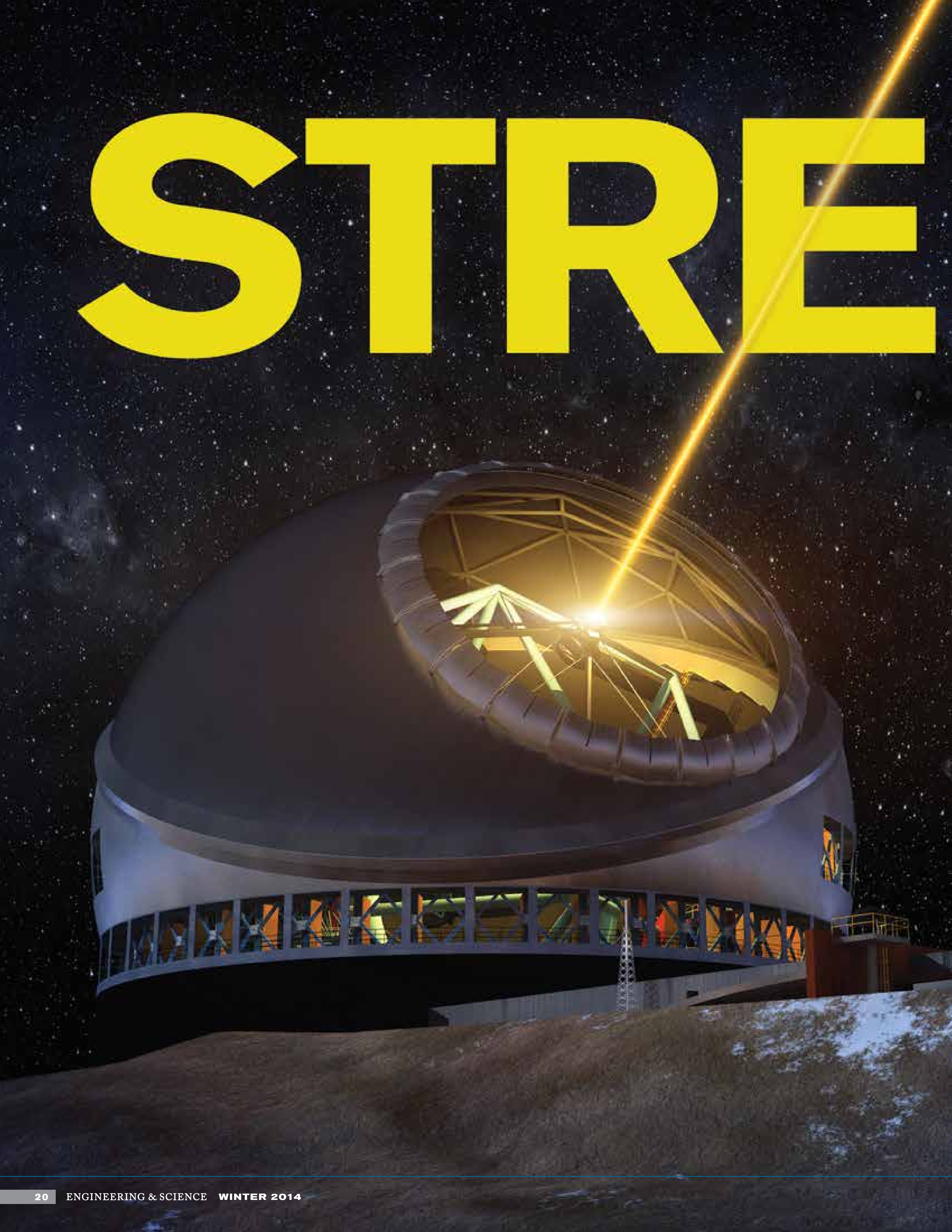


NGTH IN NUMBERS

by Katie Neith

Caltech builds on past successes to help create the world's most powerful telescope.

Since its inception, Caltech has been dedicated to undertaking big, risky projects, particularly in the area of exploring our universe. Astronomer George Ellery Hale, one of the men credited with molding the Institute into a world-class science and engineering college, was the primary creative force behind the famed Palomar Observatory. Now, nearly 70 years after the groundbreaking 200-inch Hale Telescope—then the world's largest—saw first light on that Southern California mountaintop, Caltech, along with the University of California and a group of international partners, is again leading the way toward the construction of what will be the world's most advanced ground-based telescope, the Thirty Meter Telescope, or TMT.

"Thinking big and taking on the world's largest astronomical telescopes is something we've been doing since the 1920s—it's in our blood, in some sense," says astronomer Shri Kulkarni, director of Caltech Optical Observatories.

Like those observatories that have come before, he says, TMT is an ambitious project of incredible scope, a project that both has been and will be years and years in the making. Alone, the still-ongoing process of planning and developing TMT has taken over a decade. It's estimated that constructing the telescope, building its instruments, and getting all of its mechanical systems online will take another eight years. The site where TMT will be built was blessed in the traditional Hawaiian manner October 7, and first light is currently planned for the early 2020s.

So why has Caltech taken on a leadership role in such a time-intensive challenge? The answer, like the project, is complex.

TMT is not being developed from scratch, but, at least figuratively, will be built on the shoulders of giants—the two 10-meter telescopes at the W. M. Keck Observatory (WMKO). The Keck telescopes were also a project in which Caltech played a large role, and the achievements seen there have shaped plans for TMT.

"The 200-inch telescope at Palomar was a huge success, and the Keck telescopes were just as great an accomplishment. TMT is the next step," says Kulkarni.

"There are no serious technical challenges with TMT; they were all solved in the building of Keck," adds astronomer Judith Cohen, who worked extensively on the WMKO and is a member of the TMT science advisory committee.

The twin Keck telescopes currently stand as the world's largest optical and infrared telescopes. Perched proudly on the summit of Mauna Kea in Hawaii—the same site that in 2013 was officially approved to become TMT's home—the Keck Observatory was the first to piece together segments of reflective glass to form one giant primary mirror. While the two Keck telescopes have 36 hexagonal pieces for each of their mirrors, TMT will use 492.

"The sensitivity gains of TMT over Keck will range from about a factor of 10 to a factor of 100, depending on what you are trying to do," says astronomer Chuck Steidel, who has been part of the TMT project since its inception. "As we found with Keck, such gains in sensitivity result in all kinds of new scientific discoveries that are not written down in your initial research goals."

One of the really striking things that astronomers have found with Keck, Steidel notes, is that the scientific justifications astronomers gave in the original proposal for the observatory, to convince funders to support the project, now sound so mundane compared to what those telescopes actually revealed—everything from the information that helped demote Pluto from the status of planet, to conclusive proof that the center of our galaxy harbors a supermassive black hole to the discovery and characterization of the most distant galaxies, going back to when the universe was only 10 percent of its current age.

And once these powerful instruments start gathering the kinds of data you couldn't have dreamed up, Steidel says, anything is possible.

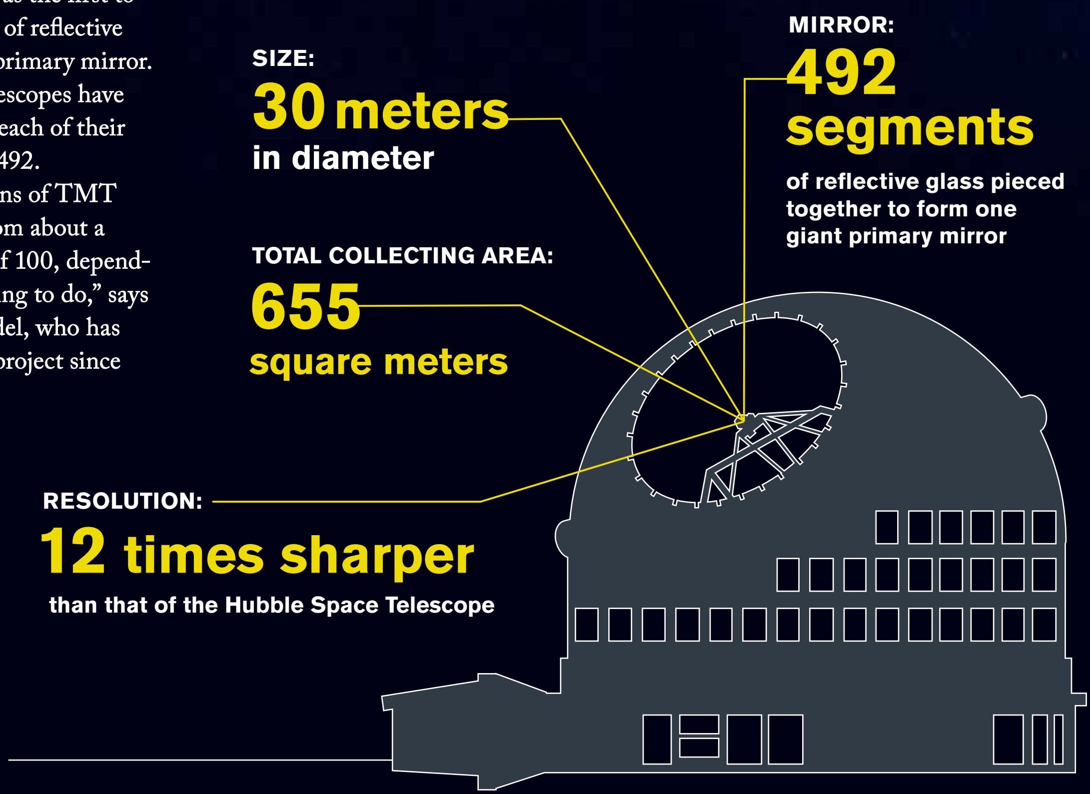
"You start experimenting, trying out observations that would have been impossible using previous equipment, and all of a sudden you have a huge number of new discoveries," he notes. "I expect that's going to happen with TMT."

A Closer Look

Almost since the WMKO telescopes saw their first light, TMT has been the dream child of astronomers imagining what they might do next.

"Very early on, we decided to get involved with the University of California [UC] system—our partners in Keck—in developing a concept for an even larger telescope," says astrophysicist Tom Soifer, a TMT board member since 2010 who is currently chair of the Division of Physics, Mathematics and Astronomy at Caltech.

Back then, that concept went by the name of CELT, or the California Extremely Large Telescope. Caltech and the UC participated in a technical and scientific study—asking what it's possible to do with a telescope of that size and considering what its most important areas of study should be—that served as the foundational argument for pursuing TMT.



"A number of the Caltech astronomy faculty were engaged in those questions and concluded that taking on this project was, indeed, an immensely exciting opportunity," says Soifer. "The only issue was money, so that was really what drove the project."

TMT was made possible thanks to the vision of the Gordon and Betty Moore Foundation, which provided funding for the development of the design of TMT beginning in 2004, followed by grants for early construction, with the foundation's support totaling $140 million to date.

"Nothing would have happened if it wasn't for Gordon Moore and the Moore Foundation," Steidel says.

"The Moores came in at the beginning when it was a very risky move," adds Cohen. "I'm sure they were well aware that this whole thing could have foundered, and they've been very patient in keeping faith that it will all happen."

Caltech alumnus and astronomer Jerry Nelson (BS '65), principal designer and project scientist for the Keck telescopes and winner of the Kavli Prize in Astrophysics for his work with giant telescopes, has helped secure further funding by pointing out that TMT isn't going to be quite the financial risk it would otherwise be.

"Jerry gave this provocative colloquium in 2000 where he claimed that we had broken the cost curve with Keck. In other words, we built a bigger telescope without its price increasing too fast compared to previously existing telescopes—meaning that it was a good value relative to the scientific benefit—and that to try for something bigger would really just be a scaling up of proven technologies," remembers Cohen.

Further bolstering the astronomer's case for another giant telescope was the National Academy of Sciences' 2001 decadal survey, which listed the construction of a 30-meter segmented-mirror telescope as its top recommendation for the advancing of ground-based astronomy and astrophysics.

In 2003, a scientific advisory committee—made up of representatives from partner institutions and the broader astronomy community—met for the newly named TMT, and Nelson was named project scientist. The aim of this committee was to "help match the technical goals of TMT with the demands of the scientific community for a next-generation observatory," according to Steidel. In other words, if you're going to build a really big telescope, you need to make sure it's going to help you answer your most interesting and difficult questions.

"TMT will be able to significantly further our search for early galaxies."

Caltech's scientists believe TMT will be able to do just that. After all, Steidel says, with big scopes comes exponentially bigger science. A telescope's ability to gather light and see faint, faraway objects increases with the area of the primary mirror, and the telescope's ability to resolve details increases with the mirror's diameter.

Uncharted Territory

A 30-meter mirror, then, should be able to tackle fundamental and currently unanswered questions regarding cosmological issues, including the birth of stars and galaxies, the composition and expansion of the universe, and the characteristics of exoplanets.

Right now, astronomers are tantalizingly close to seeing the formation of the first galaxies, but TMT will provide the sensitivity to reach that goal. This is because the sheer size of the TMT primary mirror's collecting area will allow researchers to see objects that are, at a minimum, 10 times fainter than those currently observable via the Keck telescopes, according to Cohen. Maximum gains may be closer to a factor of 100.

"But even 10 is pretty good!" she says. "That will get us back toward the earliest galaxies and give us the ability to study them in much more detail than we can now."

Where Cohen really sees TMT shining, however, is in adaptive optics, or AO. This technology works to correct distortions, such as blurriness, that can happen when light from an astronomical object travels through Earth's atmosphere. It's what you see happening when a star appears to flicker in the night; AO takes out the twinkle. "Imaging of exoplanets—those outside our solar system—should be absolutely fabulous with a 30-meter telescope," she says.

Soifer looks to TMT for help in answering what he thinks is the ultimate question: "Is there life on other planets like there is on Earth?" Runners-up, he says, include fundamental questions of physics like "What is dark energy?"—the hypothetical form of energy responsible for the accelerating expansion of the universe—and "What is dark matter?"—referring to mass that appears to be missing from the universe.

"TMT will also address the key question of when galaxies first formed," adds Richard Ellis, who served on the TMT board during the formative years of the project. "We have used our current facilities, like Hubble and Keck, to their limits in this important quest and are close, we believe, to finding the first generation of stellar systems when the universe was barely a few percent of its current age. With the combination of its large aperture and exquisite angular resolution, TMT will be able to significantly further our search for early galaxies."

Kulkarni, for his part, hopes to use TMT to look at gamma-ray bursts, which are massive, brilliant explosions of electromagnetic radiation that have been observed in distant galaxies. When a gamma-ray burst begins, he says, he will be able to scan the skies near the burst with TMT to get an infrared spectrum and will be observing the young universe when it was barely 100 million years old.

"With TMT one could even imagine taking pictures of other solar systems 30 light-years away," says Kulkarni. "This may be within reach for us—just imagine!"

He says the things TMT is expected to do will be possible simply because no one is trying to reinvent the wheel with this telescope.

"Who knows what we're going to find when things can be dissected at that level," he says. "What we call the 'discovery space'—or things we will be able to see with TMT—becomes huge."

Scope of Impact

The TMT project is not just huge in size and potential astronomical power but also in the breadth of its collaboration. In addition to Caltech and UC, the TMT collaboration now includes national institutes of Japan, China, and India, along with the Associated Canadian Universities for Research in Astronomy.

"Caltech, as an educational and research institute, will be able to draw upon the top experts in the world, and that will only enrich the project."

"We are taking all the technologies and lessons learned from Keck, Palomar, and other projects so that the instruments we are designing for TMT receive the benefit of all previous generations of instruments," says Kulkarni. "We're not spending millions of dollars on something that may or may not work. We know it works—the Keck telescopes work every night—so we're really benefiting from our past experience."

In fact, the goal of TMT is to achieve the best resolution of the telescope—something that typically takes months on a new telescope—from day one, says Steidel. For his own research, he is looking forward to using TMT to better explore how galaxies formed in the young universe and how they have evolved to the present day. TMT will allow astronomers to both map out the distribution of galaxies and the tenuous gas between them, as well as to "dissect," using extremely high spatial resolution, what is going on within individual galaxies.

"This project is unique in that it is a multinational, public/private project," says Soifer. "I don't know of any collaboration, in any field of science, that is anywhere near as large as TMT and that has governments, a state university, and a private university attached. We really are breaking totally new ground in that sense."

Kulkarni, who played a large outreach role in promoting TMT in his native India to convince that nation to join the project, says that because of the cultural differences between the various members of this partnership, the collaborative process has been a lot more work than most people had expected. Nonetheless, he thinks it is worth it.

"All the leadership has been taken by the private sector, that is, private philanthropy has funded and seeded this project, but the bulk of the money for construction and operation will come from international governments," Kulkarni explains. "In a way, that can be an ideal thing—private funding can usually move things quickly and then government is very good at maintaining support.

"I think some partners are a bit surprised that this small institute in Southern California can be a legitimate partner," he notes, "but we've proven ourselves with our history, our track record. As leaders of a global project, we've become plugged into the best of the best scientists in each of these countries. Caltech, as an educational and research institute, will be able to draw upon the top experts in the world, and that will only enrich the project."

Steidel agrees, adding that he sees TMT as a way to help expand the field of astronomy around the globe.

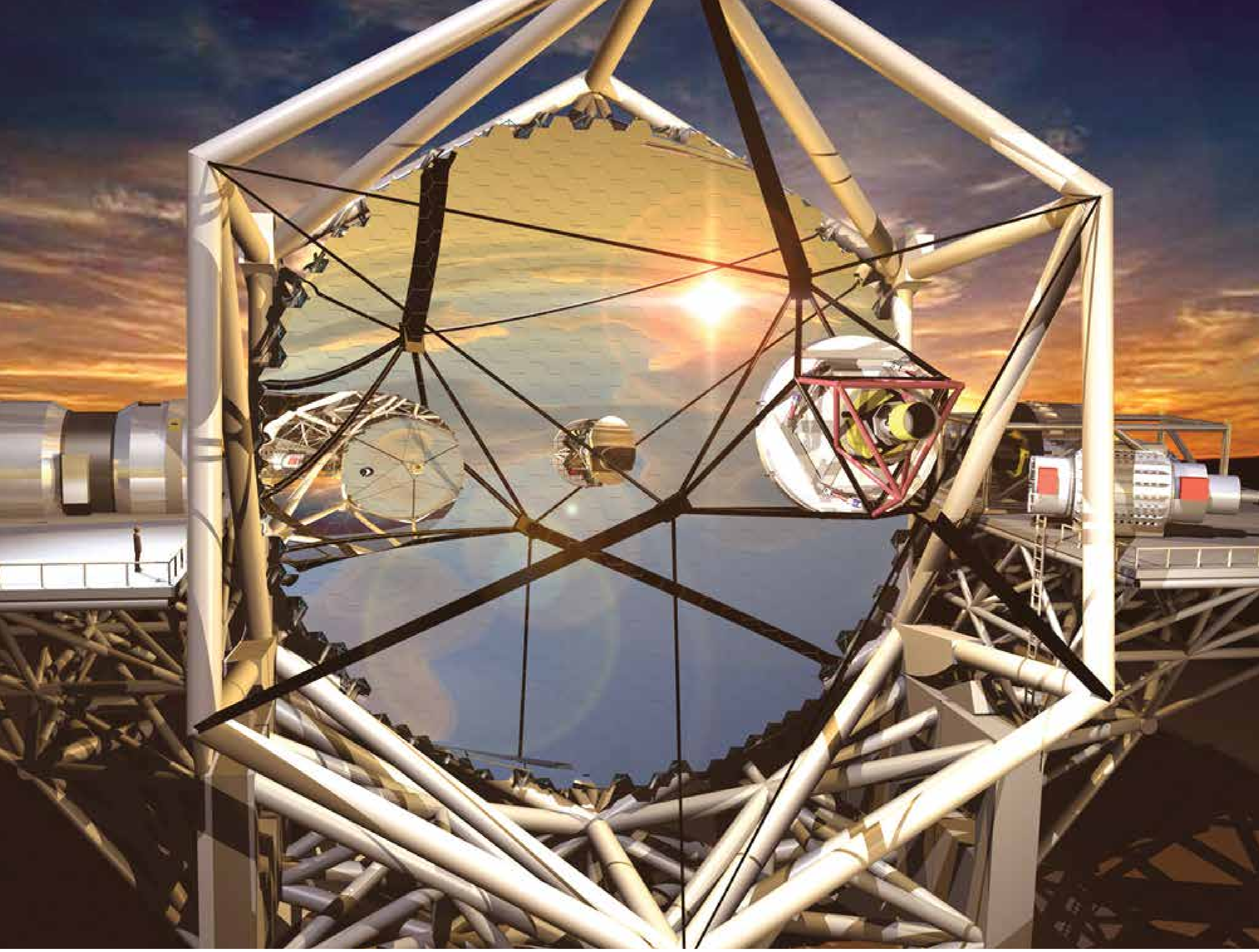
"It will be exciting to develop new ties and collaborations with scientific communities that we haven't worked with before," he says. "The potential for these collaborations is huge."

The project team has also worked with the people of Hawaii to earn the trust needed for permission to build TMT on Mauna Kea.

That's especially important because Mauna Kea is the best site for TMT. In fact, it's the premiere site in the Northern Hemisphere for any type of ground-based astronomy due to its stable atmosphere, lack of city lights, and cold and dry climate, all of which are ideal for optimal sky gazing. The fact that Caltech, along with many of the project's partners, has other observatories there is also useful, says physicist Edward Stone, who has been vice chair of the board of directors for TMT and is now the TMT executive director.

"There is creative synergy among the different capabilities offered by the telescopes that share the Mauna Kea site, and TMT would be the crown jewel," he explains.

"We'll have the world's largest telescope, an amazing site in Mauna Kea, and 10th-generation instruments—we're at the top," adds Kulkarni.



And the top is exactly where he and his colleagues would like to stay.

"Caltech has been blessed with having access to the world's biggest, ground-based telescopes ever since the opening of the 200-inch Hale Telescope in 1948, and that's been a key attractor to Caltech," Soifer says. "It's been the foundation from which we've built one of the world's great astronomy programs. I see TMT as essential to maintaining that leadership." e&s

Judith Cohen is the Kate Van Nuys Page Professor of Astronomy.

Richard S. Ellis is the Steele Family Professor of Astronomy.

Shri Kulkarni is the John D. and Catherine T. MacArthur Professor of Astronomy and Planetary Science, and director of Caltech Optical Observatories.

Tom Soifer is a professor of physics, the director of the Spitzer Science Center, and the Kent and Joyce Kresa Leadership Chair of the Division of Physics, Mathematics and Astronomy.

Chuck Steidel is the Lee A. DuBridge Professor of Astronomy.

Edward C. Stone is the David Morrisroe Professor of Physics and vice provost for special projects. He is project scientist for the Voyager mission and served as director of the Jet Propulsion Laboratory from 1991 to 2001.

An artist's rendering of TMT (above) shows the telescope without its protective domed enclosure.

On the Leading Edge of Higher Ed

by Jessica Stoller-Conrad

Caltech's new president, Thomas F. Rosenbaum, knows a thing or two about leadership. After all, he spent seven years as the provost of the University of Chicago, where he had previously served as vice president for research and for Argonne National Laboratory.

In his inaugural address on October 24, Rosenbaum spoke about what it means to lead an institute of higher education, echoing Robert A. Millikan to reflect on "the effective combination of the pure and the applied to advance knowledge and benefit society." The key elements of this successful mix "characterize the Caltech of today," he said. He went on to describe them as:

- **"An absolute commitment to excellence.** Every appointment—student, faculty and staff—matters. Intrinsic to this strategy is the need for diversity: diversity of thought, diversity of background, diversity of experience. We must cast the net as broadly as possible to recruit and retain the most inventive and original scholars.
- **"Ambition. . . .** We are at a time in the history of science and technology where competition for federal funds drives the system to conservatism, but the genius of Caltech is its fearlessness to try new ideas, its willingness to absorb risk and even fail if the potential is transforming discovery.
- **"Focus.** As the constraints become more pronounced, we will be challenged even more profoundly to define areas where the Institute can be a world leader and where it cannot. We will have to forge partnerships . . . while protecting our capacity to set the intellectual agenda.
- **"Intimacy and intensity.** This is a visceral feature of Caltech, built on an organizational structure with few disciplinary barriers and the cultural expectation of shared knowledge.
- **"Perspective.** The arts help us to function as life thrusts us into situations where we have to conceive problems outside of the structures that define them. . . ."

While challenging to achieve, Rosenbaum said, taken together these fundamental ingredients "yield intellectual magic."

As Caltech welcomes its new president, we at *E&S* thought it would be interesting to talk with other university leaders—all Caltech alumni, of course—about their roles and how they are adapting to an ever-evolving educational landscape.

Many of these systemic challenges stem from messages that students get in their K–12 experience, and at home, and in the media about, one, "What do scientists and engineers look like, and do they look like me?" and, two, "What is the work of scientists and engineers, and is that work that I would be passionate about doing?"

—LAURIE LESHIN, WPI

Looking Harder

Nearly 150 years ago, American politician, education reformer, and college president Horace Mann famously described education as the "great equalizer" of humankind—a tool that transcends cultural and socioeconomic divides to give anyone from any background an equal chance at success. Although the educational system in the United States has changed substantially since Mann's time, a college degree is still an undeniably important gateway to opportunity in our society.

Today, the fast-growing industries surrounding technology, alternative energy, and health care have spurred a need for more workers trained in the so-called STEM fields—those relating to science, technology, engineering, and math. Indeed, institutes of higher education have had a hard time recruiting enough students to meet the demand.

One approach to solving this problem is to diversify the traditional STEM classroom, opening it to a broader range of potential students. For example, although women now account for more than half of the enrolled college students in the United States, they are still underrepresented in many STEM fields—especially engineering. How can higher education recruit more women to pursue science and engineering?

"Of course that's a huge question—and if it was an easy nut to crack, we would have cracked it," says Laurie Leshin (MS '89, PhD '95), president of Worcester Polytechnic Institute (WPI). "I think the fact that progress has been slower than we'd all like to diversify STEM fields—both in higher ed and beyond—means that there are some real systemic challenges there."

Leshin—who is the first female president at WPI—says that one way institutions of higher education can address the gender disparity in STEM is to become allies in programs that encourage girls to engage with science at a young age.

As an example, Leshin points to Camp Reach, a program at WPI that shows middle school girls what a career in science or engineering is really like. "I'm on the Curiosity rover science team," she says, "and five of my women colleagues from Curiosity, who are engineers from JPL, are talking to the Camp Reach girls about what it's like to work in space exploration. We need to show examples of women doing really great and exciting jobs in the field, and that those jobs are all about interacting with others and making an impact in the world."

Caltech's alumni leaders in higher ed say that a key to encouraging

We're in the midst of a revolution in terms of how technology is applied to both education and research. On every campus today there is an unrelenting quest for greater bandwidth and access to resources that are available on the Internet. And if the United States is to remain the leading center of innovation, we're going to have to have great infrastructure.

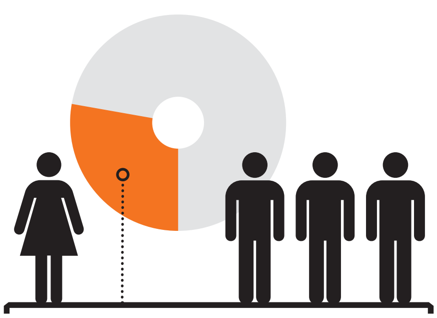
—MARK WRIGHTON, WASHINGTON UNIVERSITY

students from all backgrounds to pursue science and engineering is making schools more accessible and affordable. For Mark Wrighton (PhD '72), chancellor of Washington University in St. Louis, this means providing scholarships and supporting programs that encourage a talented and diverse student body.

"We need to be proactive with acquainting people with the opportunities for financial aid, but we also need to be more proactive in reaching out to talented people from families where people haven't traditionally gone to college," Wrighton says.

To assist first-generation college students in navigating the college application process, Washington University provost Holden Thorp (PhD '89), along with colleagues from the University of North Carolina, helped create a program called the College Advising Corps. The corps, made up of recent college graduates, is sent into schools that lack the resources to help with college advising tasks that are essential to the admissions process, such as registering for the SAT and completing financial aid forms and other paperwork.

"There are also a lot of students out there who have the background to go somewhere like Caltech or WashU, but they don't apply because they might not know that they could be admitted, or they might not know that we have programs that would take care of most of their financial needs if they come," Thorp says. "So we have a lot of work to do to get the word out about what is available."



28%

of individuals in science and engineering occupations are women

Philip Hanlon (PhD '81), president of Dartmouth College, points to his institution's College Horizons program, a six-day summer workshop that aims to attract more Native American students to campus, as helping diversify the student body. The program provides an opportunity for students to learn about financial aid and academic goal-setting as well as a chance to meet with college counselors, admissions officers, and essay specialists.

"The workshop is in support of Dartmouth's historic commitment to recruit Native American students and is partially responsible for a Native American student population greater than the rest of the Ivy League combined," Hanlon says.

And when students from underrepresented backgrounds show up to campus, schools need to continue their encouragement and support, says Hanlon. "It's not enough to say, 'Here we are. Send in your application.' We need to nurture students and make sure they have the opportunities to develop the skills needed to succeed at this level." At Dartmouth, this is done with a peer-mentoring program for first-generation college students, which offers a support network for those who don't have a family history to glean from during their transition to college.

With careful messaging, greater accessibility, and support, higher education can not only influence the classroom but also diversify the workforce of the future—which is integral to innovation, Wrighton says.

"The most challenging research questions that we're going to be asking in the future are going to be ones that will require different people with strengths in different areas," he says. And to address those questions, "we'll have to bring talented people from many different backgrounds together."

Higher ed is going to have to do more to make sure that we identify the people that we should be recruiting to our universities, and we have to do more to make sure that the folks who wind up here feel welcomed and are in a position to succeed.

—**HOLDEN THORP, WASHINGTON UNIVERSITY** *right*

Inside the Classroom

Expanding and diversifying the STEM student body is an important step in filling the growing pool of jobs in science and technology. However, STEM retention—the act of keeping students in a STEM field from their first class to the completion of their degree—is also a substantial challenge. Although around 28 percent of students seeking bachelor's degrees in the United States majored in a STEM field at some point during their college careers, only about half of *those* actually finish their degrees in STEM.

Many in higher education have attributed the high attrition rate in STEM to technical coursework that students have trouble getting excited about. One popular new methodology to resolve this problem is problem-based learning, which reinforces basic science principles in real-world situations. For example, at WPI, project-based learning experiences are required for all undergraduates, Leshin says. Each student spends a seven-week term at one of more than 40 sites around the world, working as part of an interdisciplinary team to solve a real-life problem with a social impact—often for a company, a nonprofit, or a government agency.

Programs like WPI's have seen successes in improving students' knowledge retention and attitudes toward learning, and such positive results have encouraged many other college and university leaders to find ways of customizing problem-based learning for their own curricula.

When Richard Miller (PhD '76) became the founding president of Olin College of Engineering in 1999, he got the chance to build a brand-new college focusing on design- and problem-based learning.

At Olin, Miller says, he wanted to focus on educating a new kind of engineer—one who can find creative solutions to messy, real-world problems. To do this, he says, technical concepts should be taught by applying the basic principles in interdisciplinary classes that combine science and engineering with subjects like art, business, and history. "Students learn best from stories about people, but traditional STEM courses usually leave this out. To improve learning and retention, we need to insert people back into STEM wherever we can," he explains.

Olin faculty members have experimented with this concept by teaching the basics of materials science, for instance, by recreating metals using Paul Revere's metallurgical techniques—metals that are then studied using modern tools, like electron microscopes. When these students who've seen STEM in action this way move on to their core courses in science and engineering, Miller says, they are better able to understand key principles.

An "applications first, equations later" approach isn't the norm in engineering education today, but Miller says that other fields have long embraced this method.

"If music schools taught violin prodigies the way that many engineering schools teach engineering, in the first year you'd just study the physics of violin strings," he explains. "In the second year, you'd study composition. In the third year, you'd study orchestration. Then in the fourth year, if you're still here, we'd have you play a scale on a real violin.

"In engineering, we learn how to derive all these equations about stuff, but it turns out, if you actually get a job in engineering with a bachelor's degree, very little of your job depends on using these equations," continues Miller. "Instead, you have to work on a team, you have a budget, and the thing you're making has to work in the field or you lose your job. These are skills that we need to be teaching."

Not only do we need to teach applied science, math, and calculus but also what a patent is and how you make money from these ideas. We need to teach how to work in a team. I don't know of a company that hires people and pays them for answering multiple choice tests and not talking to their neighbors.

—**RICHARD MILLER, OLIN COLLEGE OF ENGINEERING** *center right*

Dartmouth's Hanlon says that student entrepreneurship is also an important applied learning opportunity. "Student entrepreneurship is as compelling an example as you'll find of experiential learning, where innovation is required and the risk of failure is ever present," he says. He and his Dartmouth faculty hope to capitalize on this learning opportunity through their new student entrepreneurship center.

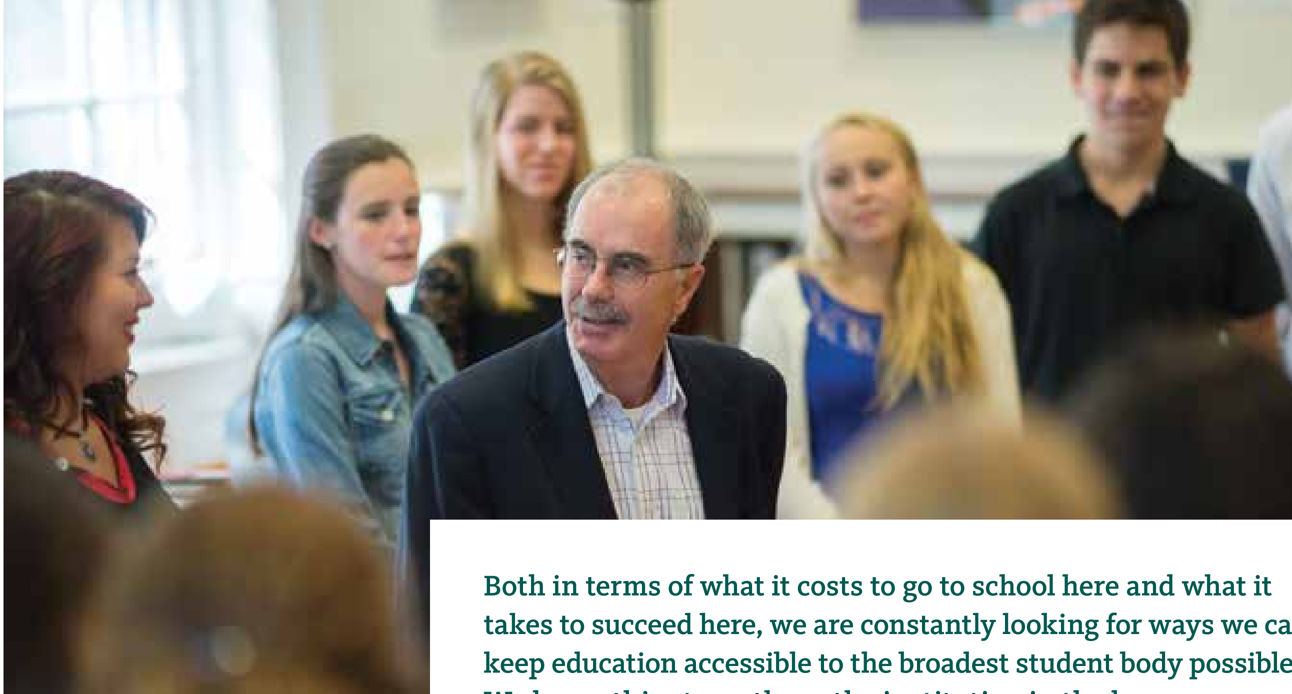
"In talking to students when I arrived back on campus last summer [2013], I was somewhat surprised to learn about dozens of really interesting business start-ups, product developments, and social entrepreneurship efforts that were receiving little or no formal help or guidance from the college," he says. "These students were working in relative isolation, navigating the entrepreneurial path alone, engaged in experiential learning of the harshest sort, as any entrepreneur can tell you!"

So Hanlon created the Innovation Center and New Venture Incubator to give students interested in start-ups and social ventures a place to gather to collaborate and share ideas. As the students work through their creative process at the center, faculty members are available to advise on legal matters, the basics of starting a business, and design feasibility. An accelerator associated with the center will even provide the opportunity for $250,000 a year in seed funding to a select few of these early-stage student projects.

"What we want to do is coordinate the brilliant minds on campus and within our global alumni family so the student entrepreneur can fast-forward into the realm of *doing*, and not have to play catch-up by learning the hard way the lessons our faculty and alumni have already learned and lived," Hanlon says.

Facing the Future

While expanding STEM programs



Both in terms of what it costs to go to school here and what it takes to succeed here, we are constantly looking for ways we can keep education accessible to the broadest student body possible. We know this strengthens the institution in the long run.

—PHILIP HANLON, DARTMOUTH

is essential for the future success of industry, the additional space and improved infrastructure for technology, laboratories, and classrooms come at a cost.

And while public money will probably remain a key source of funding in higher education for the foreseeable future, funding structures are changing, says Eric Kaler (BS ’78), president of the University of Minnesota—and leaders of colleges and universities will need to make stronger arguments of relevance to receive those limited funds for student programs and research.

One way to do this, he says, is to focus on the ways that a university can have an impact on local industries, showing how the university’s research priorities align with the needs of the state and the surrounding community. “Legislators and the public expect accountability and a return on the investment they make in a university in a way that’s more quantitative and specific than it was in the past, and I think state institutions are not alone in that,” he says.

Kaler and his colleagues at the University of Minnesota have found a way to do this with Minnesota’s Discovery, Research, and InnoVation Economy—or MnDRIVE—program.

“What we did was identify areas in which we had strengths and the state has needs and opportunities,” he explains. These areas, he says, include food safety, water management, and robotics and advanced manufacturing. The program allows the state to make an investment in its own economy by providing a source of funding for research and creating an opportunity for outreach and experiential learning for students.

“On every front, MnDRIVE is benefiting students and fulfilling the University of Minnesota’s teaching, research, and outreach land-grant missions,” Kaler says. Recently, for instance, MnDRIVE provided funds for a PhD student to develop a product prototype based on his research—a first step on the path to creating a start-up company. The program also provided support for a student group to lead a robotics summer camp for a diverse group of middle school students interested in exploring STEM careers.

In addition to developing creative funding strategies for research and student programs, college and university leaders are preparing for the future

In 2012,

60.9%

of college students received some form of financial aid of higher education by exploring the best ways to engage students through online communications, both socially and academically.

Online education has already become an important part of many colleges and universities, but WPI's Leshin says that the future will likely bring an increase in such offerings. And while many critics believe online education will lead to the loss of connection between students and faculty, Leshin says that these resources—used in the right ways—actually may help to increase meaningful learning opportunities between students and faculty.

"Online education can sometimes get too far away from that interaction between faculty and students, but our faculty members are great resources, and if we are just using highly trained faculty to transmit data in a lecture hall, that's probably not the most effective use of those resources," she says. "In the future, we need to create an environment where faculty and students interact in a way that maximizes learning."

As president, one way that Leshin interacts with students is via Twitter, which she says is a quick and informal way to break down the communication barriers between students and administrators—as well as between the university and the public.

"The amazing thing that's really true about social media is that it makes you feel more connected to people… and our students are there," she says. "On the day of the announcement of my election to the presidency here, it was amazing how many messages on Twitter I got from students."

Kaler says that, in the future, universities may rely more heavily on Twitter and other social media platforms as a viable option for more formal communications as well.

"We've found that our students in particular get a lot of their information through Twitter," he says. "Sending a student group an email is not a very effective way to be in touch, so we've tried to adapt the ways that we deliver our messages and provide connectivity."

As higher education relies more and more on online communications and coursework, many have begun to question the relevance of traditional colleges and universities. But Kaler says that the physical presence of a college campus offers something that *can't* be found online.

"I believe firmly that brick-and-mortar institutions are not going to go away," he says. "In our country, there are just a handful of pathways that constructively take an adolescent from that stage to a young adult, and going off to college is a pretty important part of our culture. That won't change. But what happens when you get here is going to be different." e&s

I think that clearly technology is going to change an enormous amount of what we do and how we do it. It's no longer about getting information to students. What we need to spend more time on is teaching students how to use that data.

—ERIC KALER, UNIVERSITY OF MINNESOTA

Read more about the leaders featured in this article at alumni.caltech.edu.

Frederick B. Thompson 1922–2014

Frederick Burtis Thompson, professor of applied philosophy and computer science, emeritus, at Caltech, passed away on May 27, 2014.

Thompson served in the Army and worked at Douglas Aircraft during World War II before earning bachelor's and master's degrees in mathematics at UCLA in 1946 and 1947, respectively. He then moved to UC Berkeley, where he received his PhD in 1951.

Thompson arrived at Caltech in 1965 with a joint professorship in engineering and the humanities. The research that Thompson began in the 1960s helped pave the way for today's "expert systems" such as IBM's supercomputer *Jeopardy!* champ Watson and the interactive databases used in the medical profession. His work provided quick and easy access to the information stored in such systems by teaching the computer to understand human language, rather than forcing the casual user to learn a programming language.

In 1969, Thompson began a lifelong collaboration with Bozena Dostert, a senior research fellow in linguistics who died in 2002. The collaboration was personal as well as professional; their wedding was the second marriage for each.

He was a member of the scientific honorary society Sigma Xi, the Association for Symbolic Logic, and the Association for Computing Machinery. He wrote or coauthored more than 40 unclassified papers—and an unknown number of classified ones.

Thompson is survived by his first wife, Margaret Schnell Thompson, and his third wife, Carmen Edmond-Thompson; two children by his first marriage, Mary Ann Thompson Arildsen and Scott Thompson; and four grandchildren.

To learn more about Fred Thompson's life and work, visit caltech.edu/content/frederick-b-thompson-0.

Allen E. Puckett 1919–2014

Allen E. Puckett (PhD '49), the engineer who helped father the delta-winged airplane, the guided missile, and the communications satellite, passed away at his home in Pacific Palisades, California, on March 31, 2014.

He earned his bachelor's and master's degrees in engineering at Harvard (in 1939 and 1941, respectively) before coming to Caltech to pursue his doctorate in aeronautics under Theodore von Kármán, the leading aerodynamicist of the era. Puckett's PhD thesis, "Supersonic Wave Drag on Thin Airfoils," laid the foundation for designing the triangular-shaped delta wings found on such diverse aircraft as supersonic fighter jets, the SR-71 Blackbird spy plane, and the Space Shuttle orbiter.

Among other honors, Puckett won the Lawrence Sperry Award of the Institute of Aeronautical Sciences (now the American Institute of Aeronautics and Astronautics) in 1948. He was named a Caltech Distinguished Alumnus in 1970, the California Manufacturer of the Year in 1980, a Chevalier of the French Legion of Honor in 1984, and was awarded the National Medal of Technology by President Reagan in 1985.

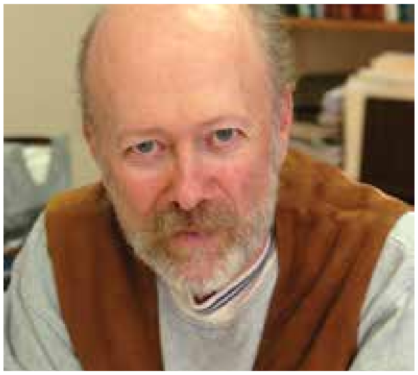
At Caltech, Puckett endowed a chair in the Division of Engineering and Applied Science. Robert McEliece is the Allen E. Puckett Professor and Professor of Electrical Engineering, Emeritus; Pietro Perona is the Allen E. Puckett Professor of Electrical Engineering.

Caltech's Guggenheim Aeronautical Laboratory, the building where Puckett spent his time on campus as a grad student, was extensively renovated in 2008. The west end of the third floor now houses the Allen Puckett Laboratory of Computational Fluid Mechanics.

Puckett is survived by Marilyn Puckett, his wife of 50 years, five children, six grandchildren, and 14 great-grandchildren.

To learn more about Allen Puckett's life and work, visit caltech.edu/content/allen-e-puckett.

Paul H. Patterson 1943–2014



Paul H. Patterson, the Anne P. and Benjamin F. Biaggini Professor of Biological Sciences, Emeritus, at Caltech, and a neuroscientist and developmental biologist who created novel behavioral models of schizophrenia and autism in mice, died on June 25, 2014.

Born in Chicago in 1943, Patterson stayed in the Midwest for college, graduating with a bachelor's degree from Grinnell College in Iowa in 1965. From there, he moved east for graduate school at Johns Hopkins University, earning his doctorate under advisor William Lennarz in 1970. In 1983, after more than a decade as a faculty member at Harvard Medical School, Patterson joined the faculty at Caltech.

His research focused on interactions between the nervous and immune systems—a connection that was not universally acknowledged in the early days of neuroscience. "Professor Patterson was a pioneer and iconoclast who was not afraid to work outside the scientific mainstream, and who consequently made a number of important and seminal contributions that opened up entire fields of research," says David Anderson, Seymour Benzer Professor of Biology at Caltech and Patterson's longtime colleague.

A mouse model he developed has been used to study the environmental factors that influence the symptoms of human neurodevelopmental disorders and has increased awareness of the importance of those influences. Recently, the model informed a possible new therapy to treat schizophrenia-associated hallucinations. In another recent study, Patterson and colleagues demonstrated that the gut microbiome, the diverse collection of bacteria that reside in the intestine, regulates behaviors in a mouse model of autism.

Patterson also contributed to the understanding and treatment of Huntington's disease, a devastating hereditary neurological disorder, and he was instrumental in developing the Institute's MD/PhD joint degree program—a collaboration that allows graduate students to combine their Caltech research experience with medical education at UCLA or USC.

He is survived by his wife, Carolyn, and his son, Paul.

To learn more about Paul Patterson's life and work, visit caltech.edu/content/noted-neuroscientist-paul-patterson-dies.

Frank E. Marble 1918–2014

Frank E. Marble, the Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion, Emeritus, at Caltech, passed away on August 11, 2014.

Marble received his bachelor of science degree in 1940 and his master's degree in 1942, both from the Case Institute of Technology. He then came to Caltech and earned an engineer's degree in 1947 and a PhD in 1948, with Professor Theodore von Kármán as his advisor. He was hired at Caltech in 1948 as an instructor in aeronautics, became assistant professor of jet propulsion and mechanical engineering in 1949, associate professor in 1953, professor in 1957, and was named Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion in 1980. He retired in 1989.

Marble made major contributions to aerodynamics, combustion, and propulsion, specifically the research and development of gas turbines and rockets. He also was responsible for the training of several generations of scientists in the field of aeronautics.

A member of both the National Academy of Engineering and the National Academy of Sciences, Marble received many honors, including the 1999 Daniel Guggenheim Medal, awarded by the American Institute of Aeronautics and Astronautics (AIAA), and the AIAA Combustion Award.

Marble was predeceased by Ora Lee, his wife of seven decades.

To learn more about Frank Marble's life and work, visit caltech.edu/content/remembering-frank-marble.

MENTORS AS LEADERS

We asked alumni to tell us about their Caltech mentors. Here is what some of them had to say.

Harry Gray, Arnold O. Beckman Professor of Chemistry

... is the most inspiring, supportive, and encouraging of mentors, and it was an honor to work with him. He **treats all students as colleagues** and made the long hours and hard work amazingly fun.

Ray Owen, professor of biology (deceased)

... knew exactly how to **BRING OUT THE BEST** in students and to train them to be successful when they left Caltech. I've spent my entire scientific career trying to emulate Ray's unique style.

Oscar Mandel, professor of literature, emeritus

... taught me **the relevance of scholarly rigor**, seasoned with dry humor, which in turn bred a lifelong curiosity about everything from prime numbers to the causes of World War I.

Candace Rypisi, director of student-faculty programs

When the Tech workload and other pressures made me wonder if I would graduate, she **INSISTED THAT I WAS A "ROCK STAR"** and would make it through. Rock star or not, I survived some rough years as a grad student by remembering her unquestioning belief in me.

Anthony Leonard, Theodore von Kármán Professor of Aeronautics, Emeritus

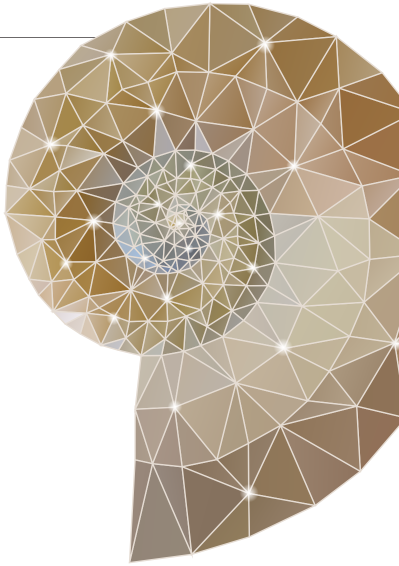
... taught me to **be kind.** Kindness coupled with competence can move mountains.

Richard Jahns, professor of geology (deceased)

At the time he was the youngest full professor on campus. He was vital, he was energetic, he had **a magnificent sense of humor,** and he was sensitive. Field trips were his specialty, where the true measure of his brilliance shone.

Herbert Ryser, professor of mathematics (deceased)

... showed me what **mathematical elegance** is all about, how from simple ideas one can discover profound truths, how seemingly simple processes like arithmetic can be so hard to understand in reality.



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