Summer 2020

# Caltech magazine

As COVID-19 began its spread across the globe, Caltech researchers worked day and night to understand the virus and combat the disease.

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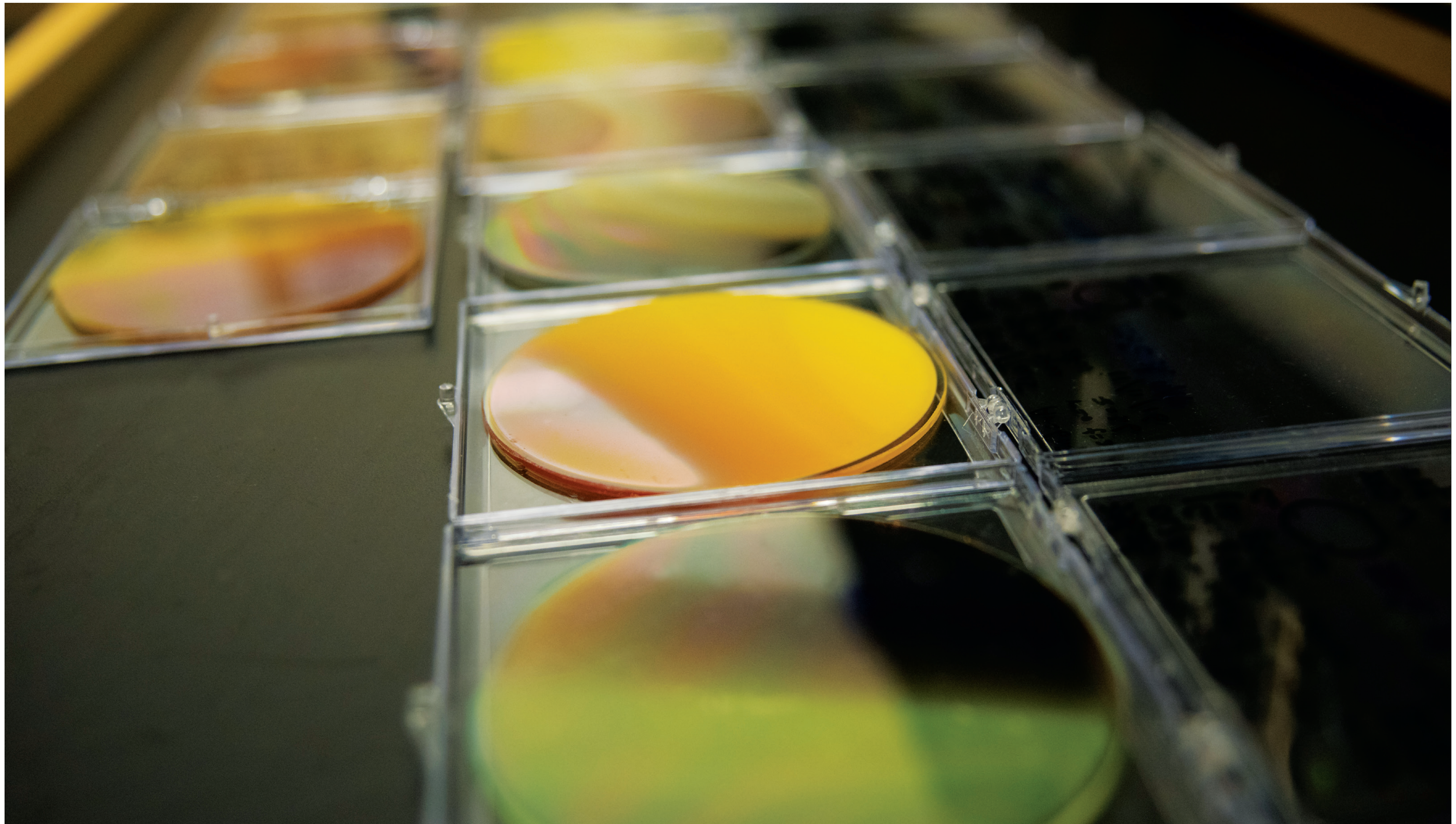


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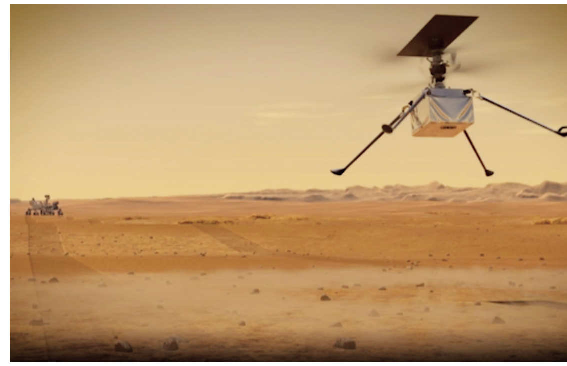

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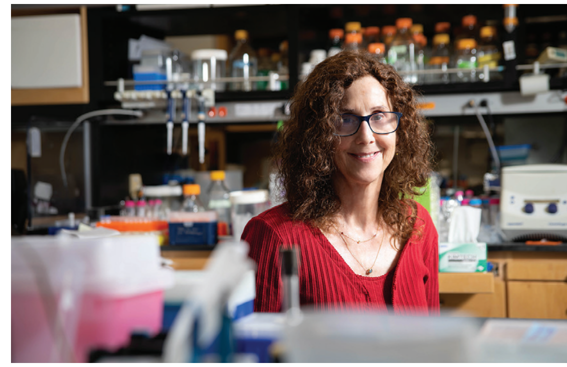

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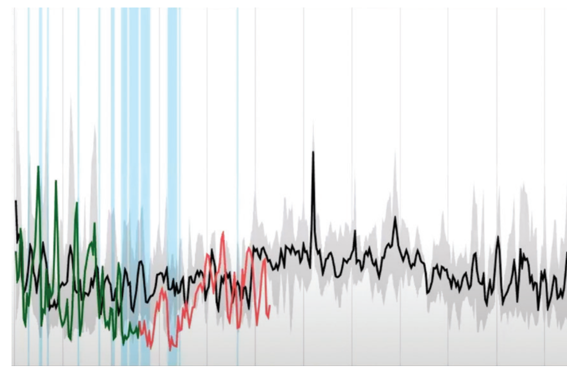

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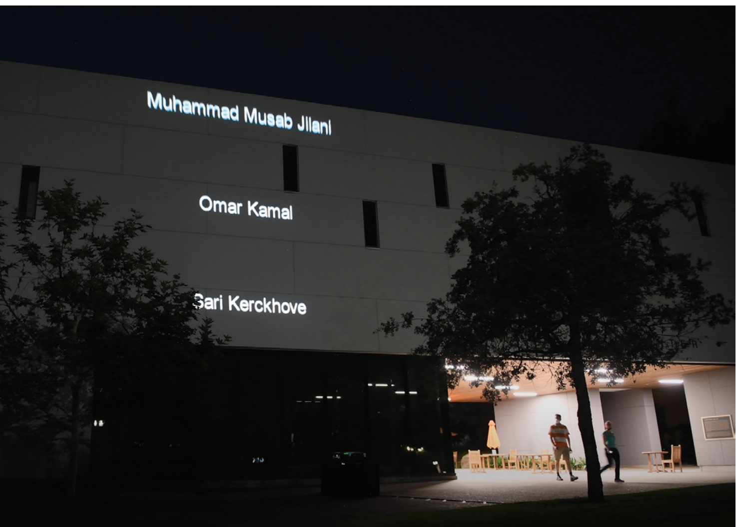


A scroll of the names of this year's Caltech graduates was projected onto the side of the Hameetman Center for two evenings following the June 12 virtual commencement. To view the commencement video, visit **commencement.caltech.edu/watch.**

# A More Inclusive Caltech

*[The following is excerpted from a note sent by Caltech's academic leadership to the community on July 6, 2020.]*

There are times of tragedy and tumult which demand change. We are at such a time now. Over the last few weeks, we have gathered as a community in conversation and joined in town halls that have provided valuable opportunities to learn from Black students, staff, and faculty about their personal and professional experiences. We have sought and received suggestions for interventions from faculty, from students, from staff, from alumni, from the President's Diversity Council, including Caltech's Chief Diversity Officer, and notably from the Black Scientists and Engineers of Caltech.

History has taught us that consistent and focused attention manifests change. History also demonstrates that when attention falters, so does progress. New generations of students, postdocs, faculty, and staff find themselves confronting the same obstacles faced by earlier generations. The lesson is clear: For there to be real change, the Institute as a whole must move forward with intention, and create a future that builds on the solid foundation of our collective efforts.

Today, as the academic leadership of Caltech, we provide an update on new steps the Institute will take to ensure that we continuously create and reaffirm a campus in which it is evident, in all that we do, that Black lives matter, that Black minds matter. We strive to become an example of how a diverse and inclusive community, committed to equity, permits individuals to thrive in fulfilling the Institute's mission of forefront research and education.

We describe in the full memo to the community (**caltech.edu/campus-life-events/campus-announcements/more-inclusive-caltech**) investments and actions that we can undertake immediately as well as those that will require more intensive examination and consensus building among the many constituencies that make up Caltech. We intend to expand the scope of interventions as success is demonstrated.

These steps range from immediate responses to programs and plans that will unfold over time. They all will move the Institute forward. There are possibilities in this moment that we must seize as individuals, as a campus, and as a community. We are committed to a Caltech that offers the access and support to ensure that every member of our community achieves their full academic and professional potential.

Stephen L. Mayo (PhD '88), Division Chair, BBE
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Dennis A. Dougherty, Division Chair, CCE
Guruswami Ravichandran, Division Chair, EAS
John P. Grotzinger, Division Chair, GPS
Jean-Laurent Rosenthal (PhD '88), Division Chair, HSS
Fiona A. Harrison, Division Chair, PMA
David A. Tirrell, Provost
Thomas F. Rosenbaum, President

# Letters

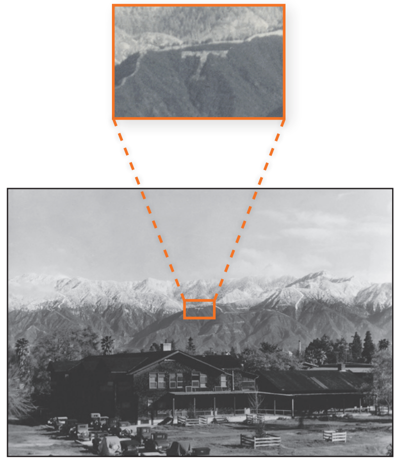
For more letters go to magazine.caltech.edu/post/letters-sum2020

## Happy Memories

The print copy of *Caltech* magazine (Spring 2020) brought me some unexpected happy memories. When I was a sophomore at the University of Colorado, I was offered a job helping Karen Simmons and Larry Esposito, scientists with the Voyager 2 team, in the lead-up to and during the Uranus flyby part of the mission. I think I worked there maybe 15 months. It was a wonderful job, where I learned a great many new things, and, what's more, it was my introduction to NASA and space missions. Honestly, it was a lucky break that opened many doors for me later on. So it was quite special for me personally to open *Caltech* magazine and discover the article about Voyager 2 (where I got my start, you could say) right there alongside the article about Spitzer, the mission I've been part of for the last 20-plus years. I'd have missed that, very likely, if I had just Googled over to the article in your online edition.

Matt Ashby, Center for Astrophysics
Harvard & Smithsonian

## Becoming Caltech



Nice winter photo ("Becoming Caltech," Spring 2020). Pre-smog. And when the "T" was prominent on the mountain (it was still just visible, smog cooperating, during my time).

Bob Wieting (BS '74)

In the very interesting piece "Becoming Caltech" in the Spring 2020 issue, Martin Luther King Jr. is cited after his visit to the campus in 1958. I was the student host of the Kings and maintained contact with MLK afterwards. Another issue that we addressed in our correspondence was the issue of recruiting Black students to Caltech.

I was ASCIT president in 1959–60 but failed miserably in not forcing the matter of Black and female undergraduate admission with President DuBridge. In the paragraph "Harold Brown," it is pointed out that 10 years passed before women were admitted, but I don't know when the first Black undergraduate arrived on campus.

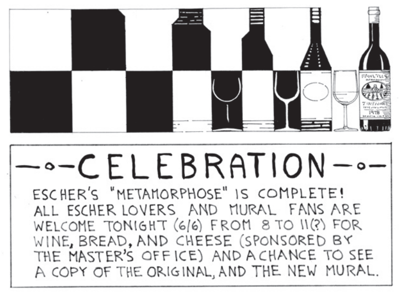
Tom Jovin (BS '60)

*Editor's Note: The first Black undergraduate at Caltech was Grant Venerable (BS '32), who transferred to the Institute as a sophomore from UCLA.*

## A Lasting Mark

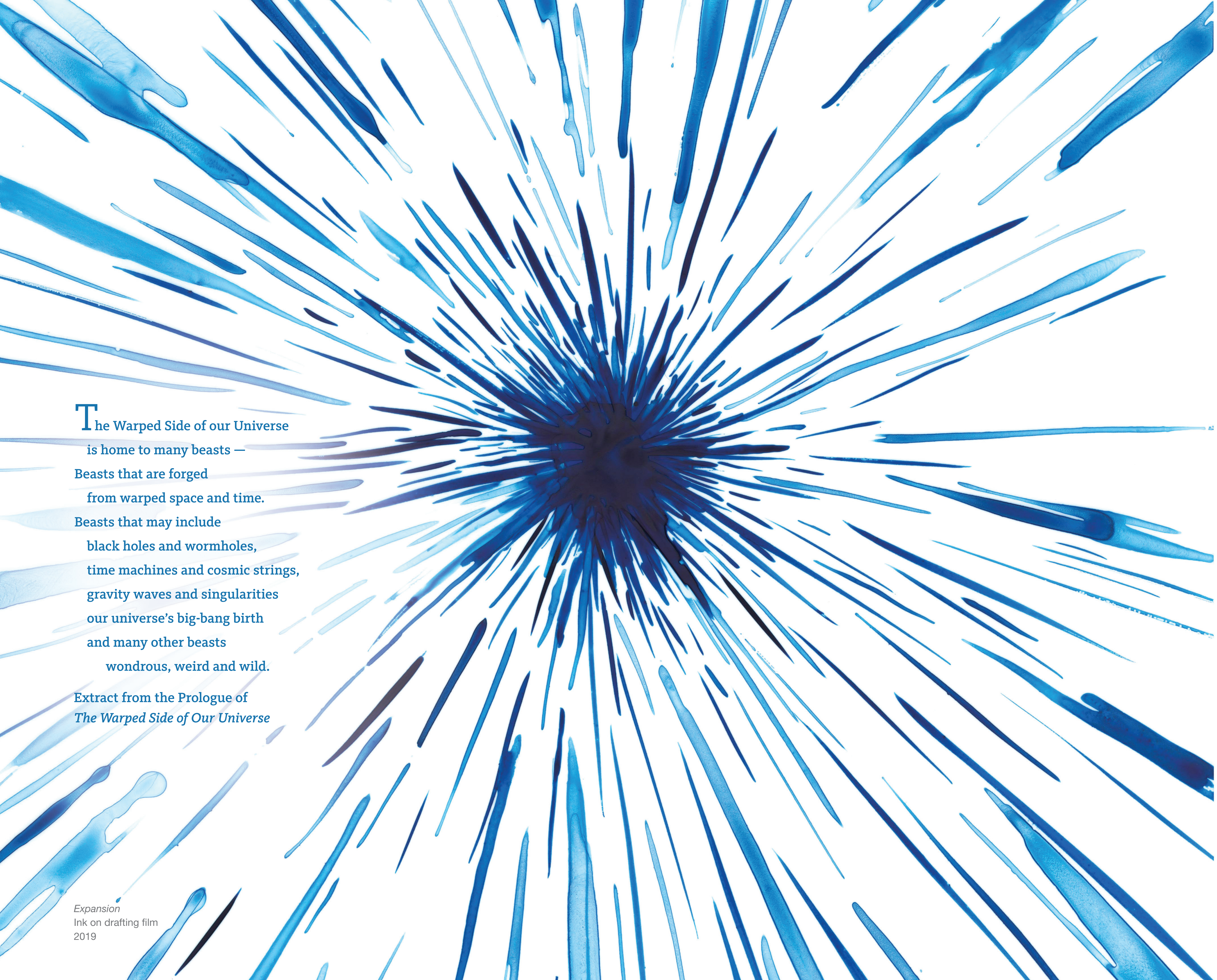
I was stoked to see the article featuring my Escher mural ("Off the Wall," Spring 2020). It looks like it's in very good shape. I was remarking to another Techer who saw the article that the mural is the only lasting mark I left on Caltech. As such, I've grown increasingly proud of it, now more than ever, with the attention that's been drawn to it.

I was inspired to dig into my old letters and found the original flyer I created as an invite to the mural completion party. I decided to echo the *Metamorphose* motif and transformed a checkered pattern into a glass and bottle of wine.




Thank you for the article and photograph. I'm delighted, and I feel honored.

Tom Berto (BS '83)



The Warped Side of our Universe
is home to many beasts —
Beasts that are forged
from warped space and time.
Beasts that may include
black holes and wormholes,
time machines and cosmic strings,
gravity waves and singularities
our universe's big-bang birth
and many other beasts
wondrous, weird and wild.

Extract from the Prologue of
*The Warped Side of Our Universe*

*Expansion*
Ink on drafting film
2019

# SoCaltech


- Meet history professor Danielle Wiggins
- Essential Caltech
- A student steps up


## Warped Space, in Paint and Poetry

This spring, Los Angeles-based artist Lia Halloran was to have joined Caltech as artist-in-residence in the Division of the Humanities and Social Sciences as part of the Caltech-Huntington Program in Visual Culture. COVID-19 upended those plans, and Halloran's residency has been postponed until the spring of 2021.

The past few months have been busy for Halloran, however, as she has put the finishing touches on a book project she has been working on for more than a decade with Kip Thorne (BS '62), Caltech's Richard P. Feynman Professor of Theoretical Physics, Emeritus, and one of the recipients of the 2017 Nobel Prize in Physics. The book, *The Warped Side of Our Universe,* is to be published by W. W. Norton & Company in 2021 and features poetic verse by Thorne alongside paintings by Halloran.

As an associate professor of art at Chapman University, Halloran has exhibited her work widely in the United States and Europe. In 2016, her art installation *Deep Sky Companion* opened at Caltech's Cahill Center for Astronomy and Astrophysics. For that exhibit, Halloran used painting and photographic techniques to create 110 prints inspired by the 18th-century French comet hunter Charles Messier.

*Caltech* magazine recently talked with Halloran and Thorne about their creative partnership.

**Lia Halloran:** During my first year of graduate school at Yale I started reading Kip's book *Black Holes & Time Warps* (W. W. Norton & Company, 1994). There was something about the way Kip described this odd warping and bending of space that just made me feel transported. Most of the paintings in my MFA thesis exhibit were based on reading what Kip wrote. So, I was collaborating with him before I even met him.

continued on page 6

## Warped Space

continued from page 5

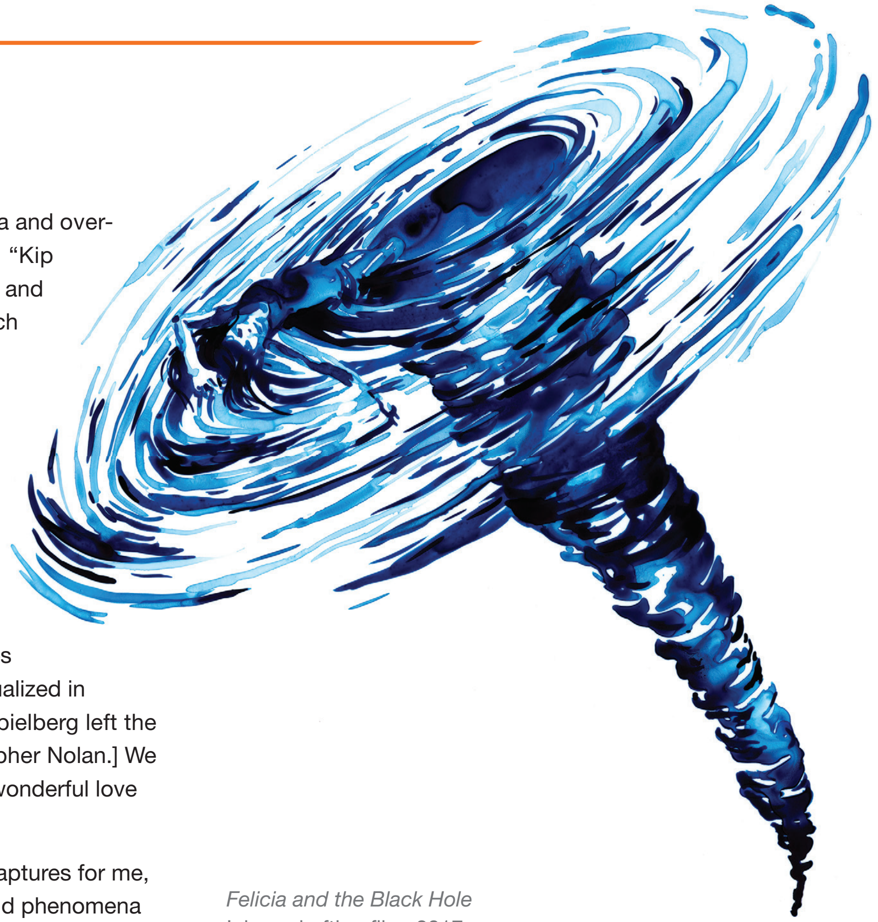
Then, in 2007, I was at a cocktail party in Pasadena and overheard someone say his name. I perked up and said, "Kip Thorne is here? I have to meet him." I went up to him, and I was effusively and unapologetically sharing how much of an impact his writing had on my artwork. He said there was "a young filmmaker" interested in making a film about his science and perhaps I could help him visualize it. The director was Steven Spielberg. So we started this wonderful dialogue where Kip would come to my studio and talk, and then, after about 45 minutes, my head would get hot from the mind-blowing things Kip was describing about the universe, and I'd try to put his ideas into an image or even some very simple doodles. He used those doodles as a way to explain how time and space could be visualized in the early, early conception of the movie *Interstellar.* [Spielberg left the project in 2009; it was ultimately directed by Christopher Nolan.] We not only became collaborators but also developed a wonderful love and respect for each other.

**Kip Thorne:** In her paintings and pencil sketches, Lia captures for me, as well as for nonscientists, the essence of objects and phenomena that are made from warped spacetime rather than from matter: the warped side of the universe. That's why her sketches were so helpful to me in my planning discussions for *Interstellar,* first with Spielberg and later with Christopher Nolan and his brother, screenwriter Jonathan Nolan. Lia's creativity and skills as an artist, her enthusiasm and easy communication with me, and her familiarity with the essence of science make her a great collaborator.

**Halloran:** At one point, Kip was invited to write an article for *Playboy,* and he asked me to do the artwork. So, he wrote a 6,000-word article about black holes and wormholes, and I made eight little paintings. We sent it over to *Playboy* and got an email back saying that Hugh Hefner had rejected my artwork because it didn't look like the iconic style of Leonard Nimoy's drawings. Sometimes, failure is the best thing that can ever happen to you! We'd had so much fun working together that we continued meeting, me making paintings and Kip expanding his prose, until we realized we had a book on our hands.

**Thorne:** I had honed the prose of our *Playboy* article so it flowed nicely and had a nice ring to it. Then, when Lia's friend did the first layout for our book, she broke some of my prose into stanzas. When I first saw this, it became obvious to me that what I had was almost poetic verse. The only verse I had written previously was love poems to my wife on her birthdays.

**Halloran:** At that point, Kip decided to rewrite all the prose into verse form. With so much of science, many people don't feel like it's theirs. But if we change the format, that can be a very different way to approach it. How many poems about black holes are out there? We really hope that the poetry community, the art world, and the physics community will all claim it as their book.



*Felicia and the Black Hole*
Ink on drafting film, 2017

**Thorne:** I hope to inspire readers of all sorts to see the weird and wonderful beauty of the warped side of the universe and to convey to them the ethos and essence of this strange bit of science. My words could not possibly do that by themselves. Lia's paintings, tightly integrated with the words, are essential.

> **"I welcomed the move from the humanities classroom to the undergraduate dean's office as an opportunity to support and work with students in new ways. What I have come to appreciate, too, is the extraordinary effort and commitment that goes into shaping the student experience at Caltech, particularly among student leaders and professional staff."**
>
> **– Kevin M. Gilmartin,** *Caltech's William R. Kenan, Jr., Professor of English and the current dean of undergraduate students, who has been named the Institute's next vice president for student affairs*

## Three Questions for:
# Danielle Wiggins

Danielle Wiggins, who joined the Division of the Humanities and Social Sciences (HSS) at Caltech as an assistant professor of history in the summer of 2019, earned her PhD in history from Emory University in 2018, where she specialized in African American political history and urban political economy.

**1. In your work on Atlanta in the '70s and '80s, you have noted that the Black Democratic leaders adopted a surprisingly punitive approach toward crime. Why do you think that was the case?**

Many folks have argued that people were just really afraid of violent crime and framed Black crime as a civil rights issue, as in, "We need to protect our good, law-abiding Black people from the lawless rule breakers who are betraying the race." Others have argued that because the federal and state governments were also embracing a punitive law-and-order type of politics, those were the tools available to them. While they weren't able to get much money to improve public schools or for public housing, they had a great deal of federal support for expanding police departments and jails.

**2. Do you have a historical perspective to share on the current uprisings against police violence and systemic racism?**

I study the period right after the urban rebellions of the mid-to-late 1960s and how cities and Black leaders, in particular, responded to those uprisings with various reforms that were intended to assuage tensions between Black communities and police departments. But, ultimately, as we now see, these reforms of the 1970s and the reforms that we saw again in the 1990s in response to uprisings in cities like L.A. and Miami were insufficient, and some of them actually worsened the problems of overpolicing in Black and brown communities and intensified mass incarceration. So I'm constantly thinking about the ways that we can learn from the mistakes of the past and how to inform and educate people about the limits of the reforms we've already seen.

**3. What would you like to say to the Caltech community at this time?**

I would say embrace those values that are at the heart of Caltech: creativity, innovation, and a belief that we can solve the world's biggest problems. And ask yourself: What would a world where Black people don't experience untimely death at the hands of police, from disease, or from neglect look like? What would a world where Black lives actually matter look like? These are things that are hard to imagine because we've never lived in such a world, but these are thoughts that should inspire us to continue the work.

Read the full interview at magazine.caltech.edu/post/danielle-wiggins

# ESSENTIAL CALTECH

While the vast majority of Caltech staff and faculty spent the spring working from home due to the coronavirus pandemic, a small number of essential employees came to campus each day, operating under strict conditions set forth by health officials, to ensure that the Caltech community, broadly dispersed, could continue to pursue scientific exploration for the benefit of all.


**Erica Crawford, Senior Residential Life Coordinator, Office of Residential Experience**

Crawford lives and works in the Bechtel Residence. Her job is to provide personal, social, and academic support to students. "During this experience," she says, "campus community members have really come together to try to make the transition as smooth as possible for everyone involved. The social-distancing requirements make it hard to interact with others who are still on campus, but we are working every day to continue to support students both on and off campus."

**Corey Campbell, Materials and Services Supervisor**

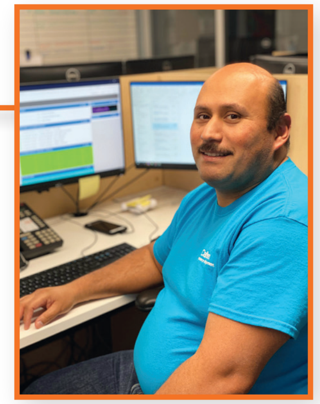
Campbell is responsible for ensuring the campus has enough of the essential supplies it needs. "I hope that my work allows critical research to continue and keeps the campus supplied and safe," says Campbell. One thing that struck him during this pandemic is the number of rolls of toilet paper required.

**Jose Alvarado-Orozco, Yoga Instructor**

Alvarado-Orozco, who has been teaching live Stretch & Flex classes every week via Zoom, says he has been struck by Caltech's "willingness to keep us moving; the support system here never stops." His message to those at home? "We are here for you, we show up to work, we are here to give you support. We want to know how you are doing and give you a sense of structure and stability during this uncertain time."


**Paul Ayala and Alex Hernandez, Building System Operators**

Ayala and Hernandez monitor the building automation console for HVAC issues and manage service calls on campus. Used to sitting side by side in a busy service center, the two are now operating solo on alternating schedules. The quiet on campus has stood out for Ayala; he is used to a faster pace and looks forward to busier days when the full campus community returns. Hernandez, too, is looking forward to life getting back to normal but is happy to support essential research during this time.



**Rick Germond, Lead Storekeeper**

Germond is responsible for liquid nitrogen service on campus. "The current campus experience can be fairly stress-fraught, yet the knowledge that we're working at an institution on the forefront of seeking to end our world-wide pandemic makes me and others around me glad to be able to contribute," he says. What is Germond looking forward to most? "I'd love to once again stand in the middle of Chandler's lunch-hour clamor and know all of us aren't focused on the same infinitesimal virus!"

**Sandra Padilla, Miguel De La Torre, and Martin Contreras, Dining Services**

Caltech's Dining Services staff never stopped cooking and serving meals to students and faculty who remained on campus. In late March, Dining Services also started offering cook-at-home meal kits (similar to Blue Apron) to all students, faculty, and staff.

# Alexander Zlokapa (senior)

*#SoCaltech is an occasional series celebrating the diverse individuals who give Caltech its spirit of excellence, ambition, and ingenuity. Know someone we should profile? Send nominations to **magazine@caltech.edu**.*

*Alexander Zlokapa, a physics major, is one of four Caltech students to receive a Barry Goldwater Scholarship for the 2020–21 academic year. The scholarships are awarded to college sophomores or juniors who intend to pursue research careers in science, mathematics, and engineering.*

"COVID-19 has painfully changed the world more quickly than I could ever have imagined. With the support of the amazing Caltech faculty, I've helped organize a Caltech student effort as we attempt to make our communities safer, working with epidemiologists and virologists from institutions around the world while bringing the Caltech community closer together. A conversation with my adviser, physics professor Maria Spiropulu, encouraged me to contact biophysics professor Rob Phillips, who graciously offered to give both a public lecture on COVID-19 and a mini-course on viruses. Reaching out to students through the Caltech Data Science Organization, [a student club] that I lead, we had over a hundred people attend online to learn about the critical problems we face today. Thanks to the enthusiasm and openness of Professor Yaser Abu-Mostafa in helping us develop a new section of an undergraduate computer science course, we've now been able to launch projects with hundreds more Caltech students and postdocs, building models that quantify the spread of the pandemic. As well as contributing to briefings for the director of the California Department of Public Health and working with scientists from Denmark to Bangalore on new COVID-19 testing strategies for hospitals, I also had a chance to put together some COVID-19 testing analysis that was reviewed by President Rosenbaum and Provost Tirrell as part of preparations for reopening Caltech. It's been very busy, but I'm always amazed at and encouraged by the dedication of everyone involved in combating the pandemic."

For more #SoCaltech, go to tinyurl.com/MagSoCaltech

**"The fact that both Caltech and the City of Pasadena were willing to act, and act decisively, on clear visions for their respective futures launched them on the trajectories that have landed us both here today. Pasadena is very proud of Caltech, our homegrown portal to the future and to the stars."**

**–Terry Tornek,** *Mayor of the City of Pasadena, at the March 5 Becoming Caltech event held on campus to celebrate 100 years since the Throop College of Technology was renamed the California Institute of Technology*

# In the Community

## Ask a Caltech Student

Group • 587 members

+ Join

On "Ask a Caltech Student," a Facebook group begun this spring, students and families in both the local Pasadena area and beyond have been encouraged to reach out to Caltech graduate students with science and math questions that are related to the schoolchildren's schoolwork and homework.

The group was created in March 2020 by the Institute's Center for Teaching, Learning, and Outreach (CTLO), in collaboration with Raj Katti (BS '14, MS '19), a graduate student in physics, in response to the closure of schools in Los Angeles County due to the COVID-19 crisis and the resultant move to distance learning.

"I realized that if there were Caltech grad students with some free time and Pasadena-area students with questions about their homework, there had to be a way to connect up those two groups," says Katti, who brainstormed with CTLO outreach program manager Kitty Cahalan (PhD '00) to come up with the plan. Since CTLO is not set up to run direct tutoring programs, Cahalan and Katti landed on the concept of an open forum on social media where people could ask questions and potentially receive multiple answers from students in a threaded conversation.

Within 24 hours of creating the Facebook group, 220 people had become members; about two-thirds of those were graduate students, and a third were local community members.

Katti attributes the enthusiasm around this initiative to three factors: "the enjoyment of teaching, an interest in helping out the community, and good old-fashioned boredom." Fellow graduate student Michael Mazza, whose expertise is in chemistry, adds, "Grad students had to suspend their research activities for weeks. Engaging with students who are learning the material for the first time can reignite the feeling of discovery and excitement that first pushed us down this career path."

"It's really providing an opportunity for the grad students to share and celebrate what they love about what they do," says Cahalan, "and they're hungry for that right now."

Rather than provide answers to specific problems or equations, the goal is for the Caltech students to explain the underlying concepts, post links to outside content, and share resources for additional help. The group is moderated by Cahalan and CTLO associate director for educational outreach Mitch Aiken.

The Caltech students need to calibrate their responses to a K–12 audience, which brings its own challenges but has become a learning opportunity those involved have embraced. "Thinking of how to best describe and introduce new scientific concepts to students is an intellectually demanding and rewarding experience in its own right, so I definitely gain a greater understanding of the material myself," says Mazza. "The sign of a talented scientist isn't how complicated they make their work sound, it is how clearly and concisely they can illustrate it."

As Cahalan notes, the threaded conversation format is also helpful, since a student who does not understand the first explanation of a problem offered may have an "aha" moment with the second or third. "Somebody may explain it one way," she says, "but then maybe somebody else says, 'Here's how I learned it,' or, 'Here's another way of approaching this problem.'"

Though the focus has been on schoolwork and homework, Cahalan sees the potential for a broader community impact. "I would love to have a space where kids who have these questions can go in and just say, 'Talk to me about your research or career path.'"

"If we all have to slow down and explore things from our computer now," she adds, "there are probably worse things to have access to than a bunch of really smart, excited grad students who have some time to talk about what they're interested in."

—Judy Hill

**"What are some good ways to explain to a 9-year-old why batteries shouldn't be allowed to connect to each other's ends?"**

**"How do scientists know what's in the middle of planets?"**

3

# Origins

## Ready, Set, Spark!

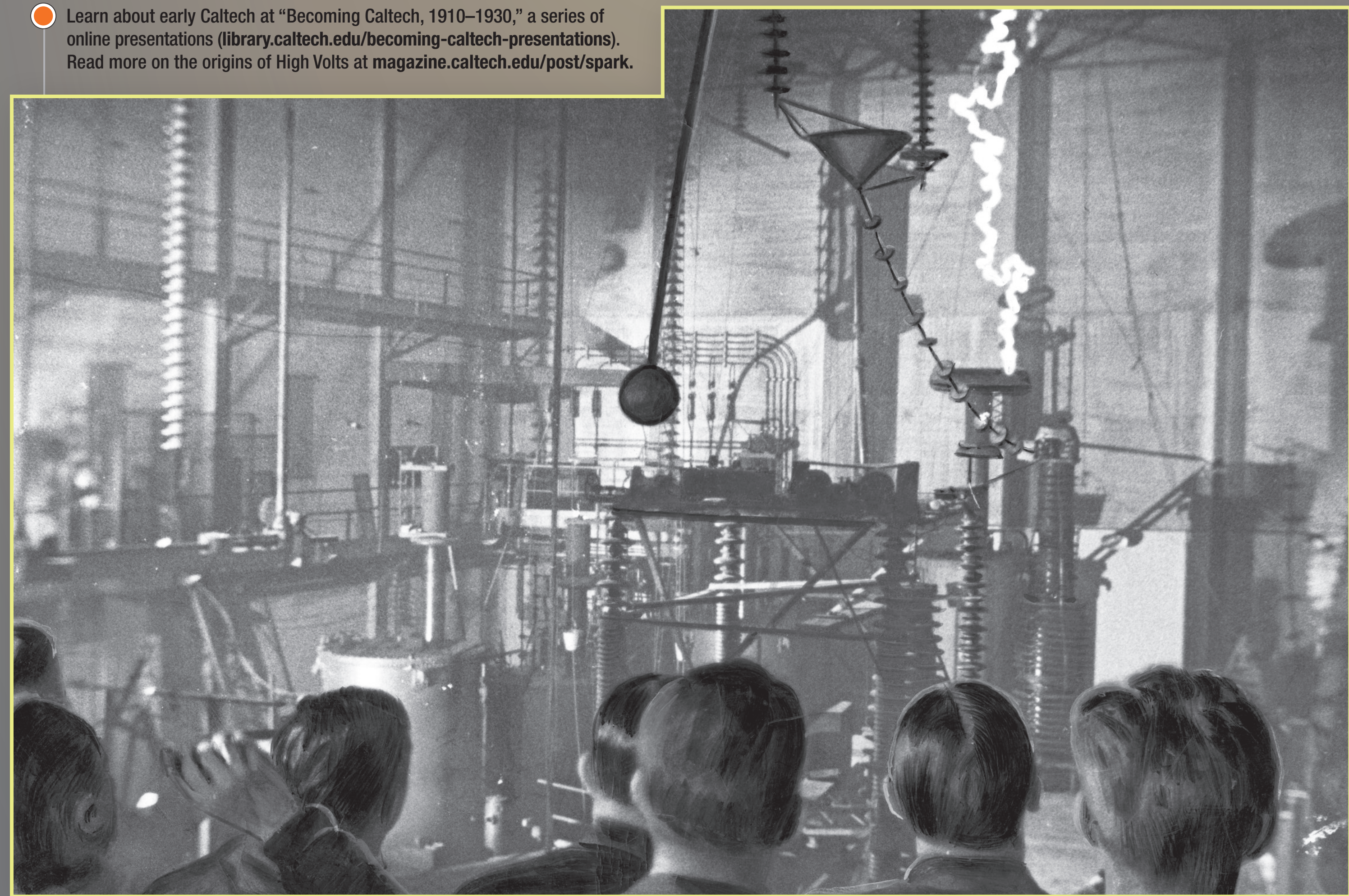
When Caltech's former Sloan Lab reopened in January 2019 as the Linde Hall of Mathematics and Physics, staff, faculty, and students encountered a structure with a transformed interior that was originally built 97 years ago. The modernized building now boasts open, flexible meeting spaces and ample blackboards for its resident mathematicians.

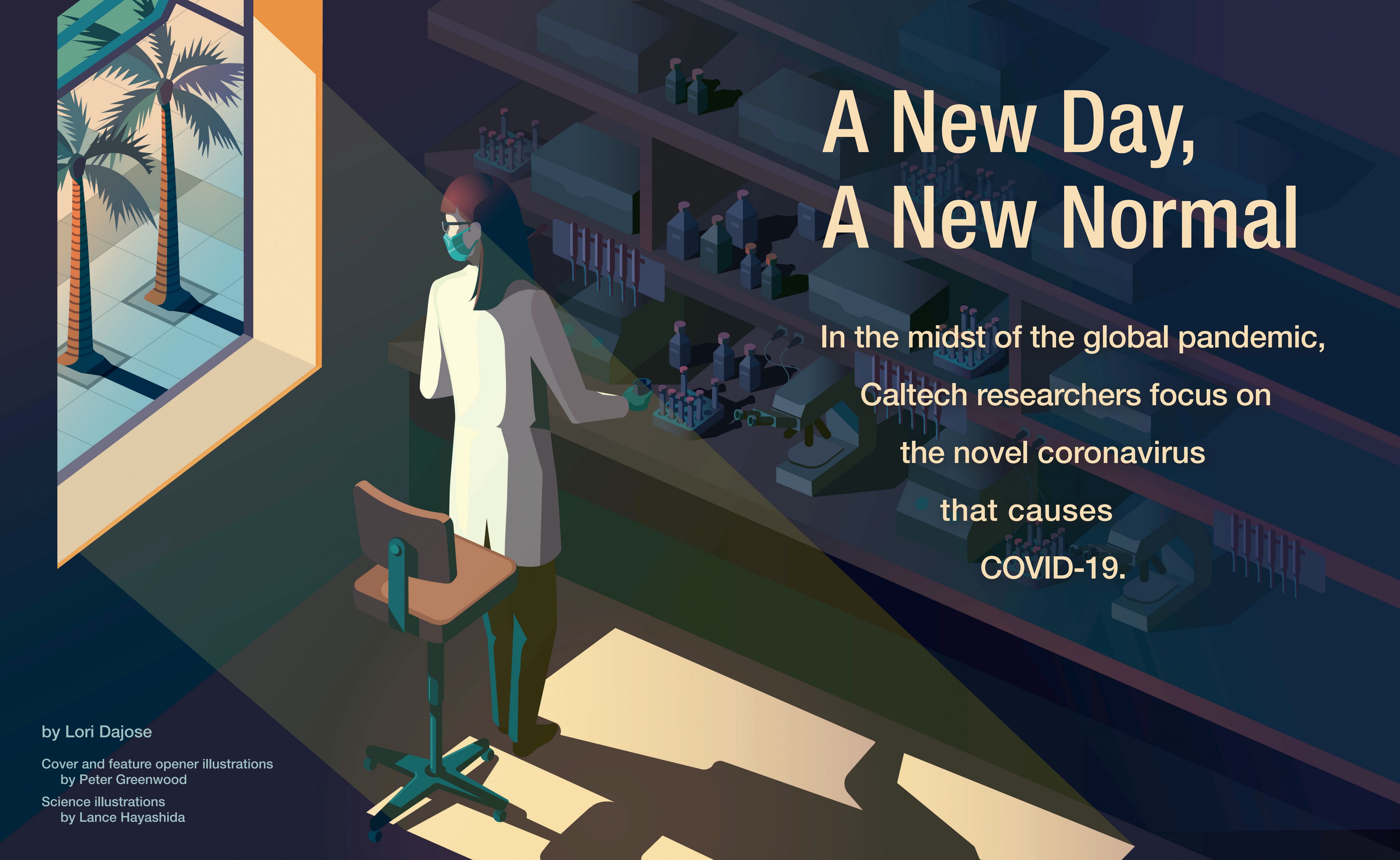
Over the course of a century, it has witnessed many changes, evolving to suit the needs of the disciplines it has served: physics, mathematics, and electrical engineering. Originally known as High Volts, the building came into being in 1939 out of a partnership between Caltech and the Southern California Edison company, which contributed money to its construction in exchange for its use for research. The interior during those early days was dominated by a single large industrial space packed with high-voltage apparatus. A million-volt surge generator produced rapid impulses of artificial lightning (as seen in the c. 1920s image below of a lab demonstration).

In a 1985 oral history, Caltech chemistry professor Jack Roberts (1918–2016) recalls visiting High Volts as a teenager for a demonstration on high-voltage electricity by Royal Sorensen, professor of electrical and mechanical engineering: "It looked like Frankenstein's laboratory. Great transformers topped with big mushroom rings … they'd charge up these things, and they'd start shooting off sparks, or they'd have a 'horn gap,' where a pair of wires would be close together at the top of the transformer and far apart at the top of the room. They would start an arc at the bottom and it would grow in length and rise to the ceiling. … They'd make this crackling noise as they'd go up. And then they'd charge up the condensers and shoot off a big spark. … That was really impressive!"

—Peter Collopy, University Archivist

Learn about early Caltech at "Becoming Caltech, 1910–1930," a series of online presentations (**library.caltech.edu/becoming-caltech-presentations**). Read more on the origins of High Volts at **magazine.caltech.edu/post/spark**.





# A New Day, A New Normal

In the midst of the global pandemic, Caltech researchers focus on the novel coronavirus that causes COVID-19.

by Lori Dajose

Cover and feature opener illustrations by Peter Greenwood

Science illustrations by Lance Hayashida

Rain fell steadily on campus the day the labs began to shut down.

A March 16 email from Caltech's president and provost had informed the community that, to limit the spread of COVID-19 and support the efforts of public-health authorities, all nonessential research needed to be deferred or transitioned to remote operations.

The atmosphere in the laboratories turned eerie, without the perpetual whir of motors and pumps. The atomic physicists carefully turned off their cryocoolers, slowly, to ensure that evaporating gas did not create too much pressure; the chemists shut down their X-ray photoelectron spectroscopy machines and electron-beam evaporators, sealing off volatile chemicals and glove boxes.

In less than a week, research operations at Caltech had been turned upside down.

But almost as suddenly as their original work was paused, some groups pivoted to a new focus: the novel coronavirus causing the COVID-19 pandemic, SARS-CoV-2.

## Studying Antibodies from Recovered Patients

Pamela Björkman's laboratory was one of a few allowed to remain open for essential research. Social-distancing protocols made the labs strangely quiet, a few lights on in some of the windows at night providing the only clues to the activity within.

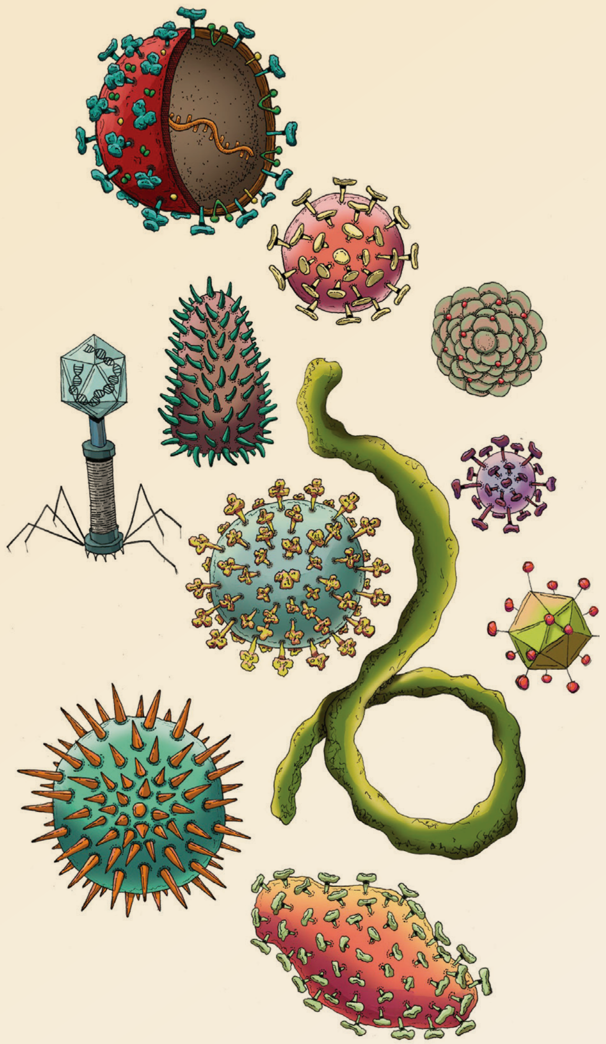
For Björkman, Caltech's David Baltimore Professor of Biology and Bioengineering, whose laboratory studies HIV, the focus was not entirely new; her research group had received funding from the NIH to begin a project on SARS-CoV-2 in February. But as her lab's research ramped up, Björkman faced another coronavirus-related matter: her daughter, who had been teaching in Malaysia as a Fulbright fellow when the pandemic began to take hold internationally, had been told she must return to the United States. But Malaysia was shutting down internal travel, and it was not clear how to get to an international airport.

"The situation was chaotic, with things changing on an almost hourly basis. In the end, our daughter was unable to return to the rural village where she had been teaching to retrieve her possessions, but she was able to get a flight back to the U.S. Fortunately, she tested negative for COVID-19; she was one of the lucky few who were able to be tested in mid-March," says Björkman. "This experience made the urgency of the global pandemic more personal for me."

The work in Björkman's lab has centered on the potential of antibodies to help individuals fight coronavirus infections. "I am very grateful that the researchers in my lab, especially [postdoctoral scholar] Christopher Barnes, who led the efforts, put in long hours and a lot of brainpower to learn how the body uses immune defenses to combat the virus. We hope that this knowledge will pave the way to create an effective vaccine, which is needed not only against SARS-CoV-2 but also against new coronaviruses that are likely to emerge from animal hosts in the future. From our research into immune responses to other viruses, we have ideas for how to create a universal coronavirus vaccine, which we are in the process of developing and evaluating."

Whenever the body is confronted by a pathogen of any sort, including the novel coronavirus, one of its responses is to develop antibodies, proteins that are specialized to recognize and neutralize new pathogens. Then, if the pathogen invades the body again, antibodies produced by memory immune cells can quickly recognize and destroy it before it can take hold. This explains how vaccines protect against specific infections and is why some diseases can infect a person only one time.

**What is a Virus?**
**Viruses occupy a gray area between the living and nonliving realms. Scientists have identified more than 200 virus species with the potential to infect humans.**



Postdoctoral scholar Christopher Barnes at work in the lab before the pandemic began. He has since pivoted his research from HIV to the virus that causes COVID-19.

For years, Björkman's laboratory has studied the HIV virus and antibodies to the myriad strains of the virus. Both SARS-CoV-2 and HIV are enveloped viruses, meaning that each individual virus has a fatty membrane around it. On this membrane are so-called spike proteins, which a virus uses like claws to grab onto a host cell. Coronaviruses have particularly large spikes that give the spherical virus an appearance similar to a crown, hence the name for this class of viruses, "corona" being the Latin word for crown.

The most effective antibodies are usually ones that block this spike protein. In a recent study published in the journal *Cell,* Barnes and a team of collaborators used antibodies isolated from people who had recovered from COVID-19. They studied the various forms that these antibodies can take and exactly how they interact with SARS-CoV-2.

In the same way that a defensive soccer player can use many strategies to block another player's shot, there are many ways for an antibody to try to block a virus. Some, however, are more effective than others. Barnes created an atomic-level model of a particularly potent antibody clinging to a SARS-CoV-2 spike using the same techniques he uses to study HIV antibodies. This antibody was found to be highly effective in its ability to neutralize the virus, or render it unable to infect. Barnes found that this antibody grabs onto a specific region of the spike protein called the receptor-binding domain, or RBD, which is particularly important for the protein to make a connection with a host cell.

"Our work suggests that if bioengineers can design antibodies that target the RBD, that could be an effective way to treat people with COVID. Or, a vaccine could be designed that induces a person's body to produce antibodies that home in on that region," Barnes says. Before the pandemic, Barnes and his wife, Caltech postdoctoral scholar Naima Sharaf, who have two young children, had been busy negotiating academic job offers. It was a challenge to then also shift their research to this urgent situation. Barnes says they make a great team; Sharaf is a co-author on the new paper.

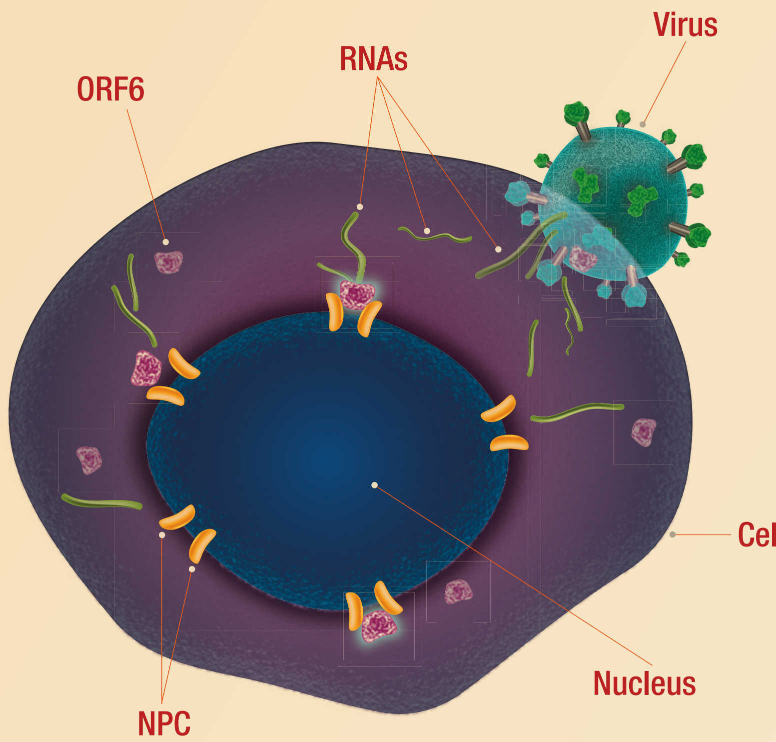



Illustration of a coronavirus infecting a cell, blocking its nuclear pore complex (yellow) with its ORF6 proteins (pink).

## A Protein's Unexpected Role in Infection

Unlike the Björkman laboratory, the research group of André Hoelz (Caltech chemistry professor, Howard Hughes Medical Institute Faculty Scholar, and Heritage Medical Research Institute Investigator) had not previously focused on viruses. Hoelz studies the microscopic machinery in the cells of eukaryotes (the so-called higher life-forms), focusing specifically on the nuclear pore complex (NPC), the massive protein machine that controls access to the DNA-containing heart of the cell. The NPC is targeted by SARS-CoV-2 when the virus infects a cell.

To understand what the NPC does and the role it plays in a coronavirus infection, it helps to know some basics about how a cell is structured.

In eukaryotes, a cell's genetic material is held inside a ball-shaped organelle called the nucleus, which holds the information the cell needs to perform its functions and controls the actions of other parts of the cell.

In a normally functioning cell, the nucleus makes copies of the instructions held in its genetic material in the form of short strands of RNA, which are then sent out via pores in the nuclear membrane into the main chamber of the cell, known as the cytoplasm. The pores are not just holes but instead are composed of a collection of proteins collectively known as the NPC.

After a strand of RNA passes through the NPC into the cytoplasm, the RNA provides the instructions to manufacture a given protein needed by the cell. Many viruses will try to block or destroy the NPC, preventing the cell from exporting its RNA strands and thus allowing the virus to have nearly unfettered access to the cell's machinery to manufacture its own proteins.

As SARS-CoV-2 began to take an international toll, Hoelz and his team started to suspect the virus was attacking the NPC in cells. They planned to pivot their research to investigate this. Then, Hoelz was contacted by a team at UC San Francisco that had found hints that a particular viral protein called ORF6 may be responsible for blocking a cell's NPC. The ORF6 protein is known to be used by the coronaviruses that cause other diseases (such as SARS, MERS, and the common cold) to prevent cells from signaling to their neighbors that they have been infected. Because Hoelz is an expert on the NPC, the UCSF team enlisted his help to examine how the NPC and ORF6 interact.

"We could show that ORF6 does indeed target the NPC and associated mRNA export machinery, and we are currently working toward elucidating the detailed chemical basis of this activity," Hoelz says.

Hoelz notes that the nature of his research has changed with the advent of the virus and social distancing. "For more than two decades, I haven't been away from the lab for longer than a few weeks at a time. While video calls do allow us to communicate and carry on with our work, I greatly miss the direct face-to-face interactions that have been a key element of our daily lives as scientists."

## Wearable Sensors to Catch Infections Early

One of the most telltale symptoms of a COVID-19 infection is a fever: an elevated core body temperature. A fever may even begin to set in before other symptoms, such as a cough. Monitoring a person's temperature, therefore, could provide an early warning that an infection may be present.

In the laboratory of Chiara Daraio, professor of mechanical engineering and applied physics, researchers have been developing polymeric materials, thin and flexible like Saran Wrap, that can measure temperature changes very precisely. When COVID-19 took hold, Daraio and her team focused on ways they could design those materials into a wearable device to continuously monitor a person's core temperature.

Wearable technology is not usually suitable for monitoring fever, because the surface of the skin does not reflect the body's core temperature. But Daraio's team realized that their polymer materials could be stacked in thin layers, and by measuring the variation in temperature between the layers in what is known as a dual heat flux calorimeter, they could extrapolate the core temperature.

Daraio then partnered with Azita Emami, Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering and Heritage Medical Research Institute Investigator, for help in building the device. "Our group is focused on materials, but we needed help with the miniaturization of electronics. Azita is the go-to person at Caltech," Daraio says.

"Wearable sensors have generally been seen as gizmos and not taken seriously," she adds. "This is an opportunity to realize how important they can be in monitoring individuals both at home and in a hospital setting. Right now, for example, a nurse in the infectious diseases ward of a hospital has to manually measure patients' temperatures, which puts that nurse at risk. Having these devices in a hospital setting would allow for safer and simpler care."

As the device is being built and tested, Daraio is looking ahead to how it may more broadly support public health. Together with Tapio Schneider, Caltech's Theodore Y. Wu Professor of Environmental Science and Engineering, and a team of data scientists, they envision that if enough people wear the device and send the data it collects to their smartphone, combined with proximity data, an algorithm could quantitatively predict risks of infection. This would enable people to make informed decisions about their actions (whether or not to visit a certain grocery store, for example), while also reducing the economic damage of blanket social distancing.

Daraio and Schneider, who are married, came up with the idea around the dinner table one evening early in the pandemic. "Blanket social distancing redundantly isolates too many people who are not infectious," Daraio says. "We were looking for ideas to safely return to a less socially distant life."

## The Social Consequences of COVID-19

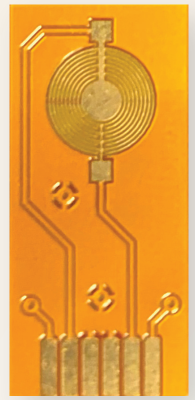
Dean Mobbs, assistant professor of cognitive neuroscience and a Chen Scholar, is studying how the viral threat has led to heightened levels of anxiety throughout the population.

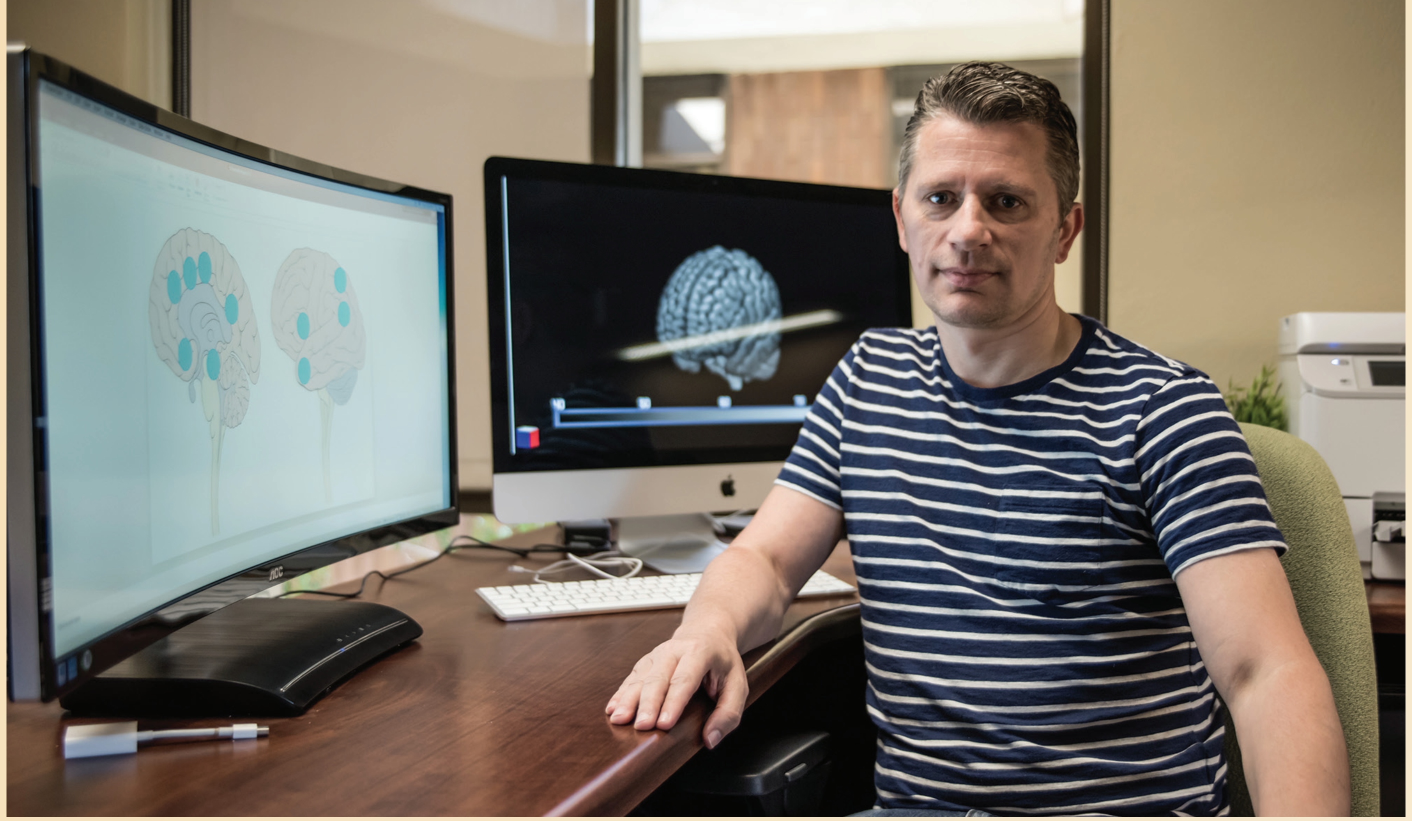
"We are coping with an unseen enemy," says Mobbs. "The human anxiety system is ramped up even higher when there's a lot of uncertainty."

When we encounter uncertainty, Mobbs says, we search for information about the threat so that we can combat it. Our brains preferentially attend to negative stories because they allow us to learn about those threats without actually experiencing them. But a constant high volume of negative information becomes overwhelming, as countless people in the midst of this pandemic can attest.

"We have this wonderful ability to think about future threats and to vicariously learn about threats in the world," Mobbs explains. "But, given the mass communication

Chiara Daraio (below) and her collaborators are developing a wearable sensor that could continuously monitor a person's temperature. Graduate student Vincenzo Costanza (MS '19) helped lead the research.





Dean Mobbs studies how the viral threat has led to heightened anxiety throughout the population.

channels that we use, it's not surprising that many of us are feeling much anxiety. That anxiety is translated into behaviors, such as panic shopping. Researchers believe there is going to be a peak to the fear and anxiety, and then, even though the danger of the threat of the virus is higher, I think we're going to see people habituate to the threat and become less anxious. You can only keep anxiety levels high for a certain period of time."

Neuroscientist Ralph Adolphs (PhD '93), Bren Professor of Psychology, Neuroscience, and Biology at Caltech, is also studying how people's psychology, biases, decision-making, behavior, and more are affected by COVID-19. He and collaborators are taking weekly surveys of approximately 1,000 people from all 50 states, with questions about their identification with various political, religious, racial, ethnic, and social groups as well as about their experiences related to COVID -19, adherence to public health recommendations, and trust in political and scientific leaders. Additionally, the researchers pose questions about various psychological factors, such as personality, mood, and coping behaviors. They are hoping to answer questions such as, "How do people's emotions reflect the COVID-related regulations in their state and county?" Adolphs hopes that the collected data and models will be useful to the people who develop public health policy.

## A Pandemic's Planetary Effects

Shortly after the stay-at-home orders were issued for Los Angeles, photos of the city began to circulate on social media that suggested the skies were clearer due to people staying home; the phrase "Nature is healing; we are the virus" was a frequent caption. But Paul Wennberg, Caltech's R. Stanton Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering, cautions that it's not always so straightforward to draw connections between staying home and clearer skies.

Wennberg is particularly interested in the effects of humanity's changed behavior and habits on the planet. In Los Angeles, he notes, nitrogen oxide (NOx) emissions that cause air pollution mostly come from trucks and other diesel-fueled engines rather than personal cars. In other parts of the world, the connection between the reduction in traffic associated with COVID-19 and a reduction in air pollution is easier to establish: in Europe, for example, there are far more diesel cars, which emit copious NOx. Their absence from the roads has made a much more noticeable impact.

In India, a substantial reduction in demand for electricity, a 26 percent drop in just 10 days, has led to the temporary closure of some coal plants, which in turn has led to cleaner air. In California, demand for electricity is down only about 5 to 10 percent. Many of the activities that demand electricity have not changed in the way they would in India or China, where the manufacturing sector is more dominant.

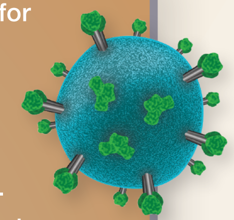
"Once you restart the activities that cause air pollution, it'll come roaring back," Wennberg says. "But there are places that have historically had really bad air pollution, and a lot of the population has never really experienced clean air. Suddenly they're experiencing it, and I just can't believe that won't have an effect. People will have seen something different, and I wouldn't be surprised if they will then demand it. We've shown in the U.S. that you can have both good air quality and substantial economic activity."

## A New Day

On a sunny summer day in June, researchers (wearing masks and schooled in new safety procedures) began to slowly trickle back onto campus and into a new normal. Tables outside the Red Door Café are now spaced out for social distancing, and heightened hygiene protocols limit the number of people in any one space at a time. Custodial and dining workers have adapted to rigorous sanitizing schedules. Although campus looks and feels different than it did in early March, and the COVID-19 pandemic is far from over, the Caltech community continues to adapt to and tackle the challenges of carrying out research one day at a time. [C]

Find more articles on Caltech's COVID-19 related research at coronavirus.caltech.edu

## Funding Rapid Responses

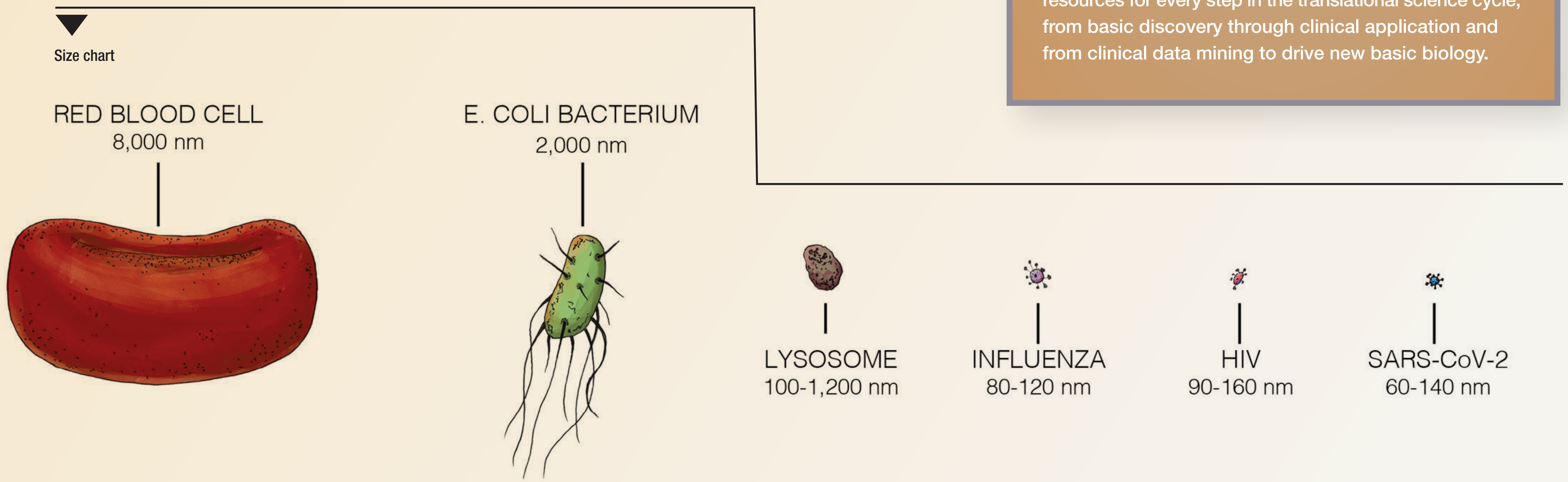


In April, Caltech's Richard N. Merkin Institute for Translational Research announced a call for proposals to initiate and accelerate research pertinent to COVID-19. Grants would be fast-tracked to support projects that meet urgent needs as well as initiatives focused on the long-term evolution of the virus. High-risk, high-reward projects across disciplines were encouraged.

More than 50 proposals were considered, and 21 new projects and working groups were funded. Reflecting the interdisciplinary nature of the COVID problem itself, investigators represent five of Caltech's six divisions. Two rounds of funds have been released to date, covering 19 grants. Projects include:

- The development of novel therapeutics
- Improved testing capabilities
- Structural characterization of infection processes
- Studies of the psychological impact of stress and isolation

The Merkin Institute was established in 2019 by a gift from Richard Merkin, Caltech trustee and founder of Heritage Provider Network. The institute's mission is to help Caltech scholars realize the full biomedical potential of their discoveries and inventions. It provides resources for every step in the translational science cycle, from basic discovery through clinical application and from clinical data mining to drive new basic biology.

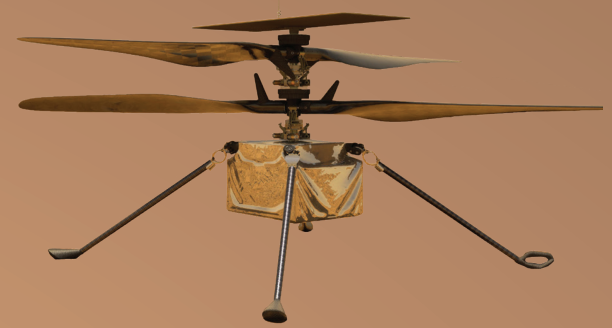


# Mars 2020

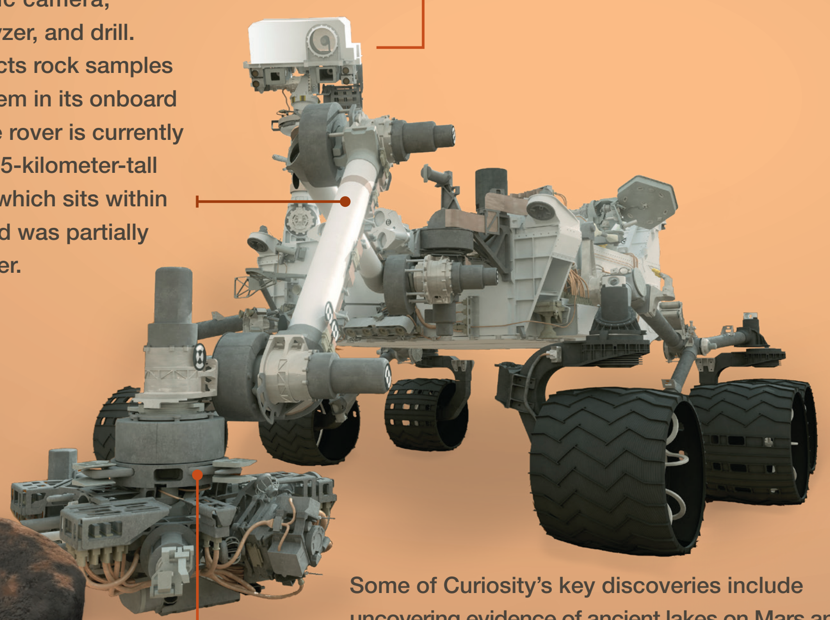
## EVOLUTION OF A ROVER

This summer, the Mars Perseverance rover will set out to join Curiosity on the Red Planet. The two rovers, both built by JPL (which Caltech manages for NASA), share many design features but play different roles in the ongoing exploration of Mars and the search for ancient life. They also differ in important mission-specific ways: while Curiosity has identified and continues to study environments where ancient microbes could have lived, Perseverance will seek direct signs of ancient life and prepare geological samples that a future mission could bring back to Earth.

For more information about Curiosity and Perseverance, visit: **mars.nasa.gov/msl/home** and **mars.nasa.gov/mars2020**



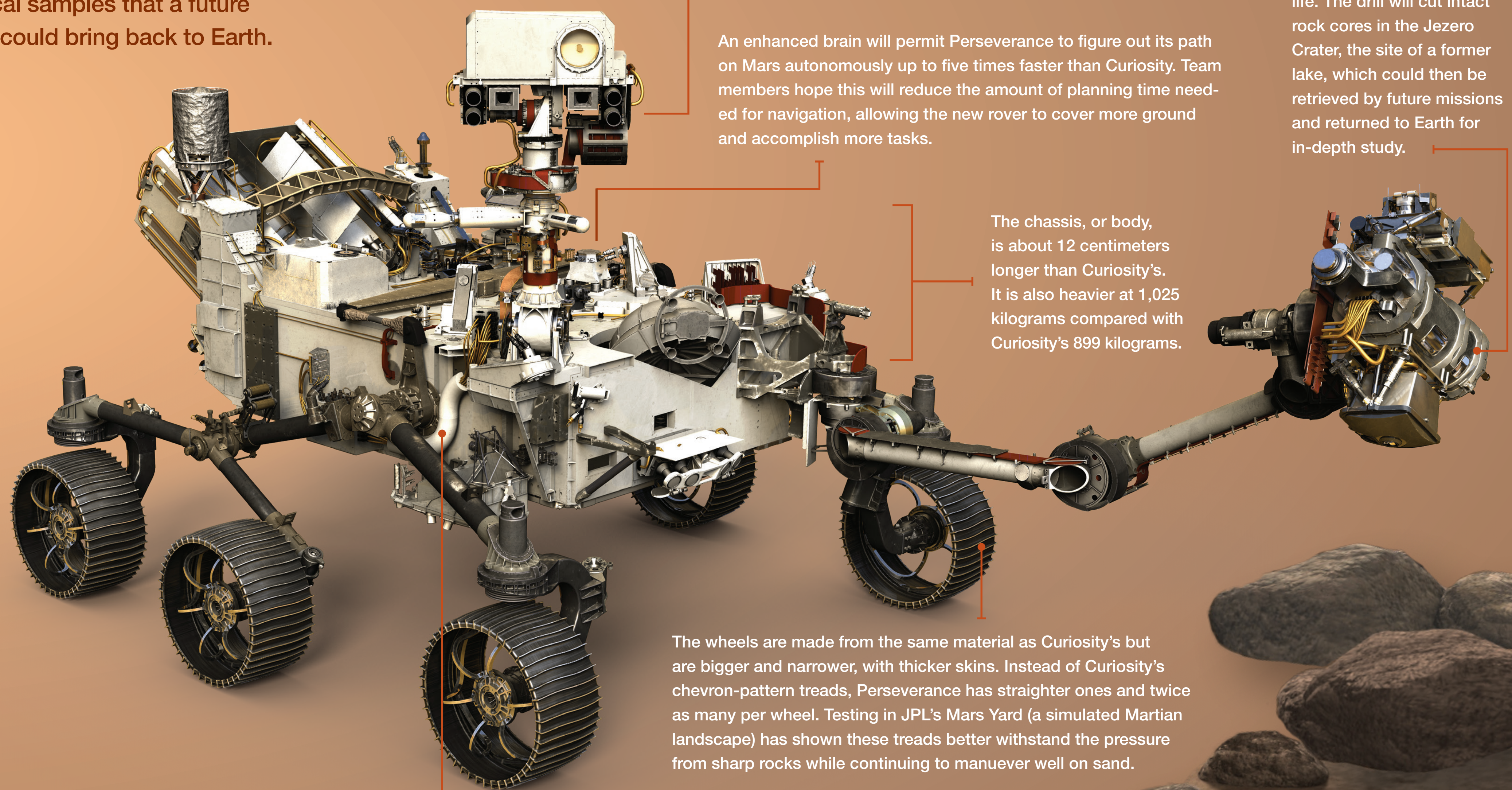
A small helicopter drone is attached to the belly of Perseverance, where it will stay protected during the landing. Once on Mars, it will test powered flight on another planet.



Curiosity has seven cameras on its mast; four of them are color cameras. Two of these cameras, making up the mast camera, or Mastcam, have taken stunning color panoramas of the Martian landscape.

The rover's arm extends 2 meters and wields a rotating 30-kilogram turret equipped with a scientific camera, chemical analyzer, and drill. Curiosity collects rock samples and studies them in its onboard laboratory. The rover is currently ascending the 5-kilometer-tall Mount Sharp, which sits within Gale Crater and was partially formed by water.

Some of Curiosity's key discoveries include uncovering evidence of ancient lakes on Mars and, with the help of a drill on its robotic arm, finding chemicals necessary for life, including sulfur, nitrogen, oxygen, phosphorus, and carbon.



Perseverance will have the most advanced set of "eyes" ever sent to the Red Planet. It has a total of 23 cameras, most of them color, as well as two microphones to capture, for the first time, the sounds of a Mars landing and the Martian wind. Mastcam-Z, an improved version of Curiosity's mast camera, has zoom capability and the ability to take high-definition video and panoramas, and improved 3-D imagery.

An enhanced brain will permit Perseverance to figure out its path on Mars autonomously up to five times faster than Curiosity. Team members hope this will reduce the amount of planning time needed for navigation, allowing the new rover to cover more ground and accomplish more tasks.

Perseverance's arm has the same reach as Curiosity's, but its turret, at 50 kilograms, weighs more because it carries larger instruments and a larger drill for coring as it looks for signs of past life. The drill will cut intact rock cores in the Jezero Crater, the site of a former lake, which could then be retrieved by future missions and returned to Earth for in-depth study.

The chassis, or body, is about 12 centimeters longer than Curiosity's. It is also heavier at 1,025 kilograms compared with Curiosity's 899 kilograms.

The wheels are made from the same material as Curiosity's but are bigger and narrower, with thicker skins. Instead of Curiosity's chevron-pattern treads, Perseverance has straighter ones and twice as many per wheel. Testing in JPL's Mars Yard (a simulated Martian landscape) has shown these treads better withstand the pressure from sharp rocks while continuing to manuever well on sand.

MOXIE, an oxygen-generating instrument the size of a car battery, will demonstrate how future explorers could produce oxygen from the Martian atmosphere.

# Call to Action

**Caltech alumni have been at the heart of the response to COVID-19, from better testing to front-line patient care.**

by Judy Hill


**In the trenches**
Prakriti Gaba (BS '13), an internal medicine resident at Columbia University Medical Center, was on the front lines caring for patients with COVID-19 since the start of the pandemic.

Spring was finally on the horizon. Two medical interns were in the midst of grueling residencies in busy urban hospitals on the east coast. In Southern California, a radiologist was juggling a lab, a start-up, and a clinical practice, while an emergency medicine physician had her hands full at two local hospitals. On the Caltech campus, a postdoc and a graduate student were engrossed in their bioengineering and chemical engineering research; at JPL, a systems engineer was at work on a mission that aims to collect space-based data to examine how airborne particles affect human health.

Then COVID-19 arrived in the United States and ratcheted up the intensity of their already hectic lives. Driven to respond to this new challenge, these Caltech alumni found ways to apply their knowledge and expertise to join the fight against the disease. They improved testing capabilities, designed face shields, addressed problems of ventilator scarcity, and had the most difficult conversations of their lives.

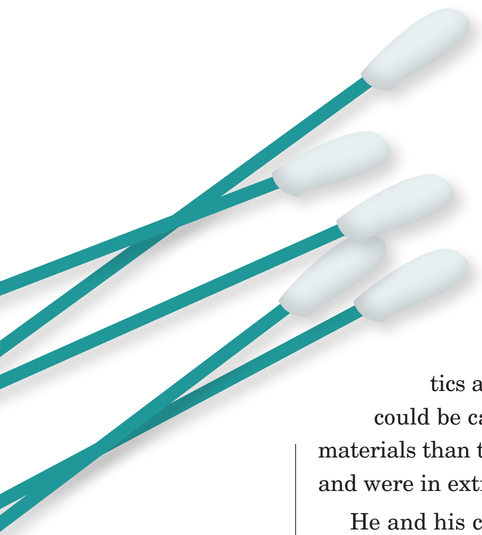
"I don't think I could have predicted that our efforts would pan out the way they have," says Albert Hsiao (BS '00, biology, engineering/computer science), a cardiothoracic radiologist who developed a machine learning algorithm to detect pneumonia. "But it is what I always hoped would happen: that the things we learned at Caltech, everything that we trained for, can now be applied and have meaning for society."

## A faster, better test

Mikhail Hanewich-Hollatz (PhD '20, bioengineering) was several months into a bioengineering postdoc appointment in Professor of Applied and Computational Mathematics and Bioengineering Niles Pierce's Caltech lab when the first rumblings of the coronavirus began to be felt on campus. He remembers that, during the same week in which Pierce sent everyone home to work remotely, his brother emailed him a screenshot of a tweet from Curative, an L.A.-based biotech company, which was looking for people with wet lab experience to volunteer on a project to scale up COVID-19 testing.

"And I thought, basically, 'I have to do this,'" says Hanewich-Hollatz, who is adept at PCR (polymerase chain reaction, a way to make vast numbers of copies of a specific DNA sample) and RNA extraction, both parts of the process of the dominant type of COVID-19 diagnostic test. "'That's me; I have those skills. Under what other circumstance is my skill set going to really be able to make a significant impact in a time of crisis?'"

When Hanewich-Hollatz interviewed for a spot and relayed his experience engineering custom RNAs for the genome-editing tool known as the CRISPR/Cas9



system, Curative suggested that rather than being a volunteer tech, pipetting samples, he might be more valuable as an associate scientist on the research-and-development team. So ended Hanewich-Hollatz's postdoc; in its place began an opportunity he could never have foreseen.

His first job was to help reconfigure the L.A. lab space for COVID-19 diagnostics and then to convince the FDA that the test could be carried out with more readily available materials than those that had been approved at the time and were in extremely short supply.

He and his colleagues also worked to adjust and automate portions of the test for extremely large-scale repetition. The FDA came through with Emergency Use Authorization approval and, in just seven weeks, the lab went from running zero tests a day to 13,000, or approximately 20 percent of all the tests run in the state of California at that time.

Toward the end of March, Hanewich-Hollatz was asked to fly to Washington, D.C., to set up a similar facility. Within 48 hours of landing, he had a functional lab set up. By early May, he had hired 50 people to process patient samples and anticipated that ultimately the lab's capacity would be around 50,000 tests a day. Recently, he was promoted to Curative's director of laboratory operations for Washington, D.C.

The most gratifying part of the experience for him has been the immediacy of the impact he has been able to make. "It's an experience that is very, very different from grad school, where you're struggling for years and whether you've made any real progress is a matter for debate."

His current role is not something he would ever have envisioned, he says, but it has reshaped what he finds interesting. "What we're doing here is integrating things in a new way. We're cutting through some of the bottlenecks. It's not pushing the boundaries of what's possible in a single experiment but pushing the boundaries of what's possible to provide society."

## An algorithm to detect pneumonia

Since the majority of seriously ill COVID-19 patients develop pneumonia, it is important to detect the condition as quickly as possible, even before a definitive COVID-19 diagnosis, says Hsiao. That way, treatment can begin immediately.

Hsiao, a cardiothoracic radiologist at UC San Diego Health, has developed an artificial intelligence (AI) algorithm that can rapidly and accurately highlight areas of pneumonia on an X-ray. "This is useful for less-experienced radiologists as well as physicians who are not radiologists," he explains. "ER docs and ICU docs who are closer to the point of care might not have as much experience reading the X-rays as a subspecialty radiologist, and the findings of viral pneumonia can be really subtle. With this pandemic, people are doing jobs they weren't necessarily experts in before."

Hsiao had previously developed a 4-D cardiac-imaging software to measure and visualize blood flow with an MRI. When the Society of Thoracic Radiology put out a challenge a year and a half ago to develop a machine learning algorithm to locate pneumonia on an X-ray, he and his lab decided to take a new approach. The algorithm they developed, which was trained with 22,000 annotations by subspecialty radiologists, overlays X-rays with color-coded maps that indicate areas of pneumonia.

When the first reports of a novel coronavirus began to surface last December, Hsiao's paper on the algorithm, which had been accepted by the *Journal of Thoracic Imaging,* had yet to be published. "I asked my research resident to download images of chest X-rays from COVID-19 patients from a couple of different journal articles and just try the algorithm out on them to see if it could pick up the pneumonia," says Hsiao, whose team immediately published a research letter with the results. "It was like magic, it just worked. So, that gave us confidence right away that we should try to deploy this in our clinical practice."

In late March, UC San Diego Health began using the algorithm, and the results in real-life cases were just as impressive. "We've had patients who weren't initially thought to have COVID come in for abdominal pain and then get an X-ray along the way," he says, "and the AI has detected their viral pneumonia, which then led to the RT-PCR [reverse transcriptase PCR] test to confirm they had COVID."

Now Hsiao is working with members of his lab to fine-tune and improve the algorithm, and has initiated collaborations with several other academic medical centers across the United States. Through Arterys, his start-up company, he has also made the initial prototype available on the web so that physicians in hospitals anywhere can try using it with their own X-ray images.

This crisis, Hsiao says, highlights the importance of physician-scientists. "I feel like the role of physician-scientists has been unfortunately fading over the years, and the divide between hospitals and new technologies has grown. Hospitals have shifted to focus on financial concerns, such as revenue and bottom line, while industry often builds technologies without a full understanding of the clinical problems. Physician-scientists are needed in between to bridge the gap between technology and medicine."

**The Power of AI**
Albert Hsiao (BS '00), a radiologist at UC San Diego Health, developed an AI algorithm to accurately pinpoint areas of pneumonia, a common affliction for coronavirus patients, on an X-ray.

## A face-shield assembly line

Dennis Ko (MS '12, chemical engineering), who is currently pursuing his doctoral degree in chemical engineering at Caltech, was inspired to get involved when his partner, Lisa Yee (BS '10, biology), an emergency-medicine physician, told him she had to continually reuse her N95 mask and face shield because supplies were so limited. When she finished her shifts at Kaiser Permanente medical centers in Fontana and Ontario, she would stash her face shield in her backpack. After a few weeks of this, the plastic guard was getting crinkly.

With hospitals in Southern California preparing for a surge in COVID-19 cases in March, Yee explains, healthcare facilities were trying to conserve their supplies of personal protective equipment for high-risk procedures such as intubations.

"I'd been reading online that a lot of people were 3-D printing their own face shields, and I thought, 'You know what? I'll just learn how to do it.' I talked to my adviser, Julia Kornfield [BS '83, Elizabeth W. Gilloon Professor of Chemical Engineering], and she said, 'Even if you only print five face shields, that's five people you managed to help.'"

After purchasing an inexpensive 3-D printer and a couple of spools of PLA (polylactic acid, a bioplastic made from lactic acid), Ko and Yee began researching face-shield designs in early April. On the National Institutes of Health (NIH) website, they discovered a 3-D-printing repository with user-submitted designs. "We found one that was clinically reviewed, meaning you can take the shield on and off 10 times without it destructing or losing its quality. So I said, 'Let's just go for that one.'"

The first shield took five hours to print and was deemed good but not perfect by Yee. From her frontline experience caring for patients, she realized that a shield with a full brim that fit snugly against the forehead would provide better coverage than the design they had printed, which had a gap at the top. Ko ended up adapting another design from the NIH site using computer-aided design software. "I think there were a total of 13 iterations," says Ko. "There was a huge learning curve."

Once the pair had settled on the optimal design, their operation quickly gathered steam as Yee identified more physicians and nurses in her department, as well as former residency colleagues now at other hospitals, in need of face shields. Ko bought two additional printers and increased his production to 100 masks every three or four days. During April and May, they supplied a total of 600 face shields to medical centers around Southern California.

For Yee, having an extra shield or two gives her an added sense of safety. "Now, with any patient who has a fever, cough, or shortness of breath, I can go into the room with my own face shield. Afterward, I just wipe down the plastic part that goes around the head and change out the transparent plastic shield, and I'm good to go."


To amplify the impact of the project, which is funded entirely through donations, Ko has uploaded their design to the NIH repository, where anyone can download it for free.

3dprint.nih.gov/
discover/face-shield

## A front-line position

As an internal medicine resident at Columbia University Medical Center, Prakriti Gaba (BS '13, biology and business, economics, and management), was on the front lines caring for patients with COVID-19 at New York-Presbyterian Hospital from the earliest days of the pandemic.

When the first few cases of COVID-19 emerged in the city in mid-March, she began working in the intensive care unit and from there moved on to the emergency room, taking care of many patients who were intubated and required ICU-level care. Since then, she has also worked on the inpatient floors and in new temporary ICUs (rooms converted from medical-surgical units to accommodate the rapid surge in cases).

"As COVID-19 spread in New York City, patients were flooding into the ER," she says. "Some were really young, in their 20s, without comorbidities, and everyone was extremely sick. Many patients were intubated as soon as they arrived."

Already accustomed to long hours as a resident, Gaba and her colleagues pushed through punishing schedules with 12-hour days and one day off a week, at most. What she found hardest, though, were the end-of-life discussions with patients' family members. "It was absolutely heartbreaking," she says. "No part of me was ready to convey that loved ones can't talk, hug, or say goodbye to their father, grandmother, or son, or that their loved ones would have to be away from family during their final moments."

She has felt inspired, though, by fellowship with her colleagues. "What has been the most rewarding aspect of this whole experience is being a part of the immense camaraderie among doctors and nurses from all specialties (orthopedics, dermatology, ENT, and many more) working tirelessly together to tackle this pandemic. It is absolutely remarkable how everyone has teamed up to fight this fight."

## A rapidly deployable ventilator

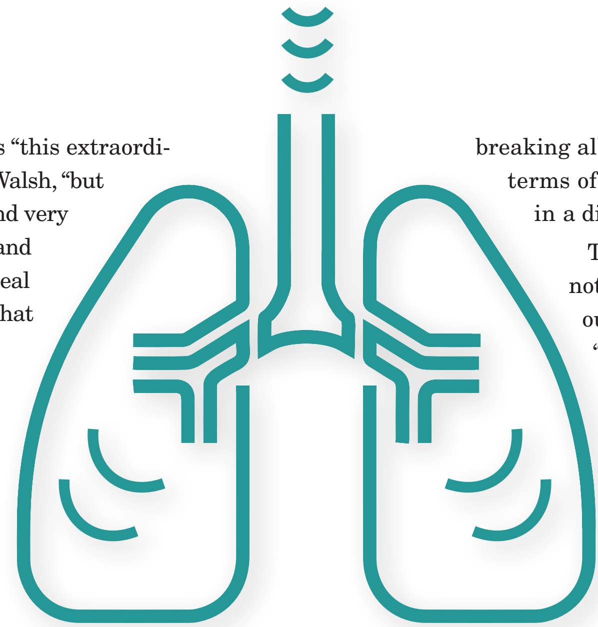
Elisa Walsh (BS '12, biology, minor in English), an anesthesia resident at Massachusetts General Hospital, remembers hearing reports in early March about hospital systems in Italy becoming completely overwhelmed with the influx of COVID-19 patients. One detail, the lack of mechanical ventilators, stood out for her.

"In our hospital, we've seen some COVID-19 patients on a ventilator for weeks while recovering," she says. "In Italy, the ventilator shortages pressed doctors into making the unimaginable decision of choosing who would get a ventilator and who would not. As an anesthesia resident, I felt an immediate calling because every single day I'm working with mechanical ventilators for patients in the operating room and the intensive care unit. I can't imagine not being able to provide this lifesaving technology to a patient who is in need."

Sometime in the middle of March, a senior resident at the hospital proposed pushing out a moonshot challenge to engage people all over the globe to design a ventilator that would be rapidly deployable and could be used in a low-resource setting. Walsh signed on, with a handful of other Mass General residents, and the CoVent-19 Challenge was born, officially launching on April 1, which was also when their hospital received its first real wave of COVID-19 patients. Walsh serves as lead on the medical expert panel of the 19-person team coordinating the initiative.

**Expert assistance**
Left: Lisa Yee (BS '10) and Dennis Ko (MS '12), designed and printed face shields for area hospitals. Right: Elisa Walsh (BS '12) joined with fellow physicians to launch a global challenge to design a ventilator for use in pandemics.





The typical ICU ventilator is "this extraordinary piece of technology," says Walsh, "but they're very big, very complex, and very difficult to manufacture in bulk and store within the hospital." The ideal ventilator for a pandemic is one that is smaller and simpler in design and able to be quickly manufactured in large quantities.

More than 150 initial entries were submitted by the May 1 deadline; seven from across the globe were invited into the final round. In July, Walsh and her fellow team members selected the winning design to be prototyped and undergo necessary regulatory testing. Though aware that their timeline meant they missed the first months of the pandemic's spread in the U.S., they hope the winning ventilator will be able to support patients in the future.

## A VITAL contribution

In Pasadena, JPL engineers also pivoted to address the ventilator problem and developed a new high-pressure ventilator in just 37 days in March and early April to treat COVID-19 patients. The new ventilator was granted an Emergency Use Authorization by the FDA on April 30. Caltech's Office of Technology Transfer and Corporate Partnerships offered a free license for the device and reached out to the medical industry to find manufacturers. Almost 100 proposals were submitted to receive the license and so far, 27 companies have received them, nine in the United States and 18 internationally.

Called VITAL (Ventilator Intervention Technology Accessible Locally), the unit can be built faster and operated more easily than a traditional ventilator and is composed of far fewer parts. The FDA has since awarded a second authorization for a modified design of VITAL that uses a compressor to generate pressurized air, which makes it ideal for a wider range of medical locations, including field hospitals.

JPL engineer Stacey Boland (PhD '05, mechanical engineering) served as the operations lead for the project, creating a communication pathway between engineers, designers, and visualization specialists with doctors, nurses, and respiratory therapists.

"With systems engineering, some of the time you're the glue and sometimes you're the lubricant," says Boland. "You just try to keep things going, make sure that people communicate with each other. We clearly hit upon a real need and are offering a compelling solution. We're breaking all sorts of new boundaries in terms of figuring out how to do things in a different way."

Though Boland knew next to nothing about ventilators at the outset of the project, she says, "You figure it out, and you follow your gut, and you fill in the blanks. You need to be willing to learn and ask questions."

Even when the ventilator project is behind her, Boland says the pandemic will still factor into her research on airborne particulate matter and health, since many of the preexisting conditions that impact response to the disease can be correlated with air pollution. "The COVID-19 aspect is going to still be there career-wise for me in terms of an interesting area of research," she says, "and that certainly wasn't something that I was anticipating." [C]

# Radio Astronomy in the High Desert

by Whitney Clavin

Since 1958, astronomers have unveiled some of the deepest mysteries of the universe with the help of Caltech's Owens Valley Radio Observatory (OVRO), located in high-desert terrain east of California's Sierra Nevada mountains. The observatory, which remains at the forefront of radio astronomy, has seen many different projects come and go, including CARMA (Combined Array for Research in Millimeter-wave Astronomy), a hugely successful set of radio telescopes that ceased operations in 2015. Now, several of those dishes are being repurposed at OVRO, and two other projects, the Deep Synoptic Array and the Long Wavelength Array (LWA), are in the midst of massive expansion efforts. "OVRO is experiencing a renaissance. We are moving radio astronomy in an entirely new direction," says Gregg Hallinan, Caltech professor of astronomy and director of OVRO. "By building large numbers of small telescopes, we can scan the skies faster than ever before. These arrays will be generating more than 40 terabytes of science data per day, making them among the most data-intensive telescopes in the world."

The OVRO-LWA project was enabled by a donation from Deborah Castleman (MS '86) and Harold Rosen (MS '48, PhD '51).



The Long Wavelength Array of telescopes at Owens Valley. Inset photos: Marin Anderson (MS '14, PhD '19) and Michael Eastwood assemble antennas for the LWA.

## In Search of Magnetospheres

The Long Wavelength Array (LWA) consists of hundreds of pyramid-shaped radio antennas that dot a vast stretch of OVRO. Since 2015, the LWA has used 250 antennas to probe the flickering of radio signals in the night skies, studying everything from the dawn of the universe, to outbursts on our sun, to glowing exoplanets. Now, the National Science Foundation (NSF) is funding an expansion of the project, bringing the total fleet of antennas to 352. Hallinan is particularly excited for the project to search for signatures of magnetospheres around planets orbiting other stars. Magnetospheres are the regions around planets dominated by magnetic fields; Earth's magnetic field protects its atmosphere from erosion by solar wind. The presence of magnetospheres on exoplanets may be a critical ingredient for planetary habitability but have eluded detection to date. "With the LWA, we will scan the entire sky every 10 seconds to monitor thousands of exoplanets simultaneously, waiting for a planet's magnetosphere to light up in radio waves," says Hallinan.

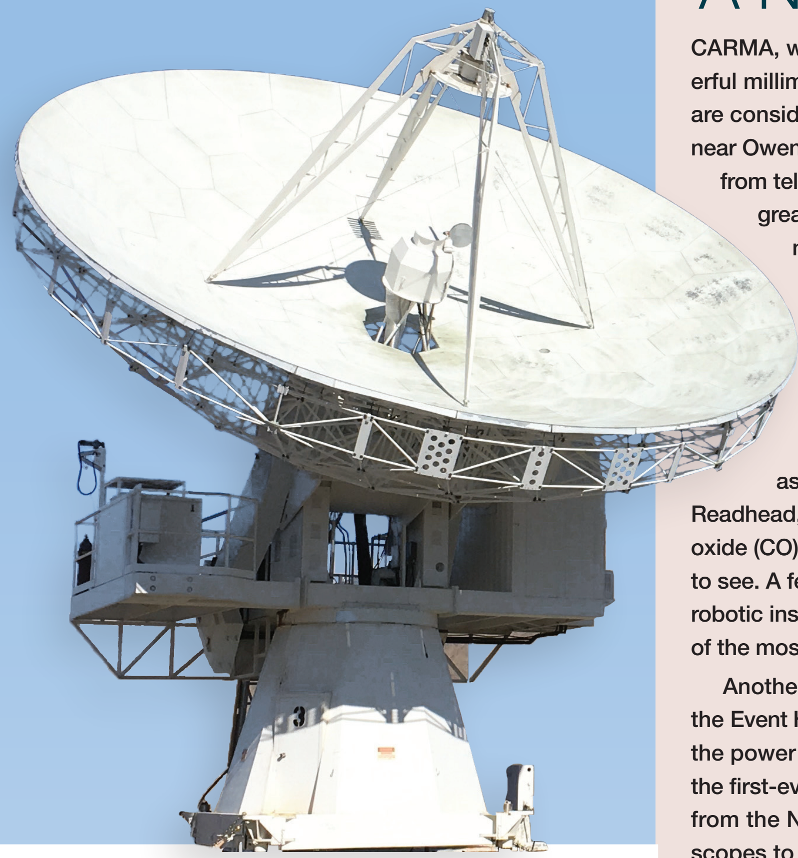
## Staring at the Whole Sky

OVRO hosts several small, focused experiments that target high-risk, high-reward science. A notable example is STARE2 (Survey for Transient Astronomical Radio Emission 2), led by Shri Kulkarni, the George Ellery Hale Professor of Astronomy and Planetary Science at Caltech. The project consists of three radio receivers located at OVRO; at NASA's Deep Space Network facility in Goldstone, California; and at Delta, Utah. The receivers scan broad swaths of the sky every night in search of the brightest fast radio bursts (FRBs). While the receivers are not as sensitive as radio dishes, what they lose in sensitivity, they gain in field of view. In April of this year, STARE2 detected what may be the first-ever FRBs seen in the Milky Way galaxy. The results are preliminary but may provide long-sought proof that FRBs are caused by erupting magnetars, a type of exotic star with powerful magnetic fields.

Below: Artist's rendering of the Deep Synoptic Array-2000. Middle right: A Leighton radio dish. Lower right: Wendy Chen, Nitika Yadlapalli, and Corey Posner assemble a DSA dish.

## Many, Many Dishes

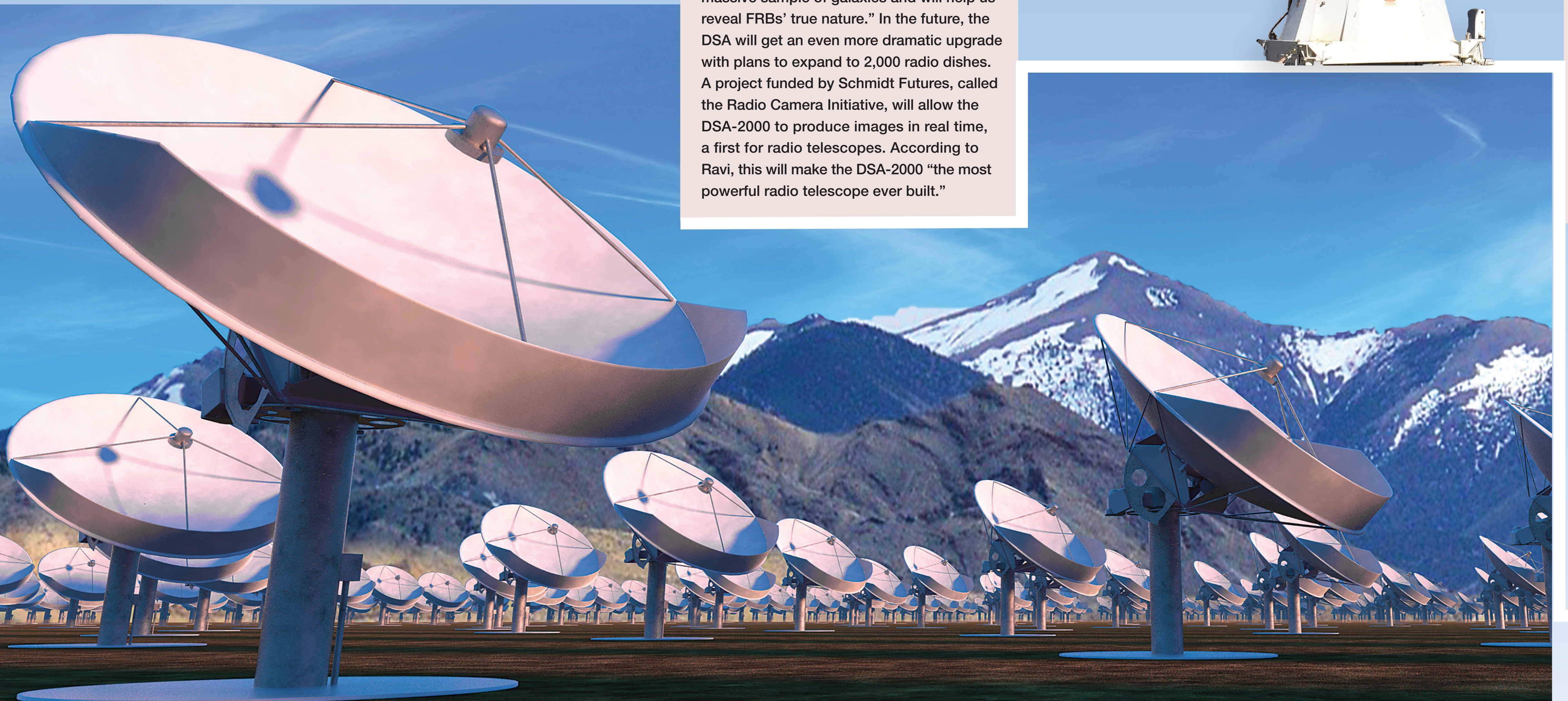
The night skies flash with intense radio pulses, called fast radio bursts (FRBs), whose causes have remained unclear. One key to unlocking the mystery of these bursts is to identify the galaxies from which they originate. In 2019, the Deep Synoptic Array-10 (DSA-10) at OVRO identified one such host galaxy of an FRB, a rare feat made even more difficult by the fact that this particular FRB did not repeat, as others have been known to do. Now, thanks to new funding from the National Science Foundation (NSF), the DSA is in the midst of a major upgrade, expanding from 10 to 110 radio dishes. The DSA-110 is expected to begin observations in October of this year. "When we begin, we will be identifying about two FRB host galaxies per week," says Vikram Ravi, assistant professor of astronomy. "That's a massive sample of galaxies and will help us reveal FRBs' true nature." In the future, the DSA will get an even more dramatic upgrade with plans to expand to 2,000 radio dishes. A project funded by Schmidt Futures, called the Radio Camera Initiative, will allow the DSA-2000 to produce images in real time, a first for radio telescopes. According to Ravi, this will make the DSA-2000 "the most powerful radio telescope ever built."



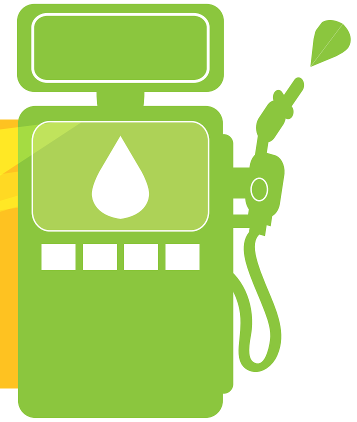
## A New Purpose

CARMA, which operated from 2005 to 2015, was one of the most powerful millimeter-wave telescope arrays in the world. (Millimeter waves are considered a type of radio wave.) Located in the Inyo Mountains near Owens Valley, the array consisted of antennas brought together from telescopes across the U.S. to create a combined array of much greater sensitivity. These antennas included the Leighton dishes, named for the late Caltech professor Robert Leighton (BS '41, MS '44, PhD '47), who designed them in the 1970s to kick-start millimeter astronomy at OVRO. After the closure of CARMA, the Leighton dishes were moved back to OVRO. COMAP, which stands for CO Mapping Array Pathfinder, is one of the projects that is repurposing a Leighton dish. Begun in the summer of 2018, this project, led by OVRO associate director Kieran Cleary and professor emeritus Tony Readhead, traces the evolution of galaxies by mapping carbon monoxide (CO), a marker of faint faraway galaxies that are otherwise hard to see. A few of the Leighton dishes are also being combined to form a robotic instrument, known as SPRITE, to determine the nature of some of the most energetic explosions in the universe.

Another project for which a Leighton dish is being redeployed is the Event Horizon Telescope (EHT), which, in 2019, famously harnessed the power of several radio observatories across the globe to create the first-ever picture of a black hole. Now, with the help of new funding from the NSF, the EHT project is tapping into even more radio telescopes to better image and study black holes. "Adding a telescope dish at Owens Valley fills a critical hole in the EHT's virtual Earth-sized telescope," says Katherine L. (Katie) Bouman, an assistant professor of computing and mathematical sciences and electrical engineering who leads the Caltech portion of the international EHT team. "This brings us much closer to one day capturing a movie that allows us to track the gas falling into a black hole over the course of a single night."



Pictured: Aniketa Shinde, materials instrumentation engineer at JCAP from 2013–19



# Everything under the SUN

by Andrew Moseman

Within the Joint Center for Artificial Photosynthesis, researchers have spent the past decade pursuing breakthrough chemistry to convert sunlight into fuels capable of meeting humanity's growing energy needs.

Nature has had billions of years to perfect the marvel of photosynthesis, in which light energy from the sun powers a reaction between carbon dioxide and water inside plants (and certain bacteria) to create food. Of all the light plants receive, however, just 1 percent is used for this process. Although that may sound terribly inefficient, it is anything but: that smidgen of sunshine provides plants with 100 percent of the energy they require.

Humanity, on the other hand, has much more intensive energy needs. To meet those needs, the world continues to rely on dirty or dangerous sources including coal, oil, and nuclear to power the electricity grid, cars and airplanes, and industrial enterprises. And yet, every hour of the day, enough sunlight shines on Earth to power all of human civilization for an entire year. The challenge is the same one plants address through photosynthesis: to transform the light of the sun into viable forms of energy. To meet society's needs sustainably, however, we must convert a much larger percentage of that sunlight into fuel than plants do, on a vastly larger scale, all while creating a fuel that is more readily useable in our society.

That is why, a decade ago, the Department of Energy funded a new Energy Innovation Hub called the Joint Center for Artificial Photosynthesis (JCAP), led by Caltech and with primary sites both at Lawrence Berkeley National Laboratory (LBNL) and on campus. In JCAP, Caltech partners with researchers from LBNL, the SLAC National Accelerator Laboratory, UC Irvine, and UC San Diego. JCAP brought together a diverse team of chemists, physicists, materials scientists, engineers, and other researchers in the search for bold new ways to improve on nature's processes in the creation of "solar fuels" (products such as hydrogen fuel and hydrocarbons) using nothing more than sunlight and basic molecules such as water and carbon dioxide.

During their 10-year run, JCAP scientists have set new records for artificial photosynthesis by increasing solar-to-chemical energy efficiency performance from less than 1 percent to 19 percent and by designing highly stable solar-fuels generators. These efforts established performance criteria for individual materials and integrated systems that guide materials discovery. Together with the world's largest materials library, built by JCAP, these efforts laid the basic-science groundwork for a new energy economy.


Pictured: John Gregoire

"I think we have a real opportunity to draw up a blueprint and a scientific path for creating not only solar fuels but also essentially all of the processes that we use for industrial production," says Harry Atwater, Howard Hughes Professor of Applied Physics and Materials Science and director of JCAP.

## Why Solar Fuels?

"At the California Institute of Technology, they're developing a way to turn sunlight and water into fuel for our cars." In that one line from his 2011 State of the Union address, President Barack Obama illuminated JCAP's mission: to discover renewable, solar-driven ways to create the kinds of liquid fuels, including hydrocarbons, that can be useful for powering cars, homes, and factories.

"When we burn fuels in a car or a jet engine or a boat, we start with hydrocarbons and we spit out carbon dioxide and water. Now we want to take that carbon dioxide and water and recycle it back into the fuel," says Tom Jaramillo, a JCAP team member and associate professor at Stanford University and SLAC.

Solar fuels promise to do what other renewable energy alternatives cannot. Liquid fuels can be easily stored and used anytime. Photovoltaic solar panels, by contrast, can soak up rays only when the sun shines, and they require major improvements to battery technology to store electricity for later use. An increasing number of electric cars have joined America's highways, but their batteries have a limited range to go with their long recharge times. The truth is, Atwater says, batteries generally cannot match liquid fuels in their ability to store a lot of energy in a small volume.

"I have a Tesla parked in my driveway, so I voted with my wallet that a battery vehicle is a good solution," Atwater says. "But if you look at the entire global vehicle fleet of 80 million vehicles, it's clear that they're not all going to go electric. And so we have to have some zero-carbon solution for all of them."

When JCAP launched in 2010, Atwater says, its scientists knew that to produce liquid fuels using only sunlight, they would need new catalysts (substances that speed up chemical reactions), new materials to carry electrical charges during the necessary chemical reactions, and new strategies to streamline the electrochemical reactions. "What we didn't know was which of these catalysts, materials, and strategies were the good ones," he notes.

To find out, JCAP built a multidisciplinary team of scientists and engineers to investigate every piece of the process. During its initial five-year run, from 2010 to 2015, which began under the leadership of Nathan Lewis (BS '77), Caltech's George L. Argyros Professor and professor of chemistry, JCAP refined the process of splitting water; breaking down $H_2O$ into molecular oxygen and hydrogen is a critical step in the chemistry required to make solar fuels. During that time, Caltech researchers achieved a 10.5 percent efficiency in converting solar energy to hydrogen via water splitting, and then in 2018 bested this record with an efficiency of 19.3 percent. Over these subsequent five years, JCAP researchers have focused on reducing carbon dioxide to create the carbon-carbon bonds required to build energy-rich liquid fuels such as hydrocarbons.

"That's one of the reasons why Caltech is so great," says Kimberly See, assistant professor of chemistry. See's research on electrolytes (substances that create an electrically conducting solution when dissolved in a solvent like water) has focused on building better batteries, and now she's bringing some of the same strategies to research solar fuels. "That's where innovation comes from: when people come from one field and start working with experts in a different field. I think good things always happen."

## One Piece at a Time

As he describes the record-breaking collection of new materials he and his colleagues have created, Caltech's John Gregoire, coordinator of one of JCAP's four research thrusts, points his finger straight up toward the second story of the Earle M. Jorgensen Laboratory, JCAP's home on the Caltech campus since 2012, where he built that materials library.

Artificial photosynthesis requires several essential steps. A device must be able to capture sunlight and transform the sun's rays into usable electrical voltage. That voltage would then provide the energy necessary to drive a variety of chemical reactions that covert existing molecules and use their ingredients to synthesize fuels.

For example, JCAP scientists want to be able to reduce $CO_2$ molecules, then combine the resulting individual carbon atoms into long chains to form energy-dense molecules. But they must do this entire process efficiently (so they do not put more energy into making fuels than they will ultimately get from burning them) and selectively (so the reactions do not produce a host of unwanted by-products), and that is not currently possible at the industrial scale.

Gregoire coordinates JCAP's efforts on photoelectrocatalysis: the use of materials that are activated by sunlight to create the electrical voltage to drive the necessary chemical reactions. Numerous materials already known to science, such as materials used in solar panels, can handle some of the tasks he requires. But such materials cannot survive and thrive in the harsh environment of an artificial photosynthesis device that splits water or reduces carbon dioxide.

That is why Gregoire and colleagues are still on the hunt for materials that can do it all. The chase takes place in the custom-built Jorgensen high-throughput experimentation laboratory right above Gregoire's office, where his team synthesizes different possible materials from the elements of the periodic table to see if the material has the needed properties. "We can synthesize and screen these materials a hundred times faster than anyone's ever been able to do before," Gregoire says. "But that still is not fast enough to make everything."

Given all the possible ways to combine the elements, there are billions if not trillions of possible candidates. Instead of relying on brute force or trial and error, Gregoire works with JCAP theorists to identify the types of materials that, based on their composition and structure, should have the kind of light-absorbing and conducting properties he seeks. But machines alone cannot do this job: computers will miss or dismiss some of the promising possibilities. The humans of JCAP, with their years of experience and intuition regarding what an auspicious material looks like, are also essential. Computers are great for reducing the size of the haystack, but sometimes you still need a human eye to find the needle.

"You're looking for an outlier," Gregoire says. "An outlier is the answer."

This human/machine research collaboration has birthed the largest known library of materials, all of them metal oxides, useful for solar fuels. Of the 70 known metal oxides with any measurable photoelectric activity (the ability to turn sunlight into current), Gregoire says, 50 were discovered in the past decade and half of them by JCAP.

When it comes to understanding the materials developed within JCAP, Marco Bernardi, assistant professor of applied physics and materials science at Caltech, pursues the theoretical. Starting with only the atomic structure of a material and the equations of quantum mechanics, Bernardi computes how well electrons move through a semiconductor or oxide candidate. Bernardi describes this theoretical effort as complementary to the experimental side; it provides a framework to microscopically understand, down to the atomic level, the materials created in the lab and their performance. "I think we're bridging the gap between theory and experiments for these highly complex materials," Bernardi says.

Jaramillo at SLAC, meanwhile, is also building a library, but his is full of catalysts: compounds that can speed up the chemical reactions behind artificial photosynthesis and that have been at the heart of just about every advance in the chemical and fuel industries since their inception. Because of humanity's long experience with fossil fuels, the oil and gas industries have had decades to perfect the catalyst that helps to transform crude oil into the refined gasoline burned in car engines. Researchers investigating renewable alternatives, including solar fuels, are in a race to catch up.

Specifically, Jaramillo focuses on finding the ideal catalysts to accelerate and refine the reactions needed to break down water and reduce carbon dioxide. His goal is to create just the right arrangement of atoms, geometric structure, and electronic structure so that if, for instance,

Pictured: Harry Atwater

a $CO_2$ molecule encounters that catalyst, Jaramillo says, "the catalyst is ready to rip that thing apart into its constituent atoms and then re-form them into the molecule we want at the expense of the one that we dont."

## Tools of the Trade

Scott Cushing, an assistant professor of chemistry at Caltech, is a self-described gearhead. "I grew up in West Virginia working on cars," he says. "I like working on mechanical systems. When I went to college, someone showed me a laser, and I fell in love. I've been working on laser-based instrumentation science ever since."

As evidence, Cushing spent his postdoctoral years working on a tabletop version of a synchrotron before joining the Caltech faculty in 2018. Typically seen in the form of a giant particle-accelerating ring, a synchrotron is a tool that takes advantage of fast-moving electrons' tendency to emit X-rays when they change direction. Cushing's downsized version fires a powerful laser to force electrons to change directions and emit X-rays. The X-rays then tell researchers how the electrons carry voltage through the ultrathin layers of a device. This is crucial for solar fuels research, Cushing says. "Our big goal is to try to measure these reactions all the way from when a material first absorbs sunlight until the product, a solar fuel, is made." Since artificial photosynthesis starts on a femtosecond timescale, or one-quadrillionth of a second, this pushes laser technology, and thus our ability to measure the electrons, right to its current frontiers.

The need for high-precision instruments including Gregoire's high-throughput characterization systems and ultrafast optoelectronic characterization at LBNL is one of the many reasons JCAP is a collaboration of researchers from scientific institutions across the state, says Frances Houle of LBNL, who serves as JCAP's deputy director for science and research integration. In addition to laboratory instruments, she says, the success of this research relies upon the large synchrotron rings at LBNL and SLAC.

Houle's focus on bringing together the many parts of JCAP requires that she also focus on another challenge: taking the fruits of the collaboration into the "real world." After all, when solar fuels are someday able to be manufactured on an industrial scale, they will not be made using simple test setups in a research laboratory. JCAP scientists are learning how to work at larger scales testing how their materials react under real operating conditions, which will include changes in light flux, temperature, and humidity. Gregoire's materials "will ultimately need to be able to sit out in the desert and work for one to three decades," he says.

"You just can't make technological advances without having a very deep science platform to work from," Houle says.

## Carbon to Carbon

Tearing water or carbon dioxide into their constituent parts is only half the battle. Scientists then need to combine those parts to make a fuel, which brings a new set of chemical challenges.

Consider, Atwater says, the problem of cooking up a solar version of Jet A, the principal variety of jet fuel that commercial airliners burn. Jet fuel abounds in hydrocarbons, or compounds in which hydrogen is bound to long carbon chains; those bonds release ample energy when burned, which means that these compounds can store a huge amount of energy in a small volume. That is why a major JCAP focus is on synthesizing the building blocks of jet fuel. Using carbon dioxide, sunlight, and their own advances in chemistry, they could create a sustainable way to manufacture the kinds of fuel airplanes must burn.

"The airplane manufacturers are interested in this because they know there is just no way that they can electrify their fleets in any reasonable timeframe that is going to bend the curve for climate change," Atwater says. "So if they're going to make an impact on climate, it's going to be through solar fuels."

Those industry hopes depend in part on the work being done on the second floor of Jorgensen, where a team of researchers led by chemistry professors Jonas Peters and Theo Agapie (PhD '07) experiments with new tactics to tackle the problem of creating multiple-carbon bonds. Typically, Agapie says, breaking down carbon dioxide leaves behind single-carbon compounds such as carbon monoxide and formic acid. To build multicarbon compounds, such as those found in gasoline and other chemicals of interest, requires additional steps, and those steps require the right kind of electrode, a conductor that carries electrical charge into nonmetallic materials like carbon dioxide.

Scientists have found that the charge carried by copper electrodes, when applied to a solution of carbon dioxide, can create the desired carbon-carbon bonds. The problem is, it cannot do so "selectively," which is a chemist's way of saying that along with the carbon-carbon bonds, the reaction creates a host of extraneous molecules as well. To address that problem, over the past several years Agapie and Peters' team has pioneered a way to grow an organic film upon a copper electrode via electrolysis (the application of direct electrical current to drive chemical reactions); that electrode can then drive the conversion of $CO_2$ into products with two or three linked carbon atoms with very few undesired by-products.

## What the Future Holds

In addition to leading JCAP, Atwater heads up one of four main initiatives within Caltech's Resnick Sustainability Institute (RSI), an effort called Sunlight to Everything. It is an apt phrase, he says. The basic chemical processes and new materials discovered during this decade of JCAP efforts have laid the foundation for the next phase of solar fuels research, which will include more affordable materials and efforts to test prototypes under real-world conditions, giving industry new starting points for tomorrow's sustainability solutions. Future research also will focus on seizing $CO_2$ from sources such as power-plant flue gas or capturing it from the atmosphere or seawater and using it for solar fuels reactions.

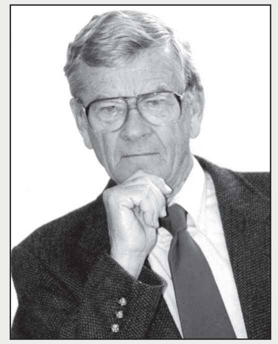
For solar fuels to be made at useful levels for society and industry, researchers must continue to find better photoactive materials, more efficient catalysts, and new ways to build fuels at the molecular level. That quest energizes Atwater. "I tell my students: when I started as a grad student, solar photovoltaics were in the same stage of development that solar fuels are today," he says. "During my professional lifetime, I've seen solar photovoltaics grow from something that was done as a curiosity in research labs to a global industry that's having an impact on the world's energy transformation."

Solar fuels hold the same promise. And as the JCAP team well knows, this kind of technological sea change begins with, and requires, basic research.

"We're focused on the fundamental science, and we recognize that that fundamental science will have broad-reaching implications," Jaramillo says. "The periodic table is our playground."

# In Memoriam

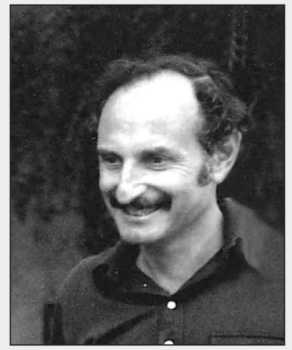
Read more about their lives at **magazine.caltech.edu/post/in-memoriam**



### Allan Acosta

(BS '45, MS '49, PhD '52), 1924–2020

Allan Acosta, Caltech's Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering, Emeritus, who spent 50 years at Caltech and helped launch the Institute's present-day mechanical engineering option, passed away on May 18, 2020. He was 95 years old. Acosta was a faculty member at the Institute in the Division of Engineering and Applied Science from 1954 until his retirement in 1993. He taught courses on fluid flow and heat transfer. His research group was a small collection of faculty with similar interests, including pioneering Caltech mechanical engineer Rolf Sabersky (BS '42, MS '43, PhD '49), with whom he published the textbook *Fluid Flow: A First Course in Fluid Mechanics* in 1963. Acosta was recognized as an exceptional teacher and mentor, and was highly influential in shaping the education and training of many generations of students. He was an elected member of the National Academy of Engineering and a Fellow of the American Association for the Advancement of Science.



### Louis Breger 1935–2020

Louis Breger, a professor of psychoanalytic studies, emeritus, at Caltech, and a psychotherapist who authored several books, passed away on June 29, 2020. He was 84 years old. Breger joined Caltech in 1970 and retired in 1994. His research centered on dreams, reformulations of psychoanalytic theory, psychotherapy process and outcome, personality development, and the application of psychoanalysis to literature. He authored numerous books, including two biographies of Sigmund Freud. His research on dreams used techniques to monitor people's sleep throughout the night and showed that dreams are symbolic attempts to master emotional conflicts rather than wish fulfillments as Freud proposed.

# Endnotes

## How are you coping with the coronavirus pandemic, and how has it changed your life?

I am online tutoring science to students using Zoom.

**William Dower (BS '77)**
AUSTIN, TX

I live and work on a remote island in Vanuatu [in the South Pacific], one of the few countries without any cases of the virus so far. I am attaching a photo of my son Alex demonstrating a "Tippy Tap" handwashing station. He made it for an awareness talk we gave about the epidemic last month.

**Michael Smith (BS '93)**
RAH ISLAND, VANUATU

I think for those of us who are not doctors or researchers searching for a cure, the best thing we can do is help our friends and family understand the scientific literature and help them educate themselves.

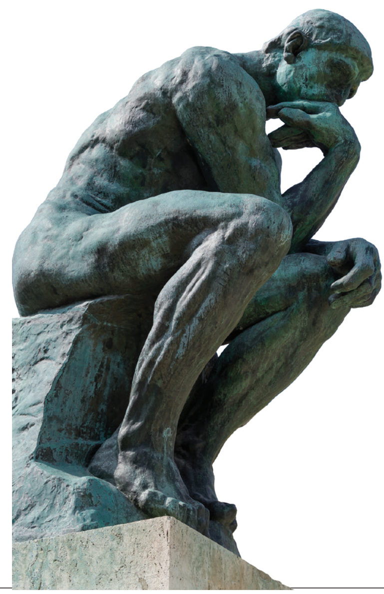
**William Woody (BS '88)**
RALEIGH, NC

I am making masks, initially in response to a request from a doctor friend in Seattle but now for friends and family. I'm using bandanas, old sheets, twist ties to make a crimpable nosepiece, and for ear-loops some small-diameter shock cord we happened to have on hand.

**Ellen Elliott (PhD '75)**
ELLICOTT CITY, MD

We stocked up on hurricane supplies about a month earlier. Preparing for a pandemic and a hurricane is much the same. The major difference is that this time we didn't lose utilities.

**Frank Matthews (BS '64)**
HOUSTON, TX



I videoconference in the mornings to keep in touch with my group and management, but in the afternoons I have time to THINK! Time to pursue my own interests and ideas, to read papers I have long neglected, and to write things I should have years ago.

**John Kitching (PhD '95)**
BOULDER, CO

Many people have realized that we are able to take time for that which is truly important, and I am feeling grateful for wonderful connections and a newfound softness within how we interact with each other.

**Louise Wannier (BS '78)**
PASADENA, CA

I am writing my memoirs and relearning how to play my trumpet. Both projects require me to once again be the blowhard that I dreamed of during my student days at Caltech. Alas, I may not be any more successful today than I was then.

**William Bloom (BS '68)**
ALTADENA, CA

## Connect with us

Email us at **magazine@caltech.edu**

## Join us

### The Show Must Go On(line)!

While all in-person campus events have been canceled until further notice due to the coronavirus pandemic, Caltech's Public Programming team has put together a curated roster of performances from world-class artists that can be enjoyed from the comfort and safety of home, from fiddle-playing virtuoso Eileen Ivers to contemporary Australian circus arts and more.

To learn more, go to **events.caltech.edu/series/theshowmustgoonline**

As a semiretired poker player, investor, and wannabe theoretical physicist, my life has changed little. Meanwhile, I do what I always do, read *The New York Times* and *Wall Street Journal*, follow the markets, and act as community TA for online physics courses. And, of course, try and whittle down my 80 books on advanced theoretical physics.

**Mark Weitzman (MS '90)**
LAS VEGAS, NV

I started rereading the Techer's Bible: *The Feynman Lectures on Physics.*

**Joseph Feng (BS '69, MS '71, PhD '75)**
SAN JOSE, CA

For more Endnotes responses, go to **magazine.caltech.edu/post/endnotes-pandemic**

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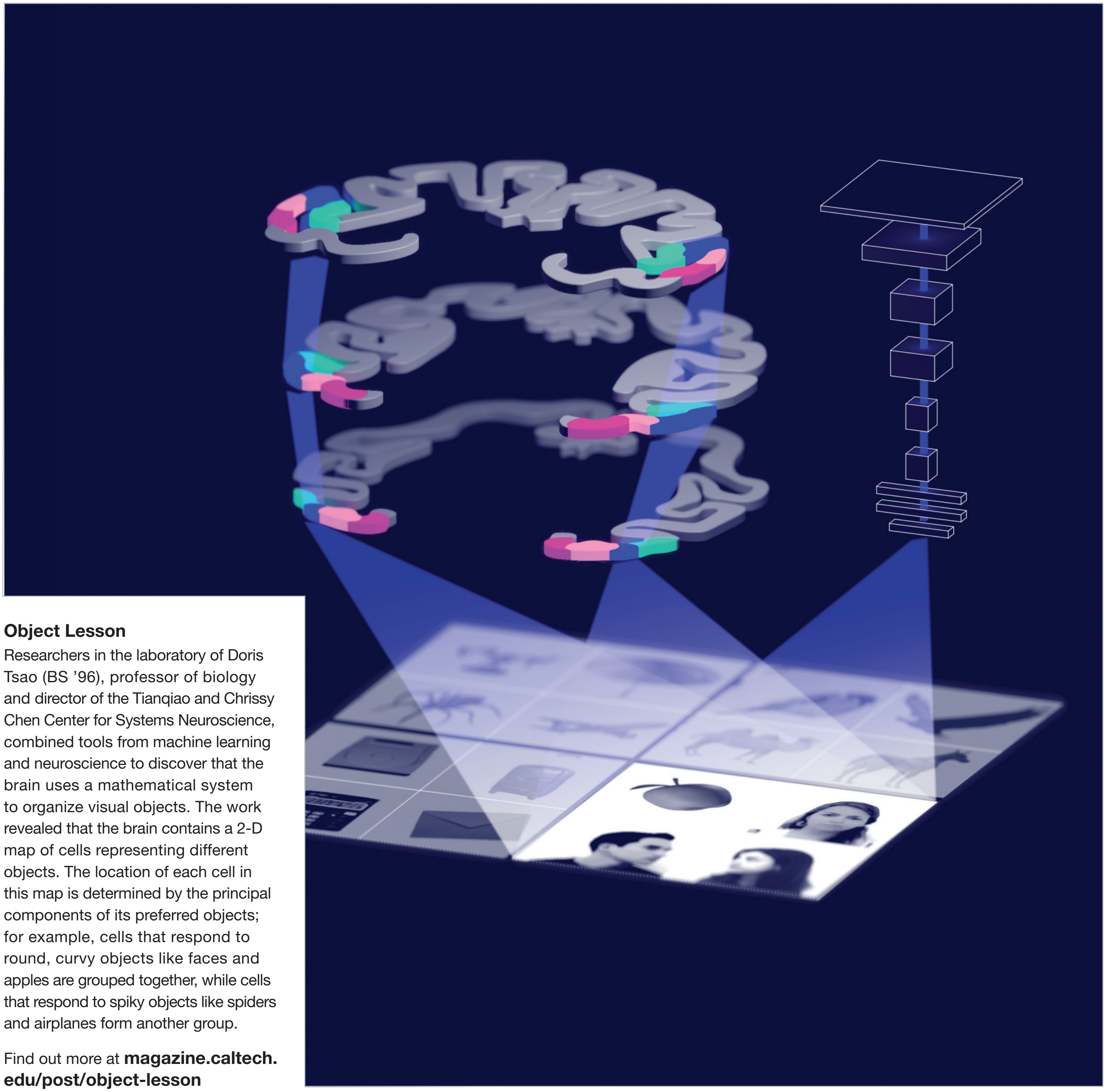

**Object Lesson**

Researchers in the laboratory of Doris Tsao (BS '96), professor of biology and director of the Tianqiao and Chrissy Chen Center for Systems Neuroscience, combined tools from machine learning and neuroscience to discover that the brain uses a mathematical system to organize visual objects. The work revealed that the brain contains a 2-D map of cells representing different objects. The location of each cell in this map is determined by the principal components of its preferred objects; for example, cells that respond to round, curvy objects like faces and apples are grouped together, while cells that respond to spiky objects like spiders and airplanes form another group.

Find out more at **magazine.caltech.edu/post/object-lesson**