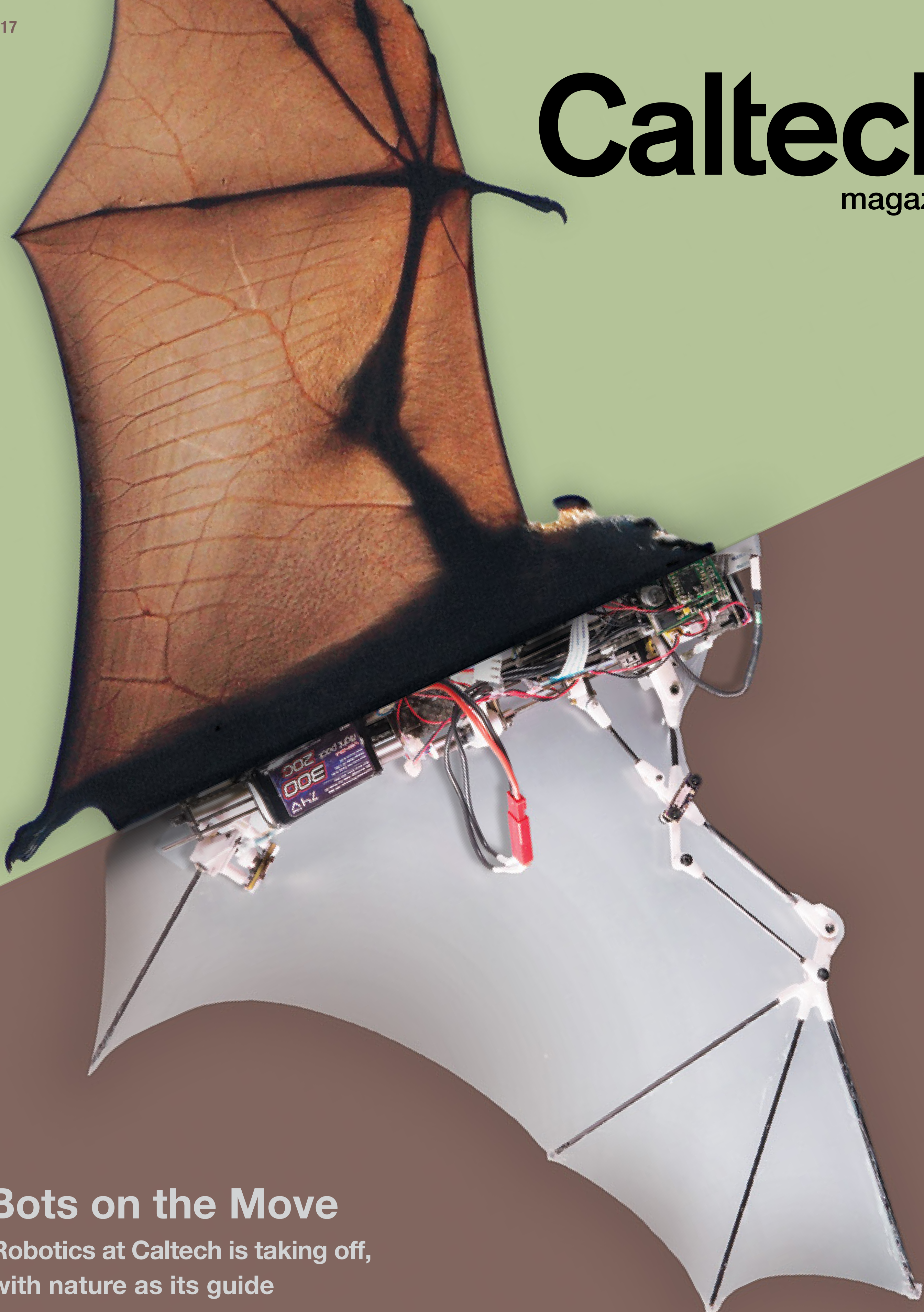
Fall 2017

Caltech
magazine



Bots on the Move

Robotics at Caltech is taking off, with nature as its guide

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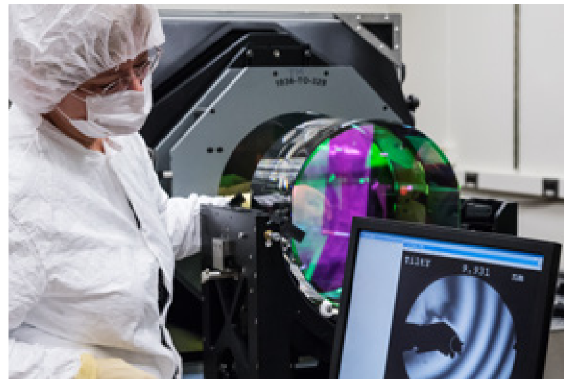
Left: Jon Webster, senior director of dining services, planting future menu options in the new aeroponics garden atop Chandler Café.

Online

How to: Clean LIGO (video)



Caltech's newest student leaders

A timeline of Caltech campus hubs through history

Visit magazine.caltech.edu

Fall 2017 Volume LXXX, Number 2

Caltech magazine

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Above: Basking turtle at Throop Pond.

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Caltech magazine ISSN 2475-9570 (print)/ISSN 2475-9589 (online) is published at Caltech, 1200 East California Boulevard, Pasadena, CA 91125.

Printed by ColorGraphics, Los Angeles, California.

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Letters

Caltech magazine: First Feedback

We received a number of notes in response to our inaugural issue of Caltech *magazine—some complimentary, others critical. All will help us plan for this magazine's future, and for that we are grateful. Here are a couple of examples.*

I just received my copy of the Spring/Summer 2017 *Caltech* magazine and I must say it is impressive. I really enjoyed the dual focus on people and science. I receive so many periodicals, and it is difficult to find the time to read them thoroughly. *Caltech* magazine was read from first to last page within the first day of receipt. I think this is a record (at least for me).

Please continue the outstanding work!

Eric J. Moore (PhD '84)

I have just read through the recent edition of *Caltech* magazine. I enjoyed your "Welcome" discussion of the magazines that have come from Caltech through the years. I particularly appreciated and used the magazine in its previous format, *E&S*, after I graduated in 1964. And later, as a faculty member at UC Davis, I was able to use some of the *E&S* stories as assignments in my classes—general (science) interest articles for some freshman seminars and more specifically biologically related articles for upper-division students in biochemistry or physiology classes. In your new format, there is nothing that I can use. There are great pictures. There is a lot on the Caltech community. There is a big article on brain studies, but it is about the people doing the studies, not the studies themselves or what has been discovered. "Gut(-Brain) Reaction" is a subject of real interest at Davis, but one page is not. I understand that this is a magazine designed to elicit pride in potential donors, but I hope that we can learn more about ongoing research at Caltech. I would like articles that I can show my students. After all, they might be potential Caltech grad students.

Terence M. Murphy (BS '64)

Engelmann Memories

Thank you so much for including the article "The End of the Oak" in the latest issue of *Caltech* magazine. That tree held special significance to our family. In 1970, when I was accepted into the first class of women at Caltech, my father—Ching Yuen Hsiao, who graduated from Caltech in 1926 as one of the first Chinese students at the Institute—could not have been more proud to have his daughter attend his alma mater. It was not until I graduated in 1974 that my father was able to make the trip to Pasadena, 48 years after his own graduation. When I gave him a tour of the campus, it was quite a shock to both my father and me that all of my father's former professors (Millikan, Gates, Bridge) were now buildings! We walked and walked, and finally we came to the oak tree. Here my father stopped as he mentally returned to his college years. "Yes," he said, "this tree was here when I went to Caltech. I remember this tree." We took pictures of the tree that day, and though those pictures and my father now are long gone, I was so happy to read your article. I so appreciate reading about the care the Institute has taken to nurture and maintain that tree for as long as it has, and on my next trip to Pasadena, I'm sure to feel a twinge of sadness looking at the spot where the oak once stood.

Joyce Hsiao (BS '74, MS '77)

Editor's note:
For more on the fate of Caltech's Engelmann Oak, go to caltech.edu/news/farewell-oak-79021

Right: On July 11, workers dissected Caltech's 400-year-old Engelmann oak, which died last year. Portions of the tree were salvaged for research and other uses.

SoCaltech

Cloud Sourcing

Caltech climate scientists help bring an artist's cloudy vision to life

How much does a cloud weigh? That was the question on Karen LaMonte's mind when she emailed Caltech climate scientist Tapio Schneider. LaMonte—an artist known for her monumental sculptures—wanted to make a cloud sculpture, but with a twist. She would find a cloud to use as a model and make the sculpture's weight equivalent to that of the original cloud.

"We see [clouds] floating in the air," says LaMonte. "We think of them as fluffy cotton balls. But they're actually amazingly heavy. I thought, wouldn't it be amazing if we could get a 'real' cloud and carve it in marble?"

Schneider, the Frank J. Gilloon Professor of Environmental Science and Engineering, who also has a joint appointment with JPL, was intrigued. His work focuses on reducing uncertainties in climate-change projections—in part through modeling cloud formation to better understand clouds' impact on the environment. Collaborating with LaMonte, he reasoned, could help raise awareness of these issues.

continued on page 6

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

Cloud Sourcing

continued from page 5

Observations of clouds with enough detail to translate into a sculpture are not available, but the equations governing clouds are known, and so the structure of clouds can be computed. Caltech research scientist Kyle Pressel, who is part of the Schneider lab, worked closely with LaMonte to produce the cloud simulation from which she would create her sculpture.

Their goal: Model conditions that would create a cumulus cloud worthy of sculpting. The result? "A classic cumulus you'd see while lying on a beach in Barbados," says Pressel.

To transform the virtual cloud model into an actual sculpture, LaMonte again turned to technology, using a robot for the initial carving. "Only by using technology could I make the diaphanous solid and the intangible permanent," she says.

It took the robots four weeks of carving and LaMonte an additional four weeks of hand-finishing before the 15-ton block of marble assumed its final form as *Cumulus,* a seven-foot-tall, 2.5-ton sculpture. *Cumulus* will remain on exhibit outside Venice's Palazzo Cavalli-Franchetti during the Venice Biennale, through November 26, 2017.

Read more about Karen LaMonte and Tapio Schneider's collaboration at magazine.caltech.edu/post/cloud-sourcing

Meet the class of **2021**

Total # of applications:
7,339
(highest ever)

Offers of admission:
568
(7.7% admit rate, lowest ever)

Enrolling freshmen:
235*

*As of printing

Women:
46%
(ties % record from 2015)

Underrepresented minorities:
16%

From public or charter high schools:
71%

First generation students:
5%

As well as being stellar scholars, our newest freshmen have some impressive talents. Individuals from this class have:

- Baked a replica of the periodic table with cupcakes
- Engineered and designed roller coasters
- Climbed Mt. Whitney three times
- Performed as a stand-up comic
- Owned a perfume company
- Played ice hockey on the Lady Huskies Travel Hockey Team

"I hung up the phone and just sat there for a second. I was going back through it in my mind, saying 'They did say yes, right? And they got the right person?'"

—Caltech postdoc **Jessica Watkins** *on learning she had been selected for NASA's 2017 Astronaut Class*

Class Act:

Graduate student Kelsey Boyle co-teaching (with Rebekah Silva) a tutorial course on DNA and cancer for the newly reinvented Chemistry 101.

Chemistry graduate students Rebekah Silva and Kelsey Boyle reinvented and launched Chemistry 101 during the last spring quarter as a low-stakes way for Caltech undergraduates to explore topics in chemistry that pique their interest. Taught entirely by graduate students and postdocs, the course also gave Silva, Boyle, and their peers a chance to hone their teaching skills.

Bite-sized learning

A group of six tutorial courses, Ch 101 focuses on topics outside of the main chemistry curriculum: revolutionary inorganic molecules, chemical nanoscience, ultrafast laser spectroscopy and microscopy, astrochemistry, a survey of the chemical-biology literature, and a look at trends in cancer-treatment strategies. With these bite-sized offerings, which undergrads can take either for a grade or as pass/fail, "students get a chance early on to explore an area of interest with little risk," says Silva.

Head of the class

"I had opportunities to tutor in college and found a lot of purpose from it," says Silva, who graduated from Stanford in 2012. "I wanted to take the next step of creating course content and being the instructor." Graduate student Olivia Wilkins was excited about the opportunity Ch 101 gave her to bring her fascination with astrochemistry to Caltech's undergrads. "I had this vision of sharing it with people, and immediately a course outline popped into my head," she says.

Next level

Silva hopes her students take away from the course a new way of understanding information. "The way I understand, for example, nucleic-acid biology is very different from when I was an undergraduate," she says. "We thought it would be great to structure a class to help students organize information more in a way that an expert does."

Teaching the teachers

To help the graduate students and postdocs make the leap into teaching, each had a faculty mentor and consulted with the Center for Teaching, Learning, and Outreach. Harry Gray, Caltech's Arnold O. Beckman Professor of Chemistry, was impressed with the dedication of the rookie professors. "The people who signed up are kids who already love teaching," he says. "It's easier to work with them because they really want this, and they're fired up."

Read more about Chemistry 101 at magazine.caltech.edu/post/chem101

Classic Cuppa Cocoa

Arthur A. Noyes moved to California—and Caltech—in 1919 to build the Institute's chemistry division, housed in what was then the Gates Laboratory of Chemistry (now the Parsons-Gates Hall of Administration). In addition to shaping the policies that would help create a world-renowned hub of science and engineering, Noyes introduced at least one early Caltech tradition: hot cocoa.

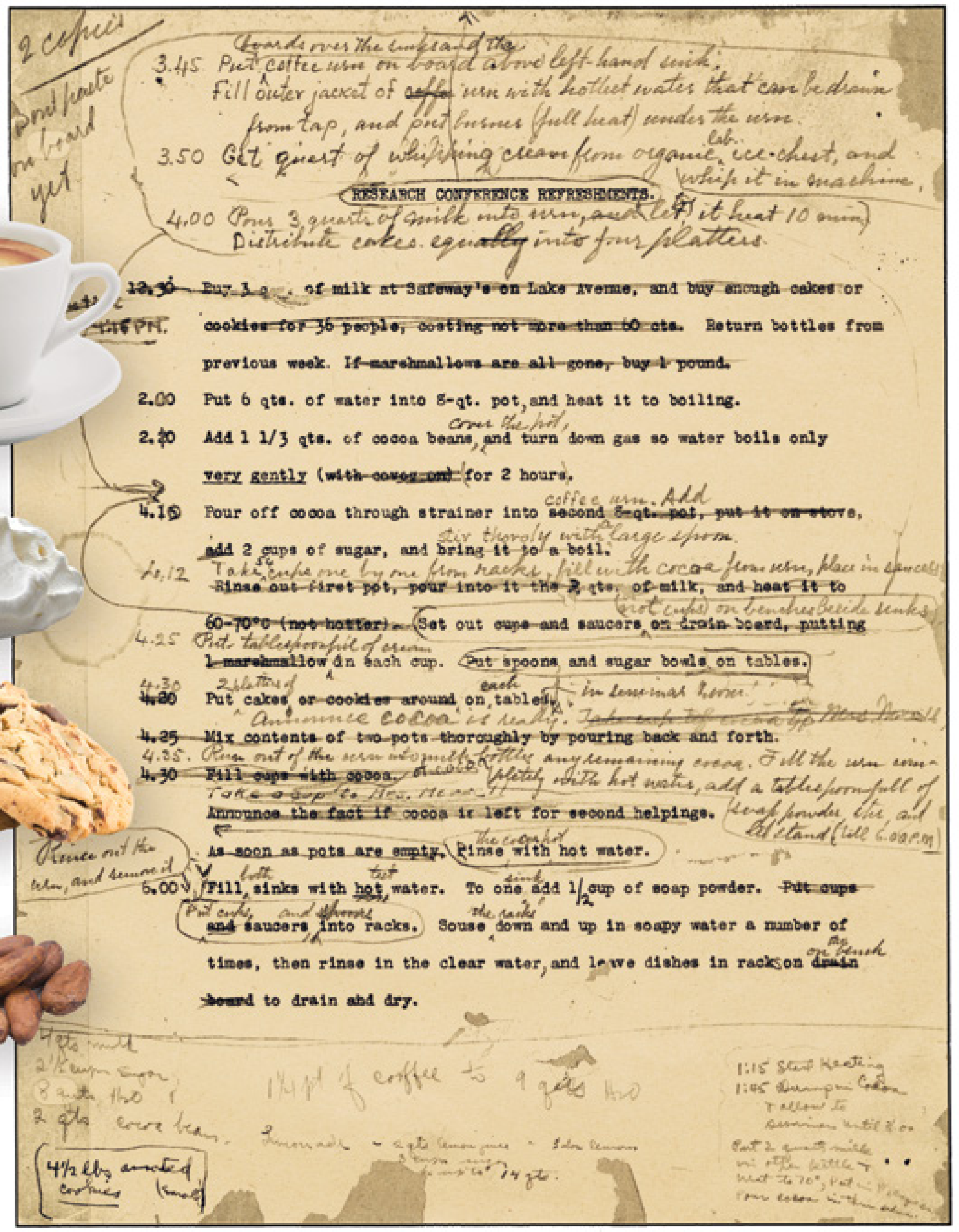
Research meetings, held weekly in Gates, featured cocoa prepared according to this precise recipe, created by Noyes and posted to a bulletin board in the kitchen.

Lyman Bonner (PhD '35) recalled, "At these seminars, incidentally, cocoa prepared by the Noyes recipe was always served. Always. No exceptions."

Whipping cream seems to have been stored in the organic lab's ice chest.

Cocoa was accompanied by cakes or cookies purchased at what had been a Safeway store on Lake Avenue.

No pre-ground cocoa here—grad students carefully weighed and boiled cocoa beans.



RESEARCH CONFERENCE REFRESHMENTS.

12.30 ~~Buy 3 q . of milk at Safeway's on Lake Avenue, and buy enough cakes or cookies for 36 people, costing not more than 60 cts.~~ Return bottles from previous week. ~~If marshmallows are all gone, buy 1 pound.~~

2.00 Put 6 qts. of water into 8-qt. pot, and heat it to boiling.

2.20 Add 1 1/3 qts. of cocoa beans, and turn down gas so water boils only very gently (~~with cover on~~) for 2 hours.

4.15 Pour off cocoa through strainer into ~~second 8-qt. pot, put it on stove,~~ ~~add~~ 2 cups of sugar, and bring ~~it to~~ a boil.

~~Rinse out first pot, pour into it the 3 qts. of milk, and heat it to 60-70°C (not hotter).~~ Set out cups and saucers ~~on drain board, putting 1 marshmallow~~ in each cup. Put spoons and sugar bowls on tables.

~~4.20~~ Put cakes ~~or cookies around~~ on tables.

~~4.25 Mix contents of two pots thoroughly by pouring back and forth.~~

~~4.30 Fill cups with cocoa.~~

~~Announce the fact if cocoa is left for second helpings.~~

~~As soon as pots are empty,~~ Rinse with hot water.

6.00 Fill sinks with hot water. To one add 1/2 cup of soap powder. ~~Put cups~~ ~~and~~ saucers into racks. Souse down and up in soapy water a number of times, then rinse in the clear water, and leave dishes in rack on ~~drain board~~ to drain and dry.

The former Gates Laboratory of Chemistry, Caltech's oldest standing building, is celebrating its 100th anniversary. Learn more about its history by visiting the Caltech Archives at ***archives.caltech.edu*** *or the Interactive History Map at* ***caltech.edu/historymap.***

Four Questions for: Peter Collopy

For more of our conversation with Peter Collopy, go to **magazine.caltech.edu/post/4q-peter-collopy**

Peter Collopy joined Caltech in May as university archivist and head of special collections.

1. What attracted you to archival science as a field and to Caltech specifically?

I have a PhD in history of science, and I'm primarily a historian of 20th-century science and technology. Caltech is one of the major places where that history has happened, so it's one of a handful of places where it makes sense for me to be.

2. How is the Archives different from the Library?

We don't collect published materials—that's what the rest of the Library does. Instead, we get things like people's lab notebooks, letters to and from colleagues, perhaps early drafts of publications.

Science is a social activity. You can find evidence of that in publications and things like coauthorship, but you can find richer evidence of it in people's letters to each other and in people's letters to a third party about their colleagues.

3. How does the Archives work?

A lot of our collections are faculty papers, so we'll have conversations with faculty on campus about what will happen to their papers when they're not using them anymore. We make arrangements to get these materials, and, once we have them, we organize them. Then, we keep things under secure and stable conditions so that they'll last a long time.

Researchers come and use the materials or contact us and ask for help in using them remotely, or increasingly view entire collections online.

4. What are your goals for the Archives?

We'd like to supplement our paper collections with an archive of Caltech websites and other electronic media. I would also like to do public history—to not only tell stories about the history of scientific and technical research done at Caltech, but also to allow visitors to touch and experience that research. For example, we could accompany an exhibit about the long history of aerospace research at Caltech by having a small working wind tunnel in which visitors could place models.

"It was like someone dragged me by the hand and took me on the most incredible journey and adventure that humanity had ever undertaken."

—**Carolyn Porco** *(PhD '83), Voyager 1 imaging specialist, on her participation in the Voyager mission, speaking at a July 29 Caltech panel and screening of* The Farthest—Voyager in Space

Work is well underway on the Bechtel Residence, Caltech's newest undergraduate housing facility. A student committee and Student Affairs staff members are both currently exploring how to best use the 95,000-square-foot residence—named for Caltech life trustee Stephen D. Bechtel, Jr.—which is slated to open in the fall of 2018.

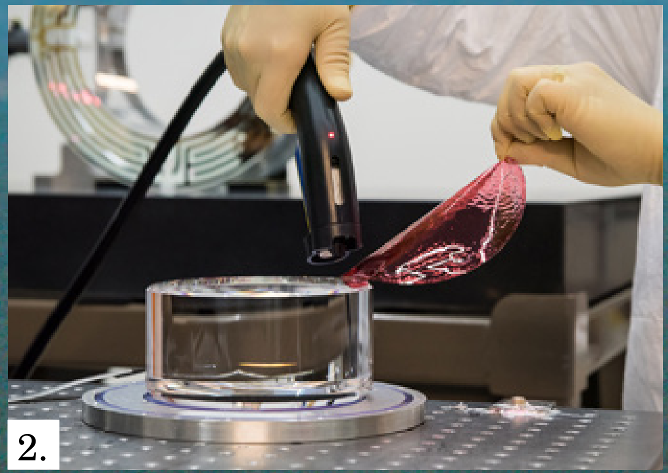
How to:

Clean LIGO

To search for ripples in space and time, the Laser Interferometer Gravitational-wave Observatory (LIGO) uses a laser beam that is split in two and travels down perpendicular 2.5-mile arms containing mirrors at their far ends. The beam reflects off the mirrors and bounces back to converge where the arms meet. A passing gravitational wave will stretch and squeeze space itself, causing the distance a light beam travels to increase or decrease ever so slightly; this changes the way the split beams ultimately converge. So far, so (relatively) straightforward. The tricky part? The setup for LIGO—at its two facilities, one in Washington and one in Louisiana—comprises tens of thousands of pieces of equipment, from massive optics to tiny screws. And if anything has so much as a speck of dust on it, it might contaminate LIGO's optics and diminish the signal of a gravitational wave. Here are some of the things Caltech engineers do to make sure that everything is beyond squeaky clean.

1. To clean LIGO's unique optics, a special polymer blend solution is applied. This technique cleans the surfaces without leaving the tiny scratches associated with the more traditional drag-wipe technique.
2. After the polymer dries, it is peeled from the surface of the optic.
3. A spray of neutralized ions prevents static buildup, keeping dust from being attracted to the freshly cleaned optic.
4. The mirrors are inspected using an extremely bright light kept within a black enclosure, to minimize light from other sources.
5. Final cleaning and inspection takes place in a custom-built clean room.
6. Smaller items like screws and bolts are placed in an ultrasonic bath for cleaning.
7. Post bath, the instruments spend time in a high-temperature vacuum oven that reaches 200 degrees Celsius (upwards of 390 degrees Fahrenheit).


1.


2.


3.


4.


5.


6.


7.


An engineer prepares a light baffle that will capture laser light scattered by dust and imperfect optics, preventing the stray light from contaminating the gravitational-wave signal.

For more information about how Caltech engineers prepare equipment for LIGO, go to magazine.caltech.edu/post/cleaning-ligo

David Tirrell Named Caltech Provost

This fall, chemistry professor and Beckman Institute director David Tirrell will become Caltech's 10th provost.

Caltech career: A Caltech faculty member since 1998, Tirrell, the Ross McCollum-William H. Corcoran Professor of Chemistry and Chemical Engineering, chaired the division from 1999 to 2009 and is currently the director of Caltech's Beckman Institute.

Research and accolades: Tirrell focuses on the genetic code and how modifying the molecular machinery of the cell might lead to new approaches in macromolecular design, protein evolution, biological imaging, and proteome-wide analysis of cellular processes. He is one of only 19 individuals elected to all three National Academies: Sciences, Engineering, and Medicine.

The role: The Institute's chief academic officer, the provost is responsible for advancing the academic agenda of the Institute. The provost works closely with the division chairs on program initiatives, serves as coordinator for curriculum development, and aids in development initiatives.

Tirrell's predecessor: Tirrell takes over the role from Edward Stolper, the William E. Leonhard Professor of Geology and the Carl and Shirley Larson Provostial Chair, who held the position for a decade. Stolper plans to return to the faculty full time to pursue his studies of the origin and evolution of igneous rocks on Earth and other planets.

> **"David Tirrell marshals insights across the intellectual spectrum in his view of Caltech and in his own research."**
>
> –*Caltech president* **Thomas F. Rosenbaum**

Object Lesson: Crushing it

What happens when you take a Styrofoam cup, put it in a basket on a deep-sea submersible, and take it down to a depth of 1,000 or so meters? It shrinks. A lot. This tiny treasure was given to Nathan Dalleska, director of the Environmental Analysis Center at Caltech, by then-graduate-student Abbie Green Saxena (PhD '13), who had the opportunity to go down in the submersible *Alvin* for a project on which the two were collaborating.

The cup had nothing to do with the project. It was just taken along for the ride, to create a fun memento of the dive. And how exactly did it end up so crushed? "A Styrofoam cup is a mass of solidified polystyrene bubbles fluffed up by a gas called a 'blowing agent,'" Dalleska explains. "When you subject it to very high pressure, the bubbles are squeezed down and down so the whole object shrinks. The cup material never returns to its original shape."

Dalleska has it on display, he says, "because I like the story and have fond memories of that particular collaboration. The usual reaction is curiosity, people wondering what it is, and then no small amount of amazement when they find out where it has been."

Student Study

Leading Edge

Elected by their peers, Caltech's student leaders allocate funding for clubs and activities, manage the rotation system in which new students are assigned housing, and help to administer the Institute's honor system.

But this year's incoming Associated Students of Caltech (ASCIT) and Interhouse Committee (IHC) officers say their most important responsibility is fostering a sense of community and connection.

"I would love to be a professor, and being able to work with people to achieve a common goal will be important. I think student leadership is a very useful experience, learning to fight for a whole group's interests."

—Gabby Tender, senior in chemistry, Dabney House president

"I think it's so empowering that a school that didn't admit women until relatively recently has so many women willing to step up and lead."

—Alice Zhai, junior in applied and computational mathematics, ASCIT social director

"I think it's amazing that students can bring big, meaningful, and positive changes to campus by working with and really getting to know faculty and administrators."

—Kavya Sreedhar, junior in electrical engineering, Academics and Research Committee chair and ASCIT vice president of academic affairs

"We're very tech-oriented here. The humanities, social sciences, public speaking—those aren't things we tend to focus on. It's nice to explore those more through student leadership."

—Rachael Morton, senior in computer science, Interhouse Committee chair and ASCIT vice president of non-academic affairs

Read more about this year's student leaders at magazine.caltech.edu/post/student-leaders

From left to right: Alice Zhai, *ASCIT social director;* Kavya Sreedhar, *ARC chair;* Gabby Tender, *Dabney president;* Diandra Almasco, *Blacker president;* Sandra Liu, *Ruddock president;* Grace Chen, *IHC secretary;* Rachael Morton, *IHC chair;* Amanda Lin, *Avery president;* Dana He, *ASCIT secretary;* Sara Adams, *ASCIT director of operations;* Sarang Mittal, *Lloyd president;* Sarah Crucilla, *ASCIT treasurer;* Sarah Cai, *Page president;* Vinciane Chen, *Fleming president.* Missing: Noah Huffman, *Ricketts president* and Sakthi Vetrivel, *ASCIT president.*

In the Community

Pulsars and Pretzels

Every night, patrons pour into a bar in Old Town Pasadena and sit themselves down at long wooden tables. Beneath the blue and white Bavarian flags that adorn the dimly lit hall, they gulp down great mugs of sudsy beer and dine on German-style pub food.

Most of the time, the bar, Der Wolfkopf, is filled with the din of sports blaring from big TVs on the walls, mingled with conversations, laughter, and glasses clinking. But once a month, Caltech astronomers take over to present Astronomy on Tap, an evening of black holes and bratwurst, wormholes and witbier, pulsars and pretzels.

Astronomy on Tap began as an outreach program in New York City several years ago and has now spread to cities across the United States and even into Canada, the Netherlands, and Chile. The idea is to take the science of astronomy out of its isolation in sterile labs and present it to the public in a fun, comfortable environment. As its slogan goes, "Science is even better with beer."

Cameron Hummels, a Caltech postdoctoral scholar in astronomy, was first exposed to the Astronomy on Tap model during his time at Columbia University, where he was the Department of Astronomy's director of public outreach. When he arrived at Caltech two years ago, he brought many of the outreach practices from Columbia with him. In January 2016, he started an astronomy lecture series on campus that has been well attended by the public, but he also wanted a way to reach out to people who might be more ambivalent about science.

"A lot of times, the audience at the lectures consists of people who already have an interest in science," Hummels says. "Astronomy on Tap breaks down the barrier of going to an educational institution to learn. This is chill."

Since Caltech's Astronomy on Tap began last year, there have been more than a dozen events, each featuring trivia games, prizes, and two astronomers discussing a topic of their choosing. In keeping with the spirit of the event, the topics are presented informally, and sometimes with colorful names like "Galaxies Are People Too" or "Pulsars: Spinning Stellar Corpses."

Rahul Patel, a postdoctoral researcher at Caltech's IPAC, led a discussion called "Jupiter: Exposed" shortly after the Juno spacecraft began sending back imagery from that planet.

"The audience was receptive. They laughed at my corny jokes, and they had a lot of fun," Patel says. "I got a lot of really good questions and people engaged me right afterward wanting to know more."

Patel says events like Astronomy on Tap give the public a better understanding of both science and the scientists conducting it, while teaching scientists how to relate better to the public.

"There's a misconception of scientists as elitists," he says. "It's good for the public to see we're really no different from anyone else—we like good entertainment and a glass of beer."

Hummels has built on the success of Astronomy on Tap with other outreach programs, like one he calls Science Train, in which volunteers board Gold Line trains with signs identifying that they're astronomers and make themselves available to answer questions from the public. Another called Sidewalk Astronomy has volunteers set up telescopes on sidewalks in Old Town Pasadena to give passersby the opportunity to observe the night sky in a different way. Both of those programs debuted in August.

For a schedule of future Astronomy on Tap and other upcoming events, visit **astro.caltech.edu/outreach/.**

—Emily Velasco

Origins

Campus Hubs—a Caltech History

The Winnett Student Center has been a campus landmark for more than 50 years. This summer, the Italianate building—home to the Red Door Café, the Caltech Store, the ticket office, and a recording studio (as well as sundry meeting spaces)—was demolished to make room for a new campus hub: the Hameetman Center—named in honor of Caltech trustee Fred Hameetman (BS '62) and his wife, Joyce—is slated for a December 2018 open.

Winnett itself is only the latest in a long line of campus hubs that have come and gone on this same site. In 1915, a building known as the Old Dorm stood there (which itself had been moved from North Los Robles Avenue where it had served as a dormitory for the original Throop Polytechnic Institute).

The Old Dorm was the Institute's first student residence, with rooms for 60 undergrads. It also boasted a lunchroom known as the Greasy Spoon. Up until then, faculty and students had brought lunch to campus. "With the advent of the 'Greasy Spoon,'" noted a Caltech press release at the time, "deluxe dinners were available, soup to nuts, for $.30, including seconds."

A student center was built next to the Old Dorm in 1924, designed by Pasadena architectural legend Henry Greene, and named the Dugout in memory of a popular campus sandwich shop. The building's focal point was its unique fireplace, built with the proceeds of a fundraiser in which engraved bricks were offered for a dollar apiece. (Forty years later, the fireplace wall was preserved and integrated into the design of Winnett—and will be preserved as the site morphs again into the Hameetman Center.)

A major remodeling of the Dugout took place in 1934, and with it came a new name: the Throop Club. The 1935 *Big T* described how the new space was celebrated with a party "in which heavy gambling and equally heavy doughnut and cider inhaling figured prominently."

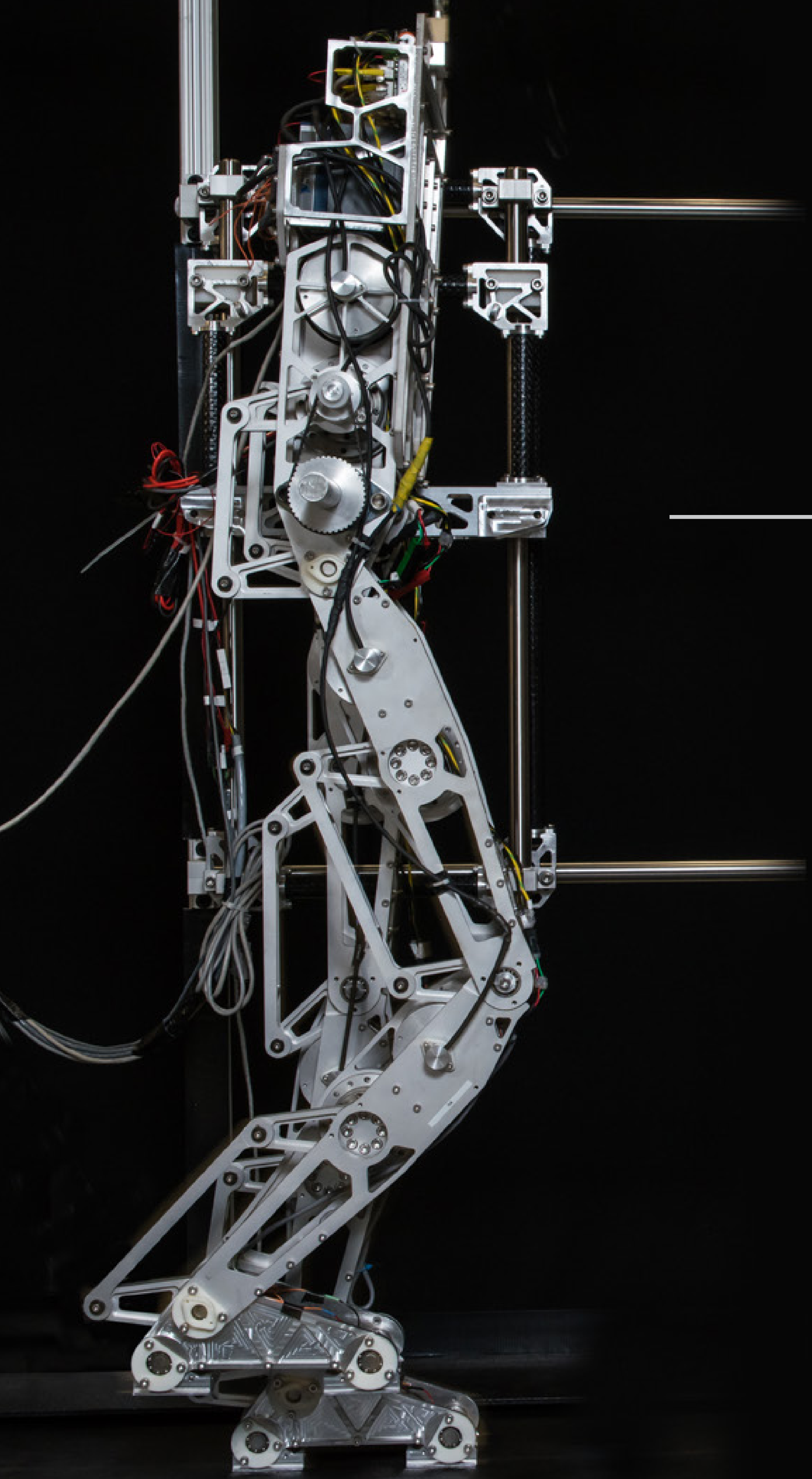
Nearly three decades later, the Old Dorm was demolished to make way for the Winnett Student Center, which opened in 1962, funded by Pasadena resident P. G. Winnett, board chairman of Bullock's department store and a Caltech trustee from 1939 to 1968. The center was enlarged and renovated in 1998.

A generous gift from Fred and Joyce Hameetman initiated the design to replace the current facility. The new Hameetman Center will include a rehearsal hall for Caltech's music programs, made possible by a gift from Steven Frautschi, emeritus professor of theoretical physics, and his wife, Mie. "With this new structure," says Joe Shepherd, vice president for student affairs, "we will be able to remedy the many limitations of Winnett to provide an attractive and inviting community gathering center as well as provide much-needed rehearsal space for our very popular music programs."

—Judy Hill

The Winnett student lounge in the 1960s.

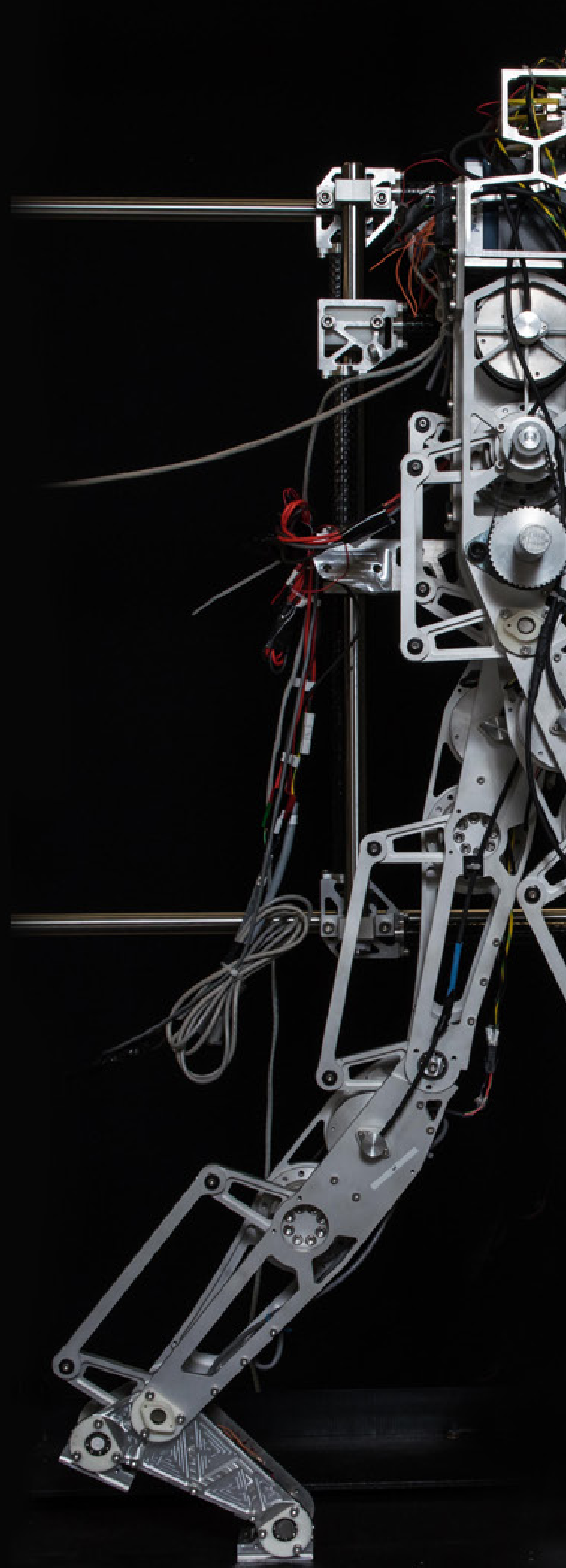
For a timeline of Caltech student hubs through the decades, go to caltech.edu/post/campus-hubs



BOTS ON THE MOVE

by Lori Oliwenstein & Robert Perkins

In Caltech labs, robots stride gracefully on treadmills and fly with the complex agility of bats. The researchers engaged in this pioneering work—two of the Institute's newest faculty members—are finding solutions to societal problems while seeking fresh insights into the most basic mechanisms of locomotion and flight.



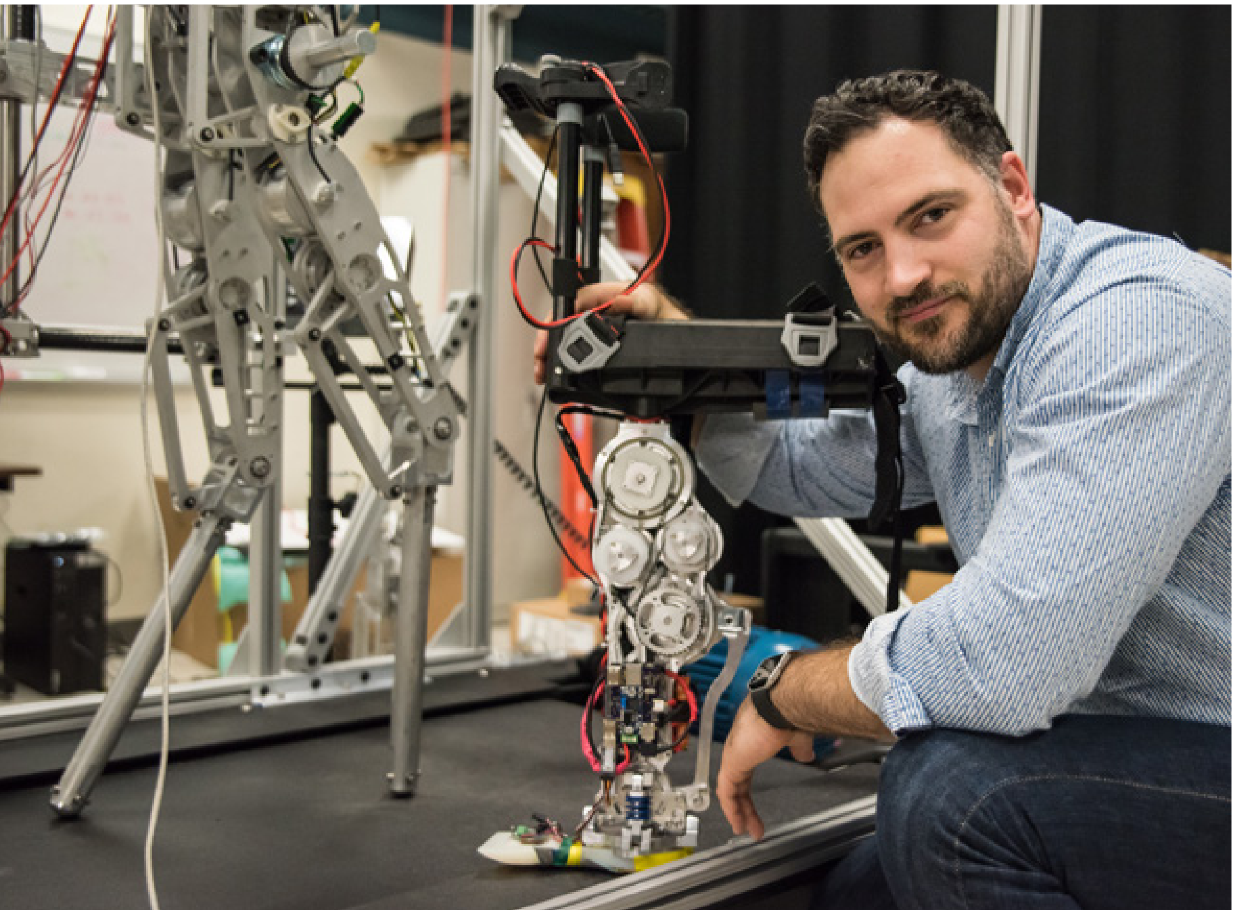
Aaron Ames's new lab at Caltech, which opened for business in mid-August, might strike a first-time visitor as part health club, part machine shop, and part museum. The latter is thanks to a bank of windows that runs along the entire basement hallway in which the lab is situated, giving passersby a glimpse of whatever intriguing robotic experiment is currently underway. Its health-club aura comes from the long treadmills upon which a headless, armless robot walks, automatically adjusting its stride as the speed of the treadmill changes. And then there are the workbenches strewn with custom-machined robot parts and electronics—a far cry from the beakers and air hoods of a conventional laboratory.

That's what it looks like. But what it is, simply, is a robotic wonderland. Especially if the kind of robot you're interested in is the kind that moves. Or, to be more specific, walks. Because Ames focuses the bulk of the time and energy of his Advanced Mechanical Bipedal Experimental Robotics (AMBER) Lab on building, testing, and—most importantly—understanding walking robots.

He does it for the most practical of reasons: to build prosthetics that can help their users achieve the most efficient and effective gait possible. But he also does it for the most theoretical of reasons: to understand how you can create a powerful and smooth gait while keeping a robot upright. In other words, to understand how walking works.

"To me, walking has always been this really special phenomenon because it's a deceptively simple thing," Ames notes. "I often say that walking is simplicity on the far side of complexity. What the human system has to do is so incredibly complex—but in the end, a smooth, natural motion flows out, and I want to understand how to do that in robots. How do you take all of this math, all these algorithms, all of these bits and ones and zeroes, and make a fluid, elegant motion? So that's what's driven me for a long time, and I've finally gotten to the point where all of these things start to intersect—the math, and the hardware, and the application on physical systems."

Of the three, however, Ames puts the math above all else. "Doing mathematics—and understanding why things work the way they do—is the only way to make fundamentally impactful contributions," Ames says. "I 'do' robots, but really, I don't do robots. What I actually do is math, and put it on robots. Robots are the expression of the mathematics."



Aaron Ames's new lab at Caltech focuses on building, testing, and—most importantly—understanding walking robots.

> **"I often say that walking is simplicity on the far side of complexity. What the human system has to do is so incredibly complex—but in the end, a smooth, natural motion flows out, and I want to understand how to do that in robots."**
>
> –Aaron Ames

While most people take a more standard approach to robotics—the version in which "it doesn't matter how we do it, if the robot does what we want in the end," Ames says—he is all about the process.

"Don't just start putting stuff together without understanding what it means, and how the pieces fit," he counsels. "Start first with the math. Start at that fundamental level, and then work your way up in complexity. I think that makes it easier, because when you finally get to the hardware and you finally get to the robot, you understand why it's doing what it's doing. And, more importantly, you can take that understanding and apply it to lots of different platforms and to a lot of places you wouldn't expect."

There are the prosthetics, for example. Ames has developed a powered prosthetic leg that, like that of its robotic counterparts, automatically senses how fast its wearer is walking and compensates its stride to match. It even has a flexible ankle with two degrees of freedom—the same as a human ankle—allowing for a natural and fluid gait. And there are the walking robots, to which Ames teaches bipedal motion using computational approaches. The robots "learn" their stride in real time, using optimization algorithms to decide how best to articulate their legs in order to walk with the greatest stability and the lowest expenditure of energy. He's even translating these ideas to exoskeletons with the goal of crutch-free dynamic walking for paraplegics and robotic assistance for a variety of mobility impairments.

"The same methodology has been applied to cars for autonomous driving applications, and to swarm robotics, to quadrotors, to flying robots," Ames notes. "Once you get that basic math, you can apply it to a lot of different application domains."

Watch Aaron Ames talking about his work at **magazine.caltech.edu/post/bots-on-move**

A Home for CAST

The new facility that will house Caltech's Center for Autonomous Systems and Technologies (CAST) will be a place where machines and researchers both work together and learn from one another. While engineers construct and test drones, robots within CAST itself will help run the facility—all while being observed by 46 cameras that will provide complete coverage of the interior, tracking each robot's motion down to within 20 microns (less than a human hair).

CAST will unite engineers, geologists, medical engineers, doctors, rocket scientists, and more, all working in the fields of drone research, autonomous exploration, and robots in medicine. Their goal: to teach autonomous systems to think independently, preparing them for the rigors of life outside the lab.

The facility will have an assembly lab, an oval track for the testing of walking robots, and, as its centerpiece, a three-story-tall, wholly enclosed aerodrome in which the researchers will test flying drones. To provide the ever-shifting environmental conditions that the drones would face in the real world, this aerodrome—the tallest of its kind—will include a 100-square-foot wall consisting of 1,296 fans capable of generating wind speeds of up to 44 mph and a side wall with an additional 324 fans. Each and every one of these 1,620 fans will be able to be individually controlled to create a nearly infinite variety of wind conditions—from a light gust to a stormy vortex—to which the drones will learn to react.

The new CAST facility is slated to open this fall.

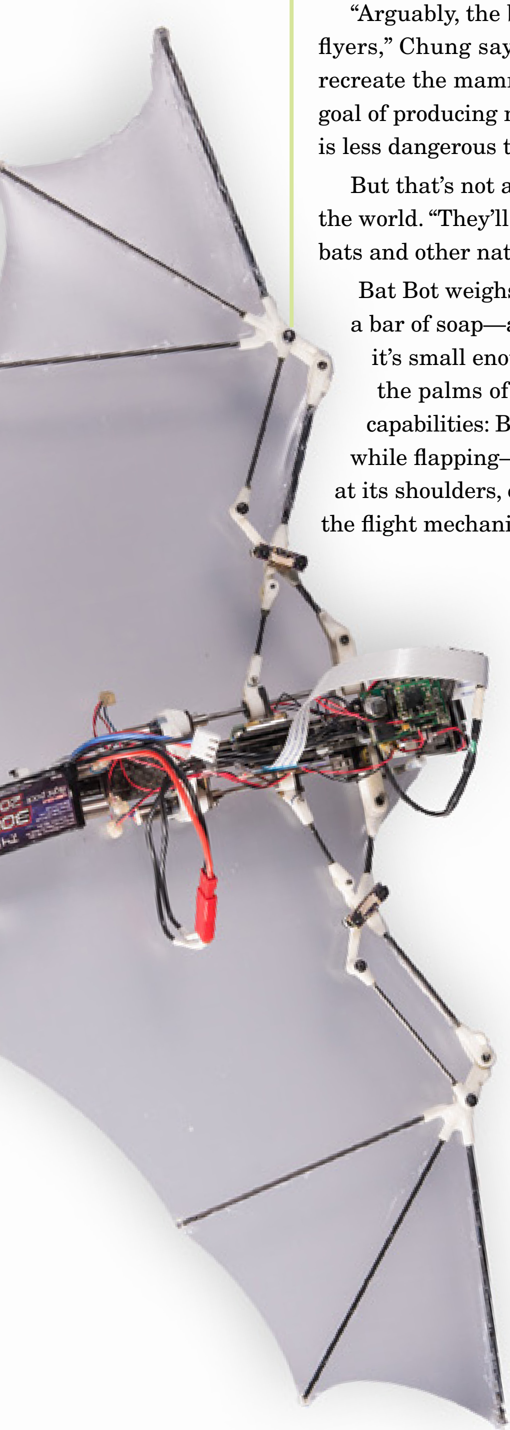
Flying Robots

While Ames focuses on ground-based locomotion, Soon-Jo Chung is reaching for the skies … and the stars. Not with a plane or even a conventional drone, but with a robotic bat equipped with soft, articulated wings, which he developed alongside colleagues at the University of Illinois at Urbana-Champaign, where he had been a faculty member in aerospace engineering for seven years, before joining Caltech in the summer of 2016. That bat—dubbed Bat Bot by the team that created it—is capable of recreating, with what they say is unprecedented fidelity, the complex wing motions and key flight mechanisms of its living counterpart.

"Arguably, the bat is one of the most advanced animal flyers," Chung says. That's why, he says, he decided to recreate the mammalian bat in robotic form, with the goal of producing mechanical flyers that are safe—a wing is less dangerous than a rotor—and energy efficient.

But that's not all Chung's Bat Bots will be able to offer the world. "They'll also give us more insight into the way bats and other natural flyers fly," Chung says.

Bat Bot weighs only 93 grams—about the same as a bar of soap—and has a roughly 1-foot wingspan; it's small enough, in other words, to be cradled in the palms of your hands. But its size belies its capabilities: Bat Bot can alter its wing shape—even while flapping—by flexing, extending, and twisting at its shoulders, elbows, wrists, and legs. This mimics the flight mechanism of biological bats, which involves several different types of joints that interlock bones and muscles, creating a musculoskeletal system capable of movement in more than 40 directions.



Bot bit

The Caltech Robotics Team took first prize at 2016's International RoboSub Competition against 47 competitors. The team's entry, nicknamed Dory, successfully navigated an obstacle course with tasks that required it to touch buoys, fire torpedoes at targets, and rescue an object under water—all autonomously. To see RoboSub in action, visit **breakthrough.caltech.edu/magazine/2017-jun/#First-Place**.

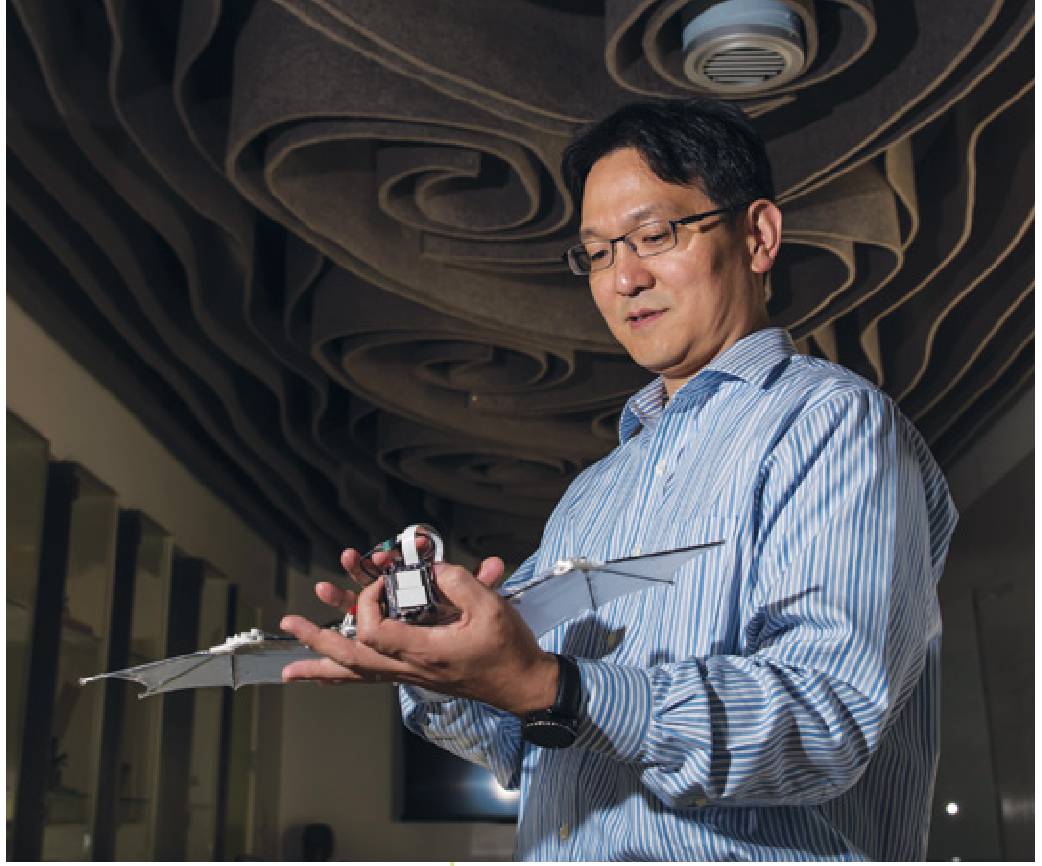
The skin on Bat Bot's wings, says Chung, is almost as important as the wings' shape-altering abilities. "The dynamics of bat flight are even more complex and elegant because of the bat's soft membrane wings," he notes.

And so Chung and his team decided to try to recreate those wings in Bat Bot to the best of their technological abilities. The problem, they found, was that conventional lightweight fabrics, like nylon and Mylar, are not stretchable enough to take on the demands of bat flight. And so, the researchers custom developed an ultrathin, silicone-based membrane—a membrane just 56 microns thick, the thickness of a human hair—that can stand in for true bat wings.

Chung's testing has shown that when a bat flaps its wings, the surrounding air pushes on the wing membranes, deforming them. Similarly at the end of the downward motion of the Bat Bot wings, the membranes snap back to their usual shape by pushing back against that air; this dynamic property of the wings hugely amplifies each flap's power, allowing the lightweight robot to stay aloft with minimal exertion. This same amplification of the power of the wings' motion means that Bat Bot has the potential to be significantly more energy efficient than current flying robots.

Bot bit

A modular space observatory proposed by Caltech's Sergio Pellegrino would feature a 100-meter mirror—40 times larger than Hubble's—whose components would be shipped into space separately and then assembled onsite by robots. The design calls for more than 300 deployable truss modules that would unfold to form a scaffolding on which small mirror plates would be placed to create a large segmented mirror.



Soon-Jo Chung and his team have created a robotic bat equipped with soft, articulated wings, which has been dubbed Bat Bot.

Watch Soon-Jo Chung explaining his Bat Bot at magazine.caltech.edu/post/bots-on-move

From its skin to its articulated wings, Bat Bot is unique among its flying-robot kin. "I wanted to challenge the status quo of drones that predominantly use high-speed rotor blades, which are quite noisy and dangerous," Chung says. Because of its soft wings, Bat Bot will potentially be useful in environments where more traditional drones, with their spinning rotors, are likely to collide into objects or people, and cause damage or injury.

Bat Bot is not Chung's only focus. He is also working on autonomy and guidance, navigation, and control of spacecraft systems, such as spacecraft swarms, as well as exploring the potential of drone swarms. "You can reconfigure your swarm system to another shape quite easily; think about autonomous flying LEGO blocks that can build whatever you imagine," says Chung. "Also, the entire system doesn't fail even if you lose a handful of individual robots from the swarm. In essence, swarms are more flexible, more robust, and possibly more capable than a monolithic system."

His vision of the robots of the future—whether they are batlike or not—is one in which we as a society think outside the box … or the paved road. Take, for instance, autonomous vehicles. "Why should self-driving cars be restricted to a two-dimensional world?" he asks. "It might be technologically easier to achieve a fully autonomous flying-car network than to add self-driving cars to the existing roads since there is no gridlock and there are no pedestrians in the sky."

Bot bit

Caltech's Andrew Thompson is working with researchers at JPL on artificial intelligence systems for robotic submersibles to help them track signs of life beneath the ocean's waves. The team hopes this artificial intelligence will someday be used to explore the icy oceans believed to exist on moons like Europa.

Aaron Ames, Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems, moved the Advanced Mechanical Bipedal Experimental Robotics (AMBER) Lab to the Caltech Division of Engineering and Applied Science from the Georgia Institute of Technology. He was a postdoctoral scholar in control and dynamical systems at Caltech from 2006 to 2008. His robotics research is funded by the National Science Foundation Cyber-Physical Systems Program and the National Robotics Initiative.

Soon-Jo Chung, associate professor of aerospace and Bren Scholar in the Graduate Aerospace Laboratories of Caltech (GALCIT), splits his time between Caltech's campus and the Caltech-managed NASA Jet Propulsion Laboratory (JPL), where he is a research scientist. His work on flying robots and spacecraft has been funded by the National Science Foundation, Air Force, Navy, Army, NASA, and JPL.

Guesstosterone

Testosterone makes men less likely to question their first impulse.

By Emily Velasco

Hotheaded, impulsive men who shoot first and ask questions later are a staple of westerns and 1970s cop films, but research conducted at Caltech is showing there might be truth to the trope.

A study by researchers from Caltech, the Wharton School, Western University, and ZRT Laboratory suggests that higher levels of testosterone make men more likely to rely on snap judgments and less likely to realize when they're wrong.

Caltech's Colin Camerer, the Robert Kirby Professor of Behavioral Economics, T&C Chen Center for Social and Decision Neuroscience Leadership Chair, and study co-author, says the topic is of particular importance because of the growing testosterone-replacement-therapy industry, which is primarily aimed at reversing the decline in sex drive many middle-aged men experience.

"If men want more testosterone to increase sex drive, are there other effects? Do these men become too mentally bold, thinking they know things they don't?" Camerer asked.

Bats, Balls, and Brain Teasers

To investigate, researchers measured cognitive reflection—a decision-making process by which people stop to consider whether their gut reaction to something makes sense.

They gathered 243 male participants (making the study one of the largest of its type ever conducted) and randomly selected half of the group to receive a dose of testosterone gel, while the other half received a placebo gel. After waiting a few hours for the testosterone to be fully absorbed, the participants returned to the lab to perform a basic series of tasks, including a basic math test to control for participant engagement, motivation level, and math skills.

Then they took a cognitive-reflection test, essentially a series of brain teasers designed so they appear to have an obvious answer that is actually wrong. The idea is that someone with reduced

1. A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?

cognitive reflection will stick with the first—usually incorrect—answer that pops into their head while someone who ponders it longer will come up with the correct answer.

The questions included on the test are exemplified by the following:

A bat and a ball cost $1.10 in total. The bat costs $1 more than the ball.

How much does the ball cost?

For many people, the first answer that comes to mind is that the ball costs 10 cents, but that's incorrect because then the bat costs only 90 cents more than the ball. The correct answer is that the ball costs 5 cents and the bat costs $1.05. An individual prone to relying on their gut instincts would be more likely to accept their first answer of 10 cents. However, another person might realize their initial error through cognitive reflection and come up with the correct answer.

Participants were not limited on time while taking the test and were offered $1 for each correct answer and an additional $2 if they answered all the questions correctly.

Wrong More Quickly, Right More Slowly

The results showed that the group that received testosterone scored significantly lower than the group that received the placebo, on average answering 20 percent fewer questions correctly.

The testosterone group also "gave incorrect answers more quickly, and correct answers more slowly than the placebo group," the authors wrote in the paper describing their results. The same effect was not seen in the results of the basic math tests administered to both groups, they also noted, concluding that the results "demonstrate a clear and robust causal effect of [testosterone] on human cognition and decision-making."

"The testosterone group was quicker to make snap judgments on the brain teasers," says Camerer. "The testosterone is either inhibiting the process of mentally checking your work or increasing the intuitive feeling that 'I'm definitely right.'"

Confidence, aka Mental Aggression

The researchers believe that the phenomena they've observed can be linked to testosterone's biological role in the male drive for increasing and protecting social status. In animals, status is often attained and maintained through physical aggression, which has a well-documented connection to testosterone. In human males, confidence—a sort of mental aggression, as Camerer puts it, is one of the primary drivers of social status, and it, too, is linked to testosterone.

"If a person acts a bit overconfident, there's a status that comes with that," he says. "As a side effect, you'll feel like you're right and will not have enough self-doubt to correct your mistakes."

2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take100 machines to make 100 widgets?

What's Next?

Researchers at Nipissing University in Ontario have been replicating the Caltech study, and their preliminary results may be released in the near future.

Testosterone might also have other behavioral effects that Camerer says warrant further exploration. During the cognitive-reflection study, the researchers also looked at how testosterone could influence bidding behavior in auctions, but they did not get clear results.

Camerer and his colleagues are now looking at how testosterone affects the desire for status symbols among men. A paper on that research has yet to be published, but their initial results suggest that men with higher testosterone levels gravitate toward the luxury goods, preferring Calvin Klein jeans over Levi's, for example.

3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?

"It's like peacocks showing off their tails," says Gidi Nave (PhD '16), a former graduate student in Camerer's lab, who was a coauthor of the paper and is now an assistant professor at the Wharton School of the University of Pennsylvania. "In many ways, buying something expensive is allowing me to signal to others my status and wealth."

Other coauthors of the paper, titled "Single dose testosterone administration impairs cognitive reflection in men," were Amos Nadler of Western University in Canada and David Zava of ZRT Laboratory.

Funding for the study came from the MacArthur Foundation, Ivey Business School, International Foundation for Research in Experimental Economics, Russell Sage Foundation, USC, INSEAD, and the Stockholm School of Economics. [C]

[Answers]

1. 5 cents

Here's why:

It's easy to assume that the ball would cost 10 cents, but if that's the case and the bat costs a dollar more, the bat would cost $1.10. Together, the bat and ball would cost $1.20 rather than $1.10. However, if the ball costs 5 cents, the bat would cost $1.05. Together, those add up to $1.10.

2. 5 minutes

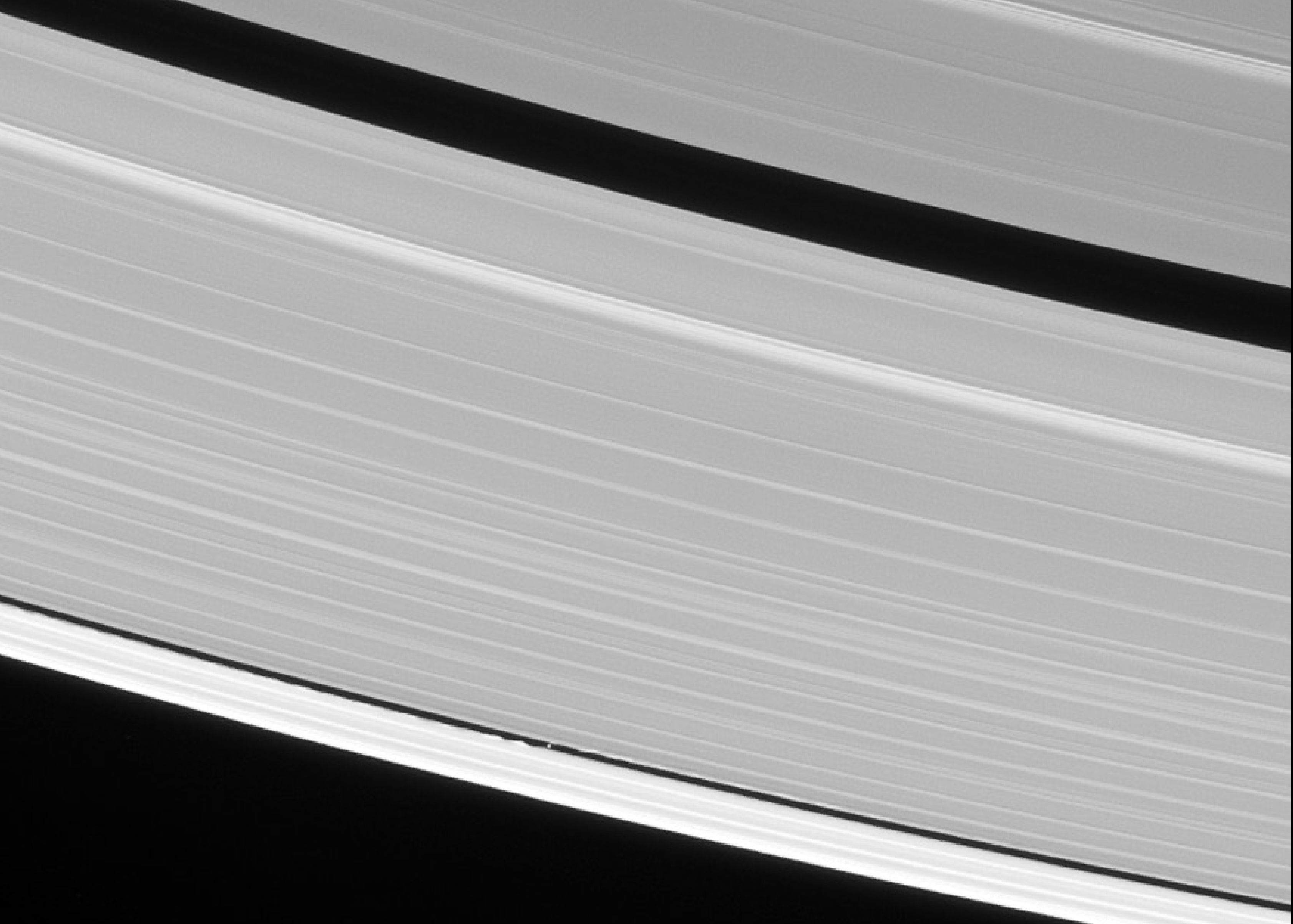
Here's why:

In the above statement, there are five machines and they make five widgets, which means each machine takes five minutes to make one widget. No matter how many machines there are, it still takes each machine five minutes to make a widget. So, if there are 100 machines and each takes five minutes to make a widget, they'll have made 100 widgets after five minutes.

3. 47 days

Here's why:

The doubling of the lily-pad patch can be described mathematically, but common sense will also get you the answer to this problem. If the patch covered half the lake on day 47 and then it doubled in size on day 48, it would cover the lake, since doubling a half makes a whole.



Cassini's Grand Finale

After almost 20 years in space, NASA's Cassini spacecraft embarked on the last chapter of its remarkable story of exploration this past spring.

On April 26, Cassini began its Grand Finale with the first of 22 planned dives between Saturn and its rings. The final orbits brought the spacecraft closer to Saturn than ever before, providing stunning high-resolution images and new insights into the planet's interior structure and the origins of the rings.

No other mission has ever explored this unique region, and what scientists have learned and will learn from these final orbits will help to improve our understanding of how giant planets—and planetary systems everywhere—form and evolve.

During its final orbit on September 15 (while this issue of *Caltech* magazine was at the printer), Cassini was set to plunge into Saturn's atmosphere, sending back science data to Earth for as long as its thrusters could keep its antennas pointed at Earth. After losing contact, the spacecraft would burn up and disintegrate like a meteor, becoming part of the planet itself.

For more on Cassini, go to saturn.jpl.nasa.gov

Launched in 1997, Cassini has orbited Saturn since arriving there in 2004. During the past 13 years, the spacecraft has made many dramatic discoveries, including a global ocean within the moon Enceladus and liquid-methane seas on another moon, Titan. Cassini's mission was brought to a close because the spacecraft was running low on the rocket fuel used for adjusting its course. If left unchecked, there was a risk that it could collide with Saturn's moons and possibly contaminate future studies of habitability.

During the ring dives—where the spacecraft's speed surpassed 75,000 miles per hour—Cassini collected a host of valuable information that was too risky to obtain earlier in the mission. "The data we are seeing from Cassini's Grand Finale are every bit as exciting as we hoped, although we are still deep in the process of working out what they are telling us about Saturn and its rings," said JPL's Linda Spilker, the project scientist on Cassini, in July.

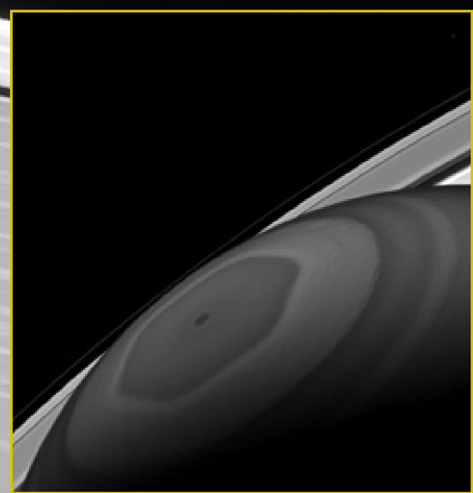
As of press time, Cassini has:

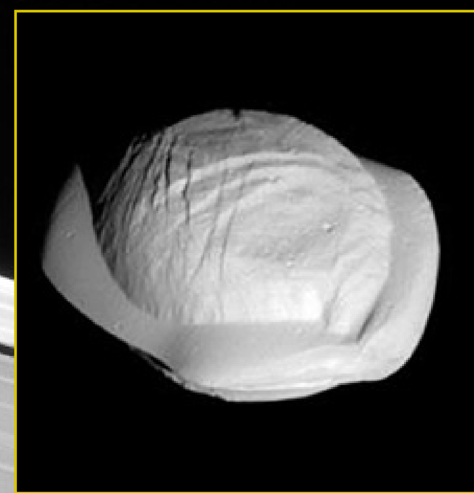
- Made detailed maps of Saturn's gravity and magnetic fields, revealing how the planet is arranged internally and possibly helping to solve the irksome mystery of just how fast Saturn is rotating
- Collected data showing that Saturn's magnetic field is surprisingly well-aligned with the planet's rotation axis, with a tilt of less than 0.06 degrees—much smaller than scientists had previously estimated
- Obtained the first-ever samples of the planet's atmosphere and main rings
- Returned extraordinary high-resolution views of Saturn's rings and the planet itself. Close-up views of Saturn's C ring—which features mysterious bright bands called plateaus—reveal that the plateaus have a streaky texture, whereas adjacent regions appear clumpy. Ring scientists believe the new level of detail may shed light on why the plateaus are there and what is different about the particles in them.

By the time you read this article, Cassini will be no more but will undoubtedly have yielded more insights into Saturn's rings … and perhaps revealed a few surprises. For more on Cassini's last days, visit **magazine.caltech.edu/post/cassini-finale.**

The Cassini mission is a cooperative project of NASA, the European Space Agency, and the Italian Space Agency. NASA's JPL, a division of Caltech, manages the mission for NASA's Science Mission Directorate. JPL designed, developed, and assembled the Cassini orbiter.

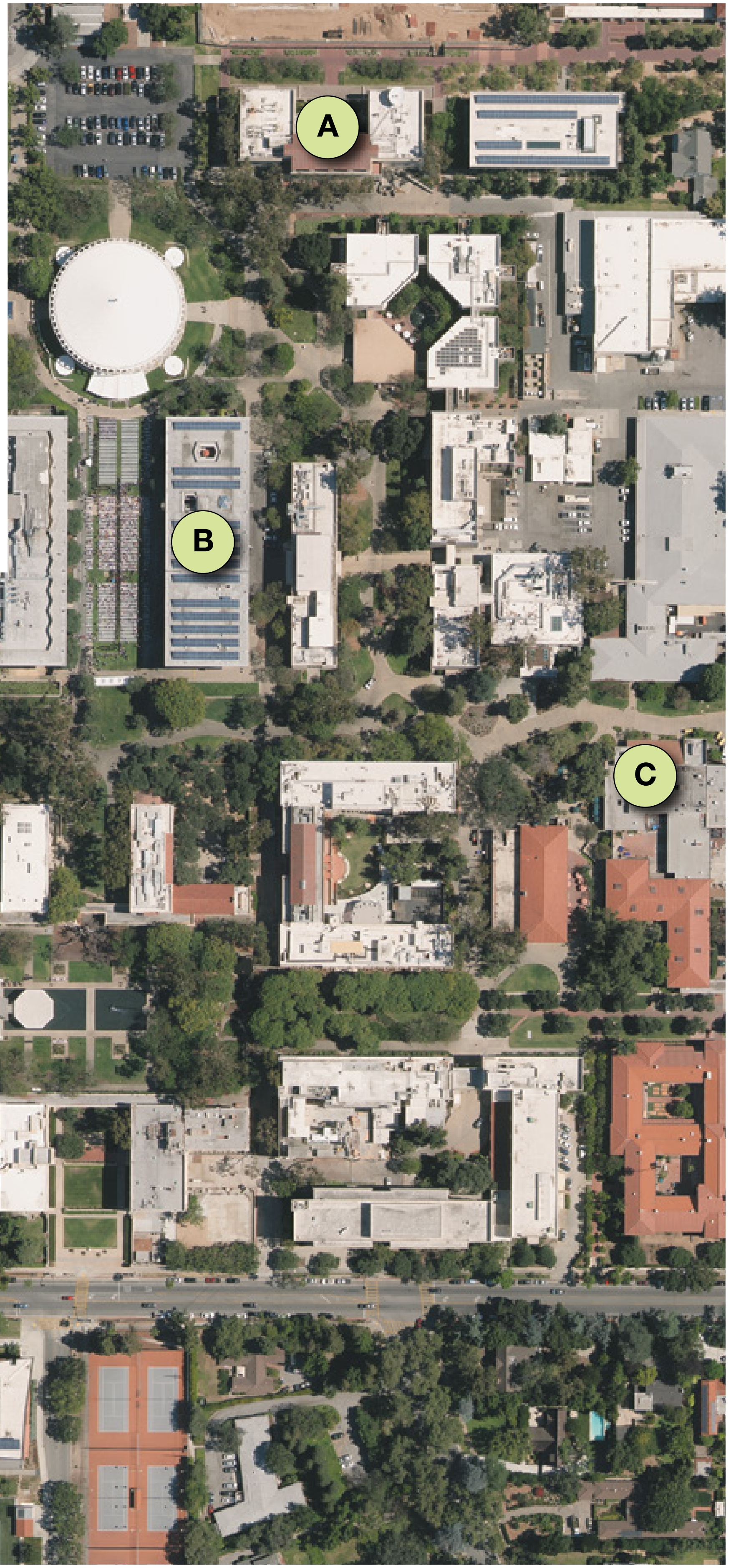
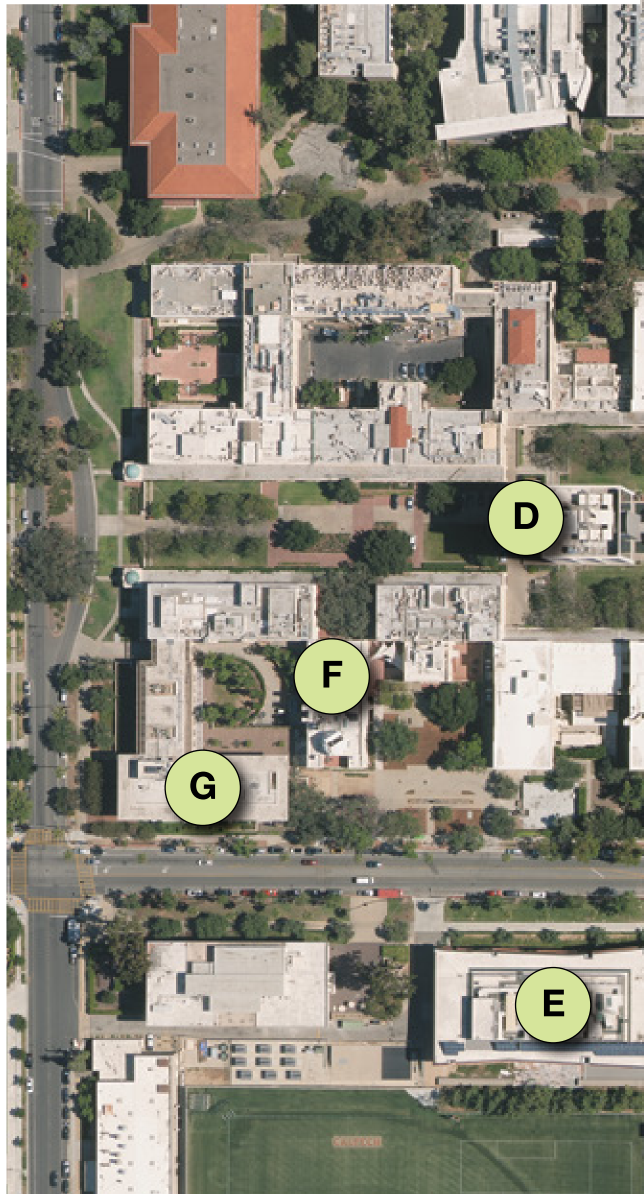
Below, left: The north pole of Saturn surrounded by a swirl of clouds. Center: Enceladus' south-polar jets backlit by sunlight, the moon itself glowing in reflected Saturn-shine. Right: The northern hemisphere of Pan, a small moon of Saturn.





ROOFTOPS *of* Caltech

Of all the fascinating research, communication, and innovation that take place on campus, some of the most interesting are hidden—often in plain sight—where most members of the community never go: on the rooftops of campus buildings. Here, we catalog a few of Caltech's notable building superstructures and reveal what they do.

A Moore Laboratory
Radio Telescope

The Caltech Radio Frequency and Microwave Group uses the six-meter telescope atop Moore Laboratory for educational purposes as well as to test amplifiers, feeds, spectrometers, software, and receivers.

B Baxter Hall (and other locations)
Solar Panels

About 5,000 solar panels—located atop Baxter Hall, campus parking structures, and other buildings—provide the campus with 1.9 gigawatt-hours of electricity per year.

C Chandler Café
Rooftop Aeroponics Towers

The aeroponics garden is now providing fresh herbs and vegetables for use at Chandler Café, reducing produce purchase and improving the facility's carbon footprint by creating a roof-to-table supply chain.

D Millikan Library
Earthquake Shaker

A synchronized vibration generator, or "shaker," is installed on the roof for forced vibration tests to simulate the effects of earthquakes.

E Cahill Center for Astronomy and Astrophysics
Rooftop Observatory

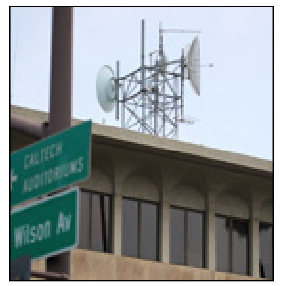
The Cahill Rooftop Observatory includes permanent 8-, 10-, and 14-inch Celestron telescopes, which can be coupled with a camera.

F Linde + Robinson Laboratory
Coelostat

The white dome atop Linde + Robinson houses a coelostat (SEE-luh-stat), a solar observatory that uses mirrors to project an image of the sun down to the main lobby.

G South Mudd
Antennas

The microwave and radio antennas atop South Mudd receive seismic data from scores of Caltech/USGS monitoring stations across Southern California.



Read more about Caltech's rooftop structures at magazine.caltech.edu/post/rooftops

Where It All Began

by Robert Perkins

Caltech's pioneering geobiology program, which began in the '90s, is uncovering knowledge about the forces that created our world and continue to shape it.

Although Caltech's focus on the once-unheard-of field of geobiology—a combination of geology, geochemistry, and biology—may have given other universities and scientists pause, it has put the Institute in a leading position to help explain why life exists on Earth.

"Geobiology is asking very systematic questions about the coevolution of Earth and life," says John Grotzinger, the Ted and Ginger Jenkins Leadership Chair for the Division of Geological and Planetary Sciences (GPS) and the Fletcher Jones Professor of Geology. "We're merging our understanding of geologic processes in the past with modern approaches in molecular microbiology and using state-of-the-art geochemistry to explore the links between these disciplines."

Already, the research the division has done has led to insights about the origin of molecular oxygen in the atmosphere and oceans, work that shows promise in the treatment of cystic fibrosis, and the naming of two Caltech geobiologists as MacArthur Fellows.

Even with 38 tenured faculty members, the division knows it cannot do everything—and so does not attempt to do so. Instead, the division leadership has cultivated a tradition of reinvention aimed at predicting and preparing for the future. In the '50s, the GPS division sold its world-class collection of fossils to the Natural History Museum of Los Angeles County—and invested the proceeds in a new program in isotope geochemistry. At the time, the move was viewed as an odd one by the American geological community, but it paid huge dividends. Within 10 years, Caltech's geochemists were positioned to take the lead in analyzing moon rocks brought back from the Apollo missions.

It was in this spirit of reinvention that GPS put together a faculty committee in 1994 to try to peer into the future of geosciences and determine where the division should go next. The committee was led by Peter Goldreich, now the Lee A. DuBridge Professor of Astrophysics and Planetary Physics, Emeritus. In what came to be known as the Goldreich Report, the faculty specifically identified geobiology as a field to build on for the future.

Joseph Kirschvink, at the time Caltech's only geobiology professor, recognized the potential to think of DNA not as a finished product but as an evolutionary record. And though the gene-sequencing revolution that made DNA analysis cheap and easy was still a decade away, Kirschvink quickly became the leading voice in the push toward geobiology.

"My colleagues [at other institutions] scratched their heads and said, 'What are you doing?'" says Kirschvink, the Nico and Marilyn Van Wingen Professor of Geobiology. "But a few years later, they were scrambling to catch up."

William E. Leonhard Professor of Geology Edward Stolper, who was division chair at the time, took the Goldreich Report and committed the division to hiring several new faculty members in the broad area of geobiology—but without increasing the size of the department. Starting with Dianne Newman in 2000, Caltech has hired five faculty members who are now part of the geobiology program. In that time, the GPS division also established geobiology options for both undergraduates and graduate students.

Right time, right place

When Stolper committed the division to building a geobiology program at Caltech, the allocation of such substantial resources was not without risk. As a field of scientific inquiry, geobiology had existed for over a century—at least since the late 1800s, when Russian microbiologist Sergei Winogradsky first began looking at how organisms metabolize minerals. But for years, it was something of an academic fringe area.

Shortly after Caltech began investing in the field, however, technological advances—including the new genome-sequencing methods—gave it a jump start. Completed in 2000, the first human-genome sequencing cost about $2.7 billion and took 15 years. Today, that same analysis costs just over $1,000 and can be completed in a matter of days—and for microorganisms, the cost is far lower, and the analysis can be completed in a matter of hours.

In broad terms, geobiology gives scientists a framework for asking questions about

Illustration by Charis Tsevis

From left: Edward Stolper, Mel Simon, and John Abelson on a field trip in Western Australia to look for evidence of the earliest history of life on Earth.

how life on Earth evolves, as well as how its evolution influences and is influenced by its environment. For example, one of the first big geobiology questions tackled by Caltech researchers focused on the origin of oxygen in Earth's atmosphere. The geological record indicates that sometime around 2.5 billion years ago, oxygen abruptly became prevalent in the atmosphere. This event, known as the Great Oxygenation Event, fundamentally changed the planet, making complex, multicellular life possible. Geobiologists at Caltech connected this event to the evolution of photosynthetic cyanobacteria.

"Only because of life do we have significant molecular oxygen, which influences the evolution of the planet. But also, life evolves and develops in a geological environment," Stolper says. Most of the genetic sequence encoded in our DNA evolved billions of years ago when Earth was a very different place, and the sequence itself and the biological processes it encodes can tell us something about what that place was like, he says.

In 2016, geobiology professor Woody Fischer proposed that the planet-shaping evolution of oxygenic photosynthesis came about just once, around 2.5 billion years ago. No other organism duplicated the process—instead, plants, algae, and other organisms that perform oxygenic photosynthesis simply "borrowed" the technique by subsuming cyanobacteria as organelles (chloroplasts) in their cells at some point during their evolution, according to endosymbiotic theory.

Geobiology's insights are not limited to the ancient past. Molecular biologist Dianne Newman, the Gordon M. Binder/Amgen Professor of Biology and Geobiology, focuses her work on microbial stress responses, with an emphasis on how microbes generate energy and survive when oxygen is scarce. Last year, she and her colleagues used soil samples collected in the courtyard of Caltech's Beckman Institute, isolating a bacterium that produces a small protein called pyocyanin demethylase (PodA), which inhibits the development of biofilms of *Pseudomonas aeruginosa*, a major opportunistic pathogen found in a variety of infections.

Grotzinger, who was recruited into the geobiology program from MIT in 2005, has applied the principles of geobiology to his work as project scientist for the NASA/JPL Mars Science Laboratory Curiosity rover, searching for evidence of ancient environments that could have been habitable for microbes. By understanding how geobiology is applied to the study of early environments on Earth, the Curiosity science team was able to constrain the salinity, redox state, and duration of ancient martian water bodies, and whether they contained dissolved nutrients and even organic compounds.

Beyond gene sequencing, several techniques and technologies that are fundamental to geobiology also blossomed during the early 2000s, including the ability to take in-situ samples of microbes and analyze their genomes without having to culture them in a lab, and to use stable-isotope labeling to reveal the composition of cells. Victoria Orphan, the James Irvine Professor of Environmental Science and Geobiology, has used these techniques to study microorganisms that live in deep-ocean sediment beds and consume large quantities of methane released from seeps in the ocean floor. She and her colleagues have also studied soil samples from the 2015 methane leak at Southern California Edison's Aliso Canyon storage facility to learn more about the methanotrophs—microbes that consume methane—that could one day be used to mitigate such disasters.

Research in the geobiology program has not only helped to attract outstanding students, postdoctoral scholars, and faculty members to this new field, but the work has also led to recognition from the scientific community as a whole, including the naming of Newman and Orphan as MacArthur Fellows last fall.

A little help from our friends

It is impossible to tell the story of geobiology without recognizing the instrumental contributions of the Agouron Institute, says Grotzinger.

A nonprofit organization formed in 1978, the Agouron Institute owned part of a successful company, Agouron Pharmaceuticals, which saw great success through the creation of a widely used HIV protease inhibitor, Viracept. The Agouron Institute has used that success to help fund research primarily in biology and geobiology. The institute has strong ties to Caltech: its president and executive director is John Abelson, Caltech's George W. Beadle Professor of Biology, Emeritus; and its chairman of the board of directors is Melvin Simon, the Anne P. and Benjamin F. Biaggini Professor of Biological Sciences, Emeritus. Grotzinger and Stolper also sit on the board of directors.

Abelson and Simon took an early interest in geobiology, starting with an assessment of the field in 2001—led by Newman. One of the Agouron Institute's most visible contributions to the field of geobiology has been the support of fieldwork, including the establishment of the International Geobiology Course, now run by Caltech, which brings together students and faculty from biology, geology, and chemistry, allowing them to learn from one another beginning with all-important course work in the field.

"It's become a legendary class," says Newman, "and many of the people now in prominent faculty positions throughout the U.S. went through that course at one point." The Agouron Institute followed up on its support of the geobiology course with a postdoctoral fellowship program that it continues to support.

From the deep past to the stars

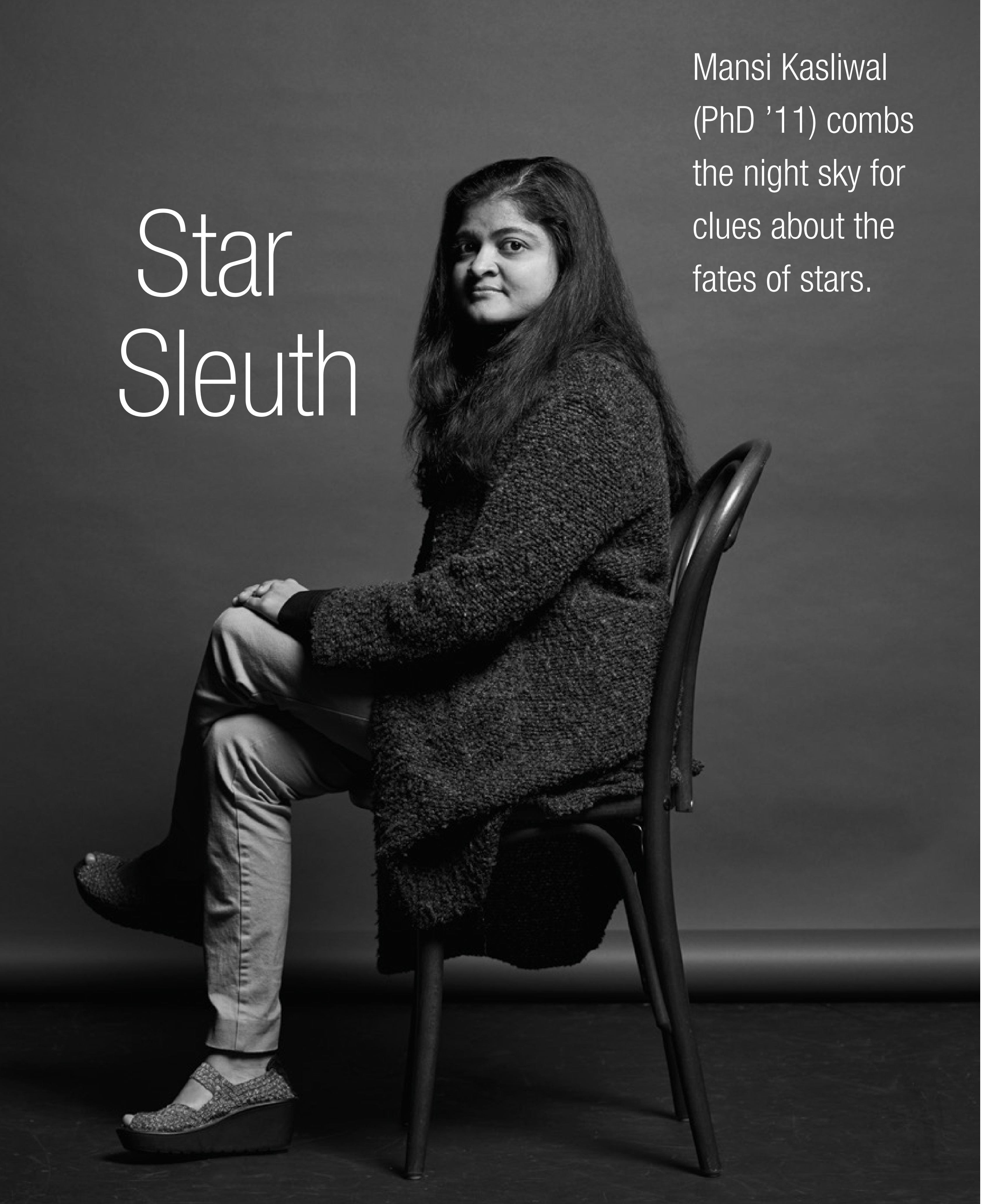
Looking to the future, Grotzinger expects geobiology to become increasingly important in the study of exoplanets. He and Fischer are currently studying Mars as an analog for an Earth-like planet that might have once had oxygen in its atmosphere as a result of inorganic processes.

In a competitive world, Stolper sees the geobiology program as another way that Caltech is distinctive. "This focus gives you an advantage—graduate students will come, postdocs will come, people on sabbatical will want to come, people who want to become faculty members in that area will come."

Geobiology is the latest success story, he says, but it's simply an example of a mind-set the Institute has always had. "These programs always started with hiring somebody about whom everybody thinks, 'This person's never going to fit in because they're a chemist, they're a physicist, they're not going to be comfortable here.' And then they just take off. In the end, those people are the pioneers." [C]

For an expanded version of this article, go to magazine.caltech.edu/post/where-all-began

Clockwise from left: Kyle Costa, a postdoctoral scholar, collecting soil in the courtyard of Beckman Institute from which Dianne Newman's lab isolated a bacterium that disrupts biofilms. Research scientist Patricia Tavormina removes a small amount of Aliso Canyon soil from frozen samples for DNA extraction as part of a collaboration with Victoria Orphan. GPS graduate student Nathan Stein (at right) conducting summer research fieldwork on Turks and Caicos's Little Ambergris Cay, along with Maya Gomes from Johns Hopkins. *Oxphotobacteria* in microbial mats in Yellowstone.



Star Sleuth

Mansi Kasliwal (PhD ’11) combs the night sky for clues about the fates of stars.

Above: In 2002, a star called V838 Mon became the brightest star in the Milky Way. This image, taken with the Hubble Space Telescope, reveals the so called light echo—the flash of light reflected from layers of dust surrounding the star.

Mansi Kasliwal (PhD ’11), an assistant professor of astronomy at Caltech, searches the night sky for astronomical transients—the flashes of light that appear when a star becomes a million to a billion times as bright as our sun and then quickly fades away. As principal investigator of GROWTH (Global Relay of Observatories Watching Transients Happen), she heads up a worldwide network of collaborators who are trying to capture the details of these transient events to find out more about how they evolved.

Kasliwal grew up in Indore, India, and came to the United States to study at the age of 15. She earned her BS at Cornell University and then came to Caltech to complete her doctoral work in astronomy. After a postdoctoral fellowship at Pasadena’s Carnegie Observatories, she joined the Caltech faculty in 2015.

We talked with Kasliwal about her fascination with the night sky, why she doesn’t mind 3 a.m. phone calls, and the dream she hopes will take her to the South Pole.

Caltech Magazine: What is the main focus of your research?

Mansi Kasliwal: It’s basically about discovering and understanding transients—the energetic flashes of light that cause the fireworks that adorn the night sky—and what they can tell us about the elements and where they are synthesized, the fates of stars, and what happens in the final stages of their lives.

There are two main themes to my research: One has to do with optical transients, or transients that can be seen with optical telescopes—that’s where GROWTH comes in—and the other is around infrared transients and exploring the dynamic infrared sky.

CM: Let’s start with GROWTH.

MK: I’ve done optical astronomy for my entire career here. GROWTH builds off of that. GROWTH is primarily looking at optical transients from a host of different observatories to build a more complete picture of the physical processes of their evolution. We have a network of 18 observatories in the Northern Hemisphere. As Earth rotates and daylight creeps in at one of our locations, we switch observations to one of our facilities westward that is still enjoying nighttime.

CM: How do you communicate with one another when one of the observatories sees an intriguing transient in the night sky?

MK: Some alerts are fully robotic, i.e., my computer calls me. Some alerts are from my collaborators on the other side of the globe. The best part about GROWTH is that even if a phone call is at 3 a.m., everyone’s sleepy voices are actually quite excited.

CM: A new system of telescopes is coming online at Caltech’s Palomar Observatory in Southern California called the Zwicky Transient Facility (ZTF). What makes it better than the Palomar Transient Factory that was there before?

MK: ZTF is an order of magnitude faster in survey speed, so we can either search more sky or we can search the sky faster or we can go deeper. This will help us find many more rare, fast, and young transients. ZTF is a fantastic new discovery engine providing targets for the GROWTH network.

CM: I know GROWTH is looking for baby supernovas, among other things. Why is that important?

MK: Supernovas shine for months. But what happens in the first 24 hours after explosion, when the supernova is in its infancy, is critical. The initial flash of light immediately interacts with the surrounding material and tells us what that pristine material was before the supernova exploded. Then, there's a 10,000-kilometers-per-second blast wave that sweeps it all up. When we study the ultraviolet light and the spectroscopic signatures with the GROWTH network, within the first 24 hours, we can get a glimpse into what type of star exploded.

CM: You're also searching for what you call the "cosmic mines," the heavy elements in the periodic table, which come from extreme gravitational events. Tell me how you work with Advanced LIGO [the Laser Interferometer Gravitational-wave Observatory] on this?

MK: As soon as the LIGO researchers think they have detected a gravitational wave, they tell me roughly which part of the sky it's in, and we drop everything we're doing and go and search this large area of the sky for any flashes of light that could be physically associated with that signal.

What we're hoping for is at least one neutron star in the merger that LIGO saw. If a neutron star smashes into a black hole or into another neutron star, then there will be light. A neutron star can feed the formation of these very heavy elements, like gold, platinum, and uranium. When these elements decay radioactively, that gives you photons.

So when we get notification of a new gravitational-wave signal, we search the sky for flashes and rack our brains about which ones are completely unrelated, which ones are in the foreground, which ones are in the background, and which one—just one, if any, out of all of them—is the real thing. It is a very complicated process of sifting through a large volume of data in a very short timescale, because we only have 24 hours before the flash, if there is one, fades away.

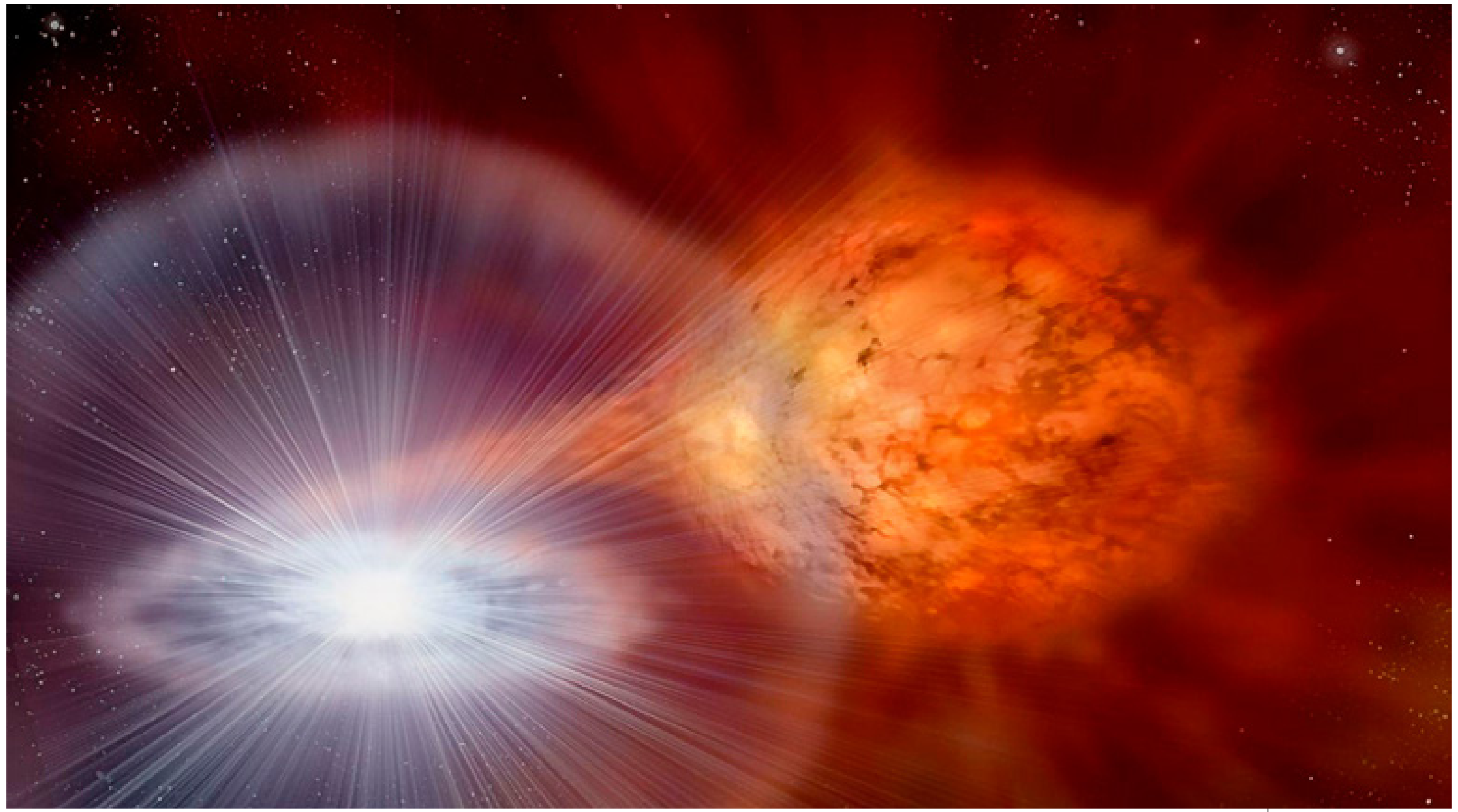
So far, every time we've done this, it turned out to be two black holes that were merging, and we found nothing because black holes are very black. They generally don't produce the electromagnetic light we are looking for. But it's all good preparation for when LIGO finds something with one or two neutron stars.

This work with LIGO ties together my two loves in my professional life, the optical and the infrared, because the signal that is expected from such a violent merger—one that should produce all these sparkling, heavy elements—has two components. One is a fast-fading optical blue component, which is what the GROWTH network is designed to pick up, and the other is a more slowly evolving infrared component. Unfortunately, no one has a wide-field infrared telescope yet.

CM: So exploring the infrared night sky is the new area you're developing now?

MK: Yes, this is the new project that I'm doing, which is something that just didn't even exist as a field a few years ago because the infrared is a very hard waveband to probe. The night sky is very bright, and detectors are very expensive. There are a lot of practical reasons astronomers have shied away from exploring the dynamic infrared night sky.

But just in the last few years, we've made some progress. I'm doing a project called SPIRITS. This is the SPitzer InfraRed Intensive Transients Survey. It's a large program of the Spitzer Space Telescope. We are looking at 200 galaxies over and over again to see if there are any new flashes of light in the infrared wavebands. The cool thing here—quite literally cool—is that the search found a class of transients that were so cold they were completely missed in optical and other wavebands. We think that some of these could be the result of the mergers of two stars, or they could be the birth of massive star binaries in which you have a shock that gets driven out. That shock excites the surrounding medium in the infrared wavebands and lights it up. We don't know what those transients are, so we just gave them a name. The project was SPIRITS, so we call them SPRITEs.



Now I'm taking this to the next level. At Palomar Observatory, I'm putting together a 25-square-degree infrared camera that will be able to cover the entire night sky in one night. I hope to commission it in November. If that goes well, and I'm able to prove the technology there, then I want to go to the cold and dark South Pole to do a really nice systematic search of the night sky for infrared transients.

CM: What is it like being back at Caltech as a professor when you were here as a doctoral student just a few years ago?

MK: Caltech is certainly a dream job for me, and it was sort of like coming back home. Caltech has the kind of students that I know are all awesome. The grad students at Caltech were my friends, and I've seen what they can do. So I knew that, being a faculty member, I would have the privilege of working with students who are not only brilliant but also have an amazing attitude.

CM: Are you down at Palomar Observatory frequently?

MK: Yes, and I'm always excited about working with Caltech's Palomar and Keck observatories. I know the telescopes well, what to do with them. Also, I've known the engineers and the staff there for many years, and I've had a really great relationship with them. It's really fun to work with the staff. They're very dedicated. They revel in the joy of discovery.

CM: You've been in the U.S. now for longer than you lived in India. Do you get back there regularly?

MK: My parents live in India, so we go back once a year. Also, I have two GROWTH co-investigators in India. In fact, one is a Caltech alum who is now a faculty member at the prestigious Indian Institute of Technology in Mumbai. His students come here for internships; I send students to him for internships. This is wonderful in terms of the collaboration.

Bringing astronomy at the cutting edge to India, with this privileged access and opportunity I have here at Caltech, to share that with my colleagues in India … it's really fun.

CM: And last, but certainly not least, you also have a young child.

MK: I have a two-year-old son. His name is Vyom. That means "the universe" in Sanskrit. I have a little baby universe who is the joy of my life. [C]

Above: An artist's impression of a white dwarf "stealing" matter from a companion star.

Endnotes

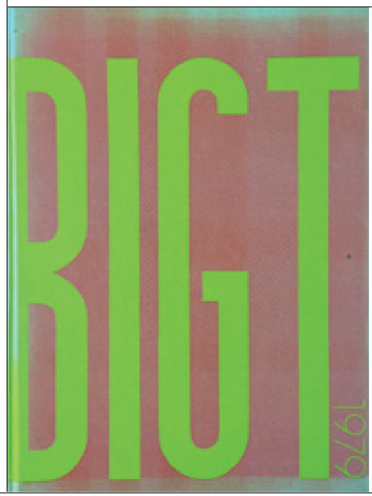
We asked alumni: What are your favorite memories of Winnett, the Red Door, or its associated spaces?

The ham radio room upstairs, to which all upperclassmen had a master key (though the room's existence was a well-kept secret). I recall nights in that room studying with friends and tuning in to conversations on the radio (though I had no ham license, nor did I know how to operate it).

Nitu Kitchloo (BS '93)
BALTIMORE, MD

Louise Hood [former Student Center manager], a trusted adviser or confidant to a great many students. Louise seemed to know whom to talk to about anything having to do with the Institute and many suspected that she actually ran the place.

Paul Levin (BS '72)
MANHATTAN BEACH, CA



Late nights working for the *California Tech* and the *Big T* (including the sounds and smells of the pre-computer typesetter and paper waxers).

Stanley Cohn (BS '79)
SKOKIE, IL

A series of Wednesday afternoons when Feynman would drop by and tell some of his stories of Los Alamos.

Steve Morse (BS '65)
OAKLAND, CA

Decompression! It meant finals, but it also meant free food!

Vivian U (BS '06)
WALNUT, CA

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And remember to get social:

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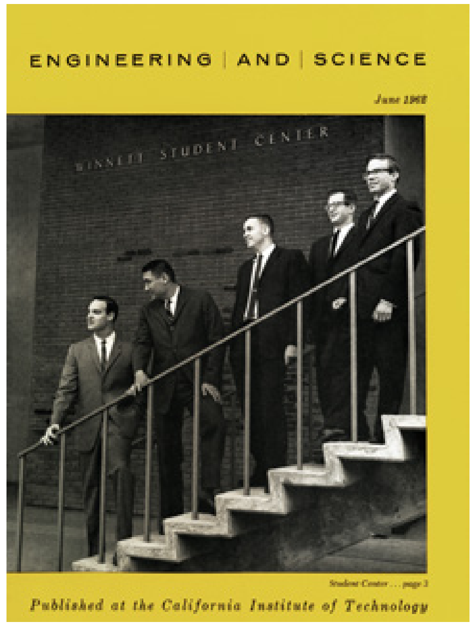

[2017]

In 1962 on our graduation day, Winnett was also being dedicated. As we came out of Page House in our suits and skinny ties for graduation, a photographer called us over and five of us stood on the steps for our first and only cover appearance in *Engineering and Science*.

Fred Hameetman (BS '62)

The construction of the Hameetman Center, which will replace Winnett, was made possible by Fred and Joyce Hameetman with their generous gift to the Institute.

For more Endnotes answers, go to **magazine.caltech.edu/post/endnotes-1**

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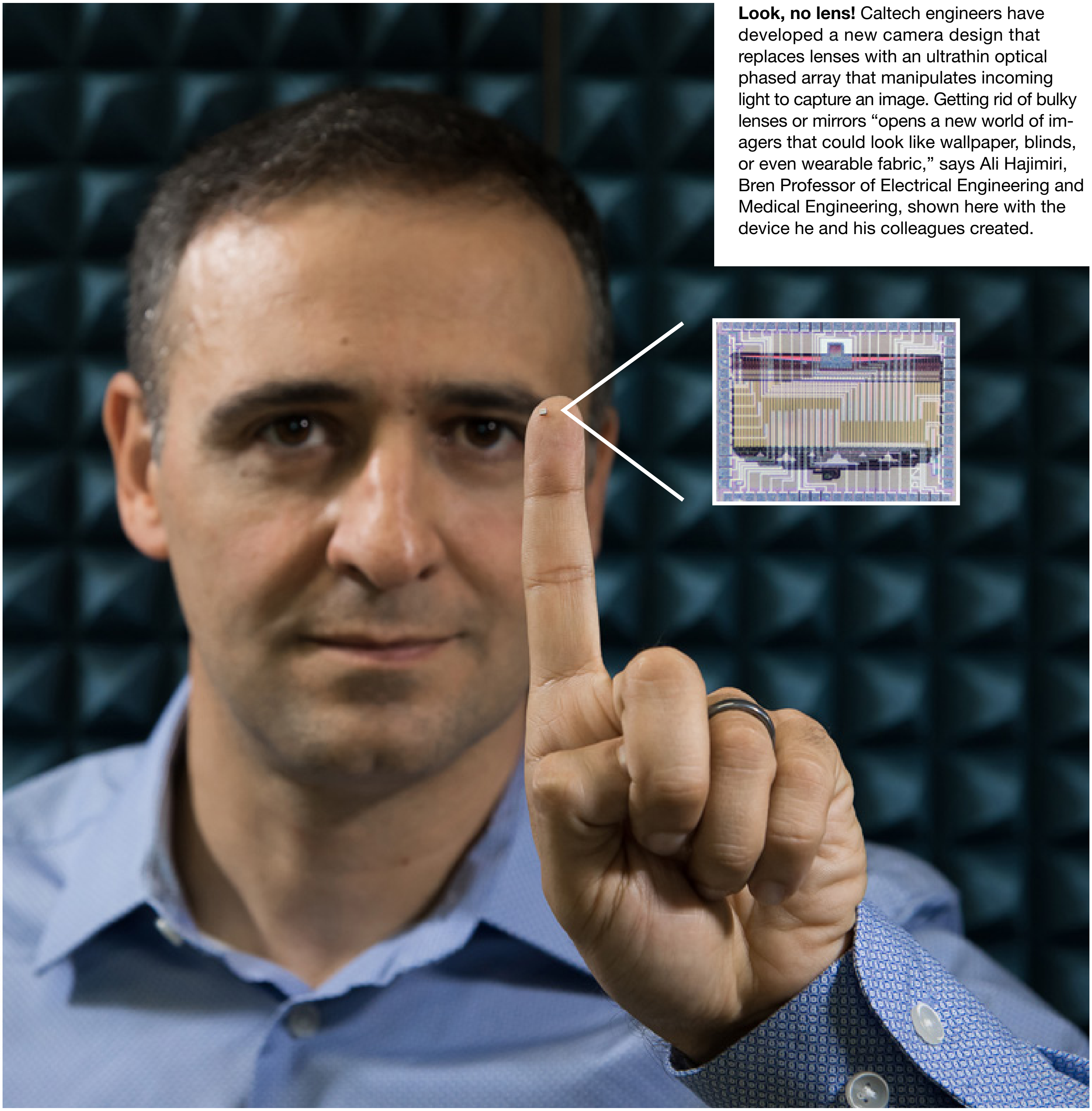

Look, no lens! Caltech engineers have developed a new camera design that replaces lenses with an ultrathin optical phased array that manipulates incoming light to capture an image. Getting rid of bulky lenses or mirrors “opens a new world of imagers that could look like wallpaper, blinds, or even wearable fabric,” says Ali Hajimiri, Bren Professor of Electrical Engineering and Medical Engineering, shown here with the device he and his colleagues created.