Fall 2020

Caltech
magazine

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Left: A collage of simulated galaxies; the simulations were created to probe the nature of dark matter.

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Caltech magazine

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CONTRIBUTING WRITERS
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CONTRIBUTING DESIGNER
Brandon Hook

PHOTOGRAPHY AND VIDEOGRAPHY
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COPY EDITORS
Sharon Kaplan, Carolyn Waldron

PRODUCED BY CALTECH'S OFFICE OF
STRATEGIC COMMUNICATIONS
Shayna Chabner, Chief Communications Officer

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magazine@caltech.edu

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The cover illustration was created by Aurélia Durand, a multidisciplinary artist based in Copenhagen who creates illustrations, murals, animations, and augmented reality. Her first illustrated book, *This Book is Anti-Racist* (written by Tiffany Jewell), was a number one *New York Times* bestseller in July 2020. See more of Durand's work at **aurelia-studio.com.**

Letters

Memories Sparked

Your recent Origins article ("Ready, Set, Spark!" Summer 2020) stirred memories of my youth. My home was a short distance from Caltech, and I was able to enjoy several of the demonstrations at High Volts, which were just as Royal Sorenson described in 1985.

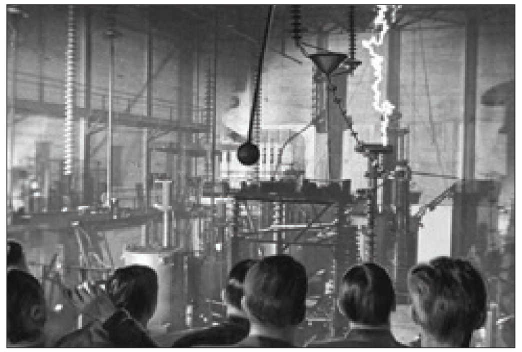
As for the article, the picture should not have been photoshopped! Those slick hairdos are a distraction from the real event. Also, the impulse generator was not rapid! It took many seconds, as Sorenson states, to charge the capacitors for a single pulse.

Also, the virus size chart in the recent issue ("A New Day, A New Normal") is misleading. The influenza viruses, of which there are many variations, are about 100 nm in diameter, as is the SARS CoV-2 virus. The HIV virus is a bit larger, about 120 nm in diameter. The range listed in the table may be correct, but, in general, the size difference among those viruses is not significant.

William Hassenzahl

Note from University Archivist Peter Collopy: Alas, the photograph was "photoshopped" long before it got to us. It was manually retouched, probably many decades ago, before it made it to the collections of the Caltech Archives, where it now resides. I'm not sure where I got the word "rapid," but I suspect I used it because it or a similar word appeared in a contemporary account of the lab or the demonstrations. I appreciate learning that it took several seconds to charge the impulse generator.

This interesting article ("Ready, Set, Spark!") raises questions about dates. For Jack Roberts, born 1918, to have seen demos "as a teenager," the lab must have been operating by 1937, not 1939, per the article. I recall attending lectures in High Volts, probably in freshman physics, for me 1952–53. Roberts's vivid description is right on the mark. The lab, we were told, had been built in support of the 1931–36 construction of Boulder Dam



("Hoover Dam"), which would explain the support by Southern California Edison. It's unlikely that the photo could have been made "in the 1920s."

Some equipment had an extracurricular life. I recall the Jacob's ladder (horn gap) arcing noisily in the courtyard of Ricketts House, presumably to impress our female guests at the Interhouse Dance, long before women students (and OSHA).

Sam Phillips, (BS '56, MS '57)

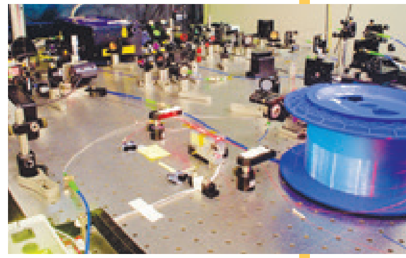
Editor's note: You are correct. Due to an editing error, the date when High Volts opened was stated incorrectly. Construction on High Volts was completed in 1923, and Southern California Edison's research there was completed well before they actually built the Hoover Dam.

Earnest C. Watson Lecture Series

Since 1922, the Earnest C. Watson Lecture Series has brought Caltech's most innovative scientific research to the public. Due to the coronavirus pandemic, this year's lineup of lectures will be offered online as Zoom webinars. Each Watson Lecture begins at 5 p.m. Pacific Time, with a live audience Q&A at the end. The events are free, but registration is required. For information, visit **caltech.edu/watson.**

October 7, 2020
Can America Have a Safe and Secure Presidential Election?
Michael Alvarez
Professor of Political and Computational Social Science

November 11, 2020
The Power of Nonlinearities: Unlocking Opportunities for Sensing and Computing with Light
Alireza Marandi
Assistant Professor of Electrical Engineering and Applied Physics



December 9, 2020
The Inner Life of the Brain: Fear, Sex, and Violence
David Anderson
Seymour Benzer Professor of Biology

January 13, 2021
Artificial Intelligence: How it Works and What it Means for the Future
Yisong Yue
Professor of Computing and Mathematical Sciences

February 17, 2021
What Cosmic Fireworks Unveil About the Universe
Mansi Kasliwal
Assistant Professor of Astronomy

March 10, 2021
Perseverance on Mars
Ken Farley
W. M. Keck Foundation Professor of Geochemistry

April 21, 2021
Sunlight to Everything: Catalyzing a Sustainable Future
Jonas Peters
Bren Professor of Chemistry; Director, Resnick Sustainability Institute

May 12, 2021
From the Soil to the Clinic: How Infection-Causing Microbes Thrive Without Oxygen
Dianne Newman
Gordon M. Binder/Amgen Professor of Biology and Geobiology

All lectures can be found on YouTube.com

SoCaltech

To Capture a Comet

Since 2010, the JPL mission NEOWISE has scanned the skies for asteroids and comets. On March 27, 2020, it identified a bright comet approaching the sun. Comet NEOWISE emerged from behind the sun on July 3 and, in the following weeks, dazzled the public and inspired amateur astronomers to capture photos, including the one at left, taken by Corey Husic, a graduate student in the lab of Assistant Professor of Chemistry Maxwell Robb. Of the image, Husic says: "I've been interested in nature photography for some time. More recently, I've become fascinated by astrophotography. I'm blown away by the idea that the same camera I use to take a photograph of a butterfly right in front of me can also take pictures of distant objects in space. I was very excited about the discovery of Comet NEOWISE, since there hadn't been a comet this bright since the mid-'90s. I traveled to darker skies in the San Gabriel Mountains and Mojave Desert to see the comet. But given NEOWISE's connections to Caltech/JPL, I thought it would be cool to view it from campus. I knew it would be a challenge because of the light pollution here in Pasadena. Even on the darkest of nights, it can be difficult to make out more than a few stars, but I had to give it a try. Armed with binoculars and camera, I ventured out onto Beckman Lawn on the evening of July 20. With a bit of searching, using the Big Dipper as a guide, I found the comet. With the naked eye, it was just a faint smudge, although binoculars revealed a bit of the tail. I set up my camera on a tripod, focused on a bright nearby star, and took a six-second exposure, trying to balance light coming in from the faint comet with the overpowering lights in the foreground of the image. The final image is actually a stack of multiple exposures of the same scene, a trick used to combat thermal noise, which becomes a big problem on digital camera sensors on warm summer nights. The final result is the image you see!"

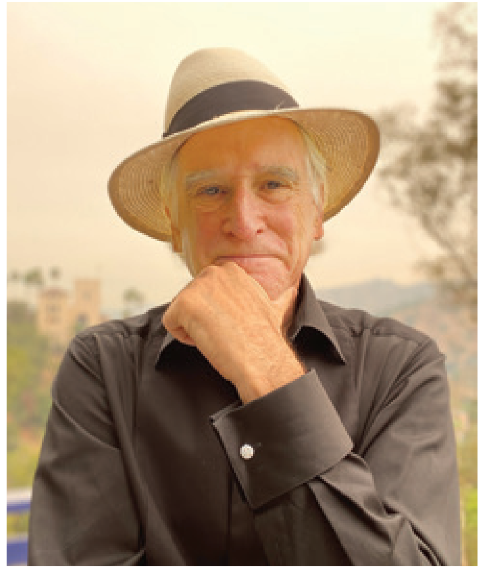
Data from NEOWISE are processed at IPAC, an astronomy center at Caltech.

Learn more at **neowise.ipac.caltech.edu**

Together, *from a distance*

Michael Alexander, Caltech's public programming director, likes to say he is in the "people-gathering business." At the helm of CaltechLive!, which brings musicians, actors, and dancers to Beckman Auditorium, Alexander has cultivated opportunities to attract diverse audiences and bring people together for informal post-performance discussions at the Red Door Marketplace.

The COVID-19 pandemic changed all that. With all performances online for now, Alexander has had to adapt the series. A live YouTube concert in April with Irish fiddler Eileen Ivers featured both music and banter as Ivers fielded questions from Alexander and responded to comments from the chat stream. The event attracted more than 1,000 viewers and bolstered Alexander's confidence in the viability of an online-only program.



"We are not in a position to create something that is going to compete with a Broadway show or a commercial network presentation," says Alexander, who came to the Institute in 2018. "What we *can* do is create unique conversations with a Caltech stamp that cannot be replicated elsewhere. We are looking at opportunities to find artists who have some kind of connection to science and are addressing issues that are uniquely appropriate for Caltech."

Here is what Alexander and his team have planned this fall for the series now named **The Show Must Go On(line)**:

Live theater

"In November, we will be presenting a live play called *Blood Sugar* by actor Diana Wyenn, who is a Type I diabetic. The play will actually be produced in her house with a three-camera shoot that she and her husband will manage, with the director sitting about 3 miles away, looking at the screens and deciding which camera to use at a given moment. And at the end of this 65-minute play, we will switch into a dialogue-friendly program where audience members and Caltech scientists can discuss the play. I've seen the play before onstage, and it's a very, very powerful piece. At one post-performance conversation, I heard a diabetic say it was the first time they'd ever seen their story onstage."

Author interviews

"At this point, we have three great authors who we're working with. One of them, Blake Hill-Saya, wrote about her great-great-grandfather, Aaron McDuffie Moore, who was the first Black physician in Durham, North Carolina. And then we've got a memoir by [Caltech vice provost, English professor, and chief diversity officer] Cindy Weinstein about her mother's struggle with Alzheimer's, which she co-authored with a physician. Our third author, Indre Viskontas, is a neuroscientist and also an operatic soprano who teaches at the music conservatory of San Francisco. She has a book about how the brain turns sounds into music. These presentations will follow the model I often hear on public radio, with a host in conversation with the author and time set aside for the author to read one or two passages from the book."

Music and dialogue

"Konstantin Batygin (MS '10, PhD '12) [professor of planetary science] is one of three faculty members, along with Julia Greer [materials science professor] and Lucy Jones [visiting associate in geophysics], who were probably at some point in their life caught in that spot of, 'Am I going to be a musician or a scientist?' Konstantin is a rock and roll musician, Julia is a concert pianist, and Lucy plays the viola da gamba. We will be presenting short programs in which they will play some of their music and then we will have some dialogue about the role that art plays in their lives. It is part of what we can do to help the community stay in touch in the absence of those occasional encounters at the Athenaeum and at the Red Door."

For more details, go to **events.caltech.edu**

The Fight to Save Mount Wilson

On September 6, a wildfire began deep in the San Gabriel Mountains. Dubbed the Bobcat fire, it quickly grew and began to threaten several of the foothill communities near Pasadena; it also began to move westward into Santa Anita Canyon, heading rapidly up the slopes toward the Mount Wilson Observatory, the home of modern observational cosmology and the site of some of the world's most significant astronomical discoveries, including evidence for the expansion of the universe and the first evidence of dark matter. Also located within the perimeter of the observatory is the Caltech-operated Mount Wilson Seismic Station, one of the first six seismic stations installed in Southern California in the 1920s. Data from this seismic station have been used to locate and determine the magnitudes of earthquakes for the past 100 years.

The historic mountaintop site was evacuated on September 7, and the staff, from a safe distance, watched the approaching flames (captured by the observatory's webcam) and took to social media to share updates and extend their gratitude to the firefighters.

One of those anxious observers was Sam Hale, chairman of the board of trustees of the Mount Wilson Institute and grandson of George Ellery Hale, the astronomer who founded the observatory in 1904 and was one of Caltech's founders. In a note to supporters of the observatory on September 15, Sam Hale pointed out that personnel had been preparing all year for a fire, "as we do every year." He continued:

"Trees have been cut. New high-flow hydrants have just been installed a few months ago to help replenish the fire department's tanker trucks with water. … Our giant 530,000-gallon reservoir has just been topped off and is ready to supply 33 hydrants across the observatory. … Another 270,000-gallon tank, belonging to the U.S. Forest Service and maintained by the observatory, lies just outside our main gate to help defend the observatory and the broadcast towers, which provide radio, television, and communications to most of the LA Basin.

"As we go to battle, a skeleton crew of four of our maintenance staff will be on hand to assist the firefighters until such time as they are ordered to leave. They have been working all week in extremely smoky conditions readying hoses on all the hydrants, lowering metal shutters on building windows, and countless other critical fire-safety preparations. …

"While we hope the observatory makes it through relatively unscathed, the battle could go either way. … We cherish the historic telescopes on the mountain that revolutionized humanity's understanding of the cosmos and hope they will be safe. That is the most important thing."

The firefighters were successful in pushing back that initial threat to the observatory. As of press time, Mount Wilson was still safe.

Watch webcam footage of the fire's approach at **mtwilson.edu**

The latest issue of **The Caltech Effect,** an e-magazine featuring stories from the *Break Through* campaign, is now available online at **breakthrough.caltech.edu.** This issue features researchers who redirected technologies for vital new uses, two graduate students who joined forces to fight cancer, a host of initiatives made possible through leadership chair funding, and five members of the Caltech community on the moments that transformed their careers.

Working it out:
on campus today

Over the past seven months, the Institute's response to COVID-19 has focused on prioritizing the health and well-being of students, faculty, and staff through a number of preventative measures to reduce transmission of SARS-CoV-2. These efforts have significantly reduced the number of people physically on campus each day in order to allow others to safely advance the research and education initiatives that are so central to Caltech. A recent call for images of this new normal drew photos of **1)** chemistry graduate student Molly McFadden and colleagues in Maxwell Robb's lab; **2)** the entrance to a shared instrument facility with sticky notes on a white board indicating who is inside (maximum capacity: four); **3)** painter Steve Benson as he takes care of business; **4)** an oddly quiet Red Door Marketplace; **5)** Darrell Goudeau, manager of mail services, at the Caltech post office; **6)** a teacher and a preschooler enjoying the sunshine at the Caltech Child Educational Center; **7)** the office setup of Computing and Mathematical Sciences Teaching Assistant Professor Konstantin Zuev, ready for fall teaching; **8)** chemistry graduate student Jake Evans as he records an upcoming online lecture; **9)** postdoctoral scholar in geochemistry Eugenia Hyung in the lab; **10)** social distancing outside Sherman Fairchild Library.

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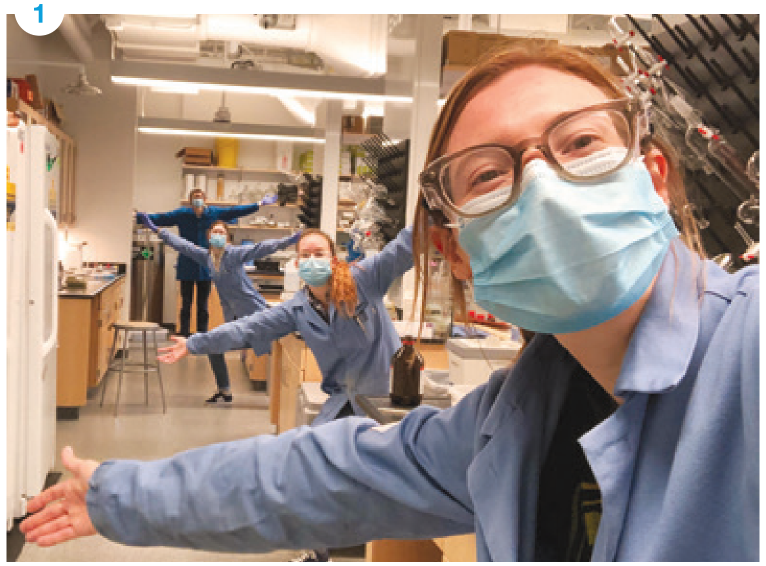

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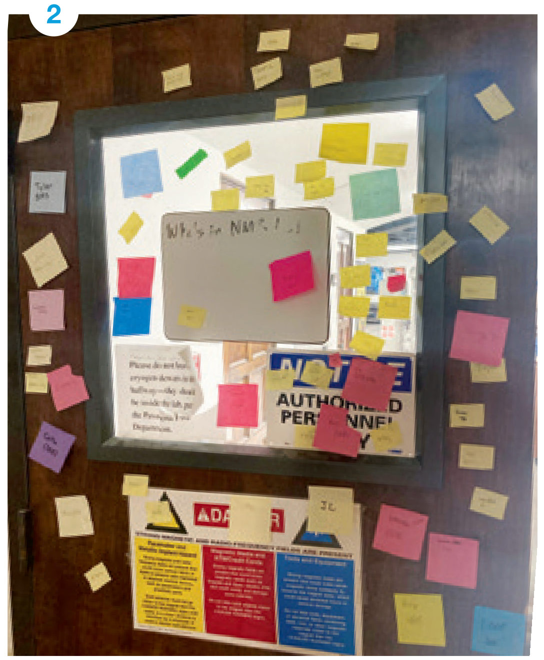

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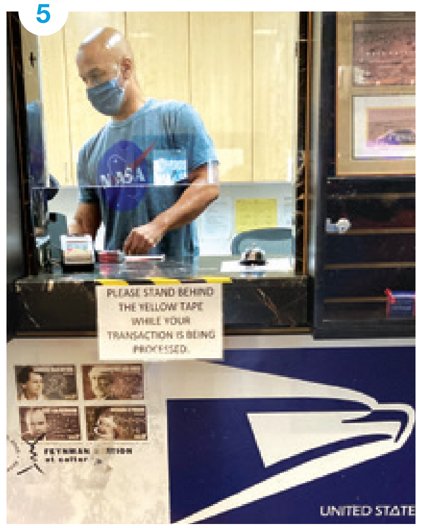

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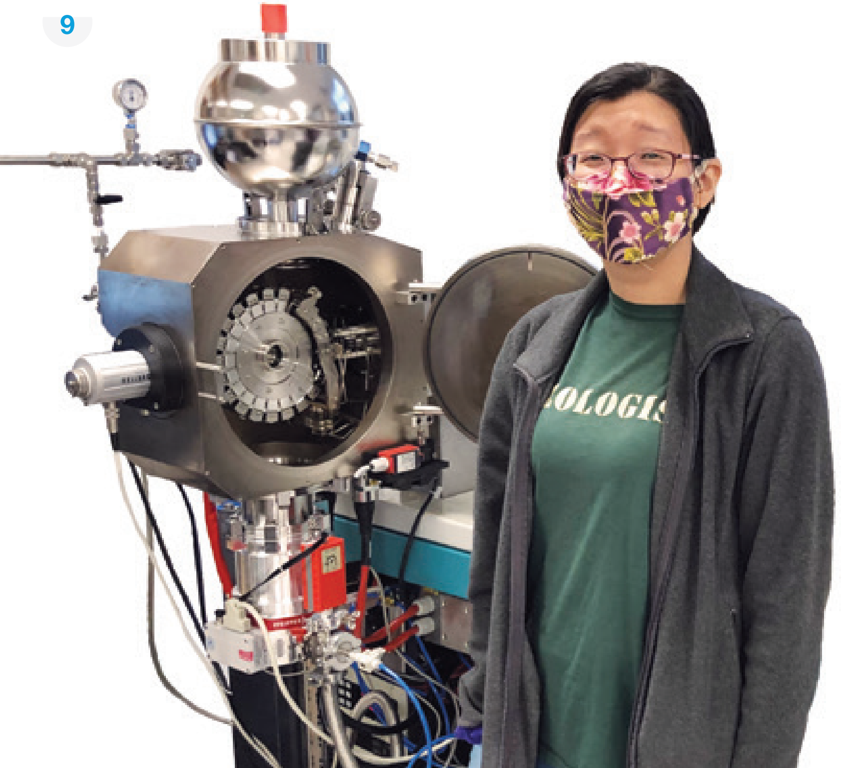

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4

Annabel Gomez (sophomore)

***#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**.*

Annabel Gomez is a sophomore at Caltech majoring in mechanical engineering (with a minor in aerospace engineering). This past summer, she participated in Caltech's SURF (Summer Undergraduate Research Fellowships) program, which, for the first time, was conducted remotely. Gomez, the 2020 Northern California Associates SURF Fellow, talked with Caltech *magazine about her experience in the midst of the 10-week program.*

"As a first-generation Mexican American and the first female in my family to pursue a degree in STEM, my dream has always been to work for NASA. When I got to Caltech and realized that JPL was offering SURF positions, I was determined to land one. This was a big accomplishment for me, and I feel very fortunate. My SURF experience allows me to use my skill set to contribute to the foundation and development of a project that will eventually impact the lives of many people around the world. My mentor [JPL senior research technologist Xiaoqing Pi] and I plan to use machine learning to generate small-scale ionospheric irregularity predictions that will help improve the accuracy and integrity of navigation and communication signals. The exciting thing is that the impact of my SURF trickles down to everyone I interact with. It motivates my little brother, who wants to follow in my footsteps, and it inspires my cousins to pursue a college education, which up until recently they thought was impossible. Most importantly, it has changed my family's perception of higher education; now they realize its importance, especially for women, and no longer see it as a waste of time. My SURF is more than just a summer internship. It's propelled me one step closer to achieving my dream of working for NASA."

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

Watch Convocation 2020 at **studentaffairs.caltech.edu/convocation**

CONVOCATION 2020

"This diverse population of scholars, namely you, your peers, and your teachers, must be nurtured in an environment in which you are free to express your ideas boldly and fully, and have those ideas challenged and rebutted, shaped, and honed. . . .

"You need to understand other cultures and perspectives. ... Virtually, and as soon as it's safe to do so in person, you need to take advantage of theater and art and music on campus. A humanistic education helps us to function as life thrusts us into situations where we have to conceive problems outside of the structures that define them. What better description of the moment we face now? It provides us with an elasticity of thought and familiarity of experience not fully our own, while challenging us to define the essence of what we believe."

– Caltech President Thomas F. Rosenbaum
welcoming new undergraduate students at a virtual convocation ceremony, aired on September 21, 2020

Sandwich board signs in high-traffic areas remind those on campus of the steps to follow to protect themselves and the community. The signs are part of Caltech Together, a new campuswide initiative designed to help community members support one another and take responsibility for their collective health and well-being during the pandemic. As well as communicating clear guidelines, Caltech Together aims to bolster a sense of connection and provide wellness support during this time of change and isolation.

New Amazon Quantum Center

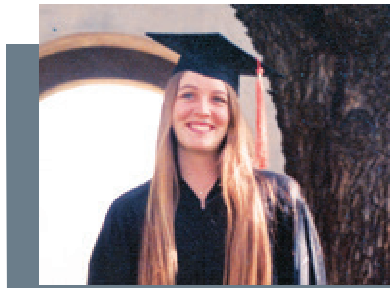
Preparations are underway for the new Amazon Web Services Center for Quantum Computing, scheduled to open in spring 2021.

The two-story, 21,000-square-foot facility, which will be located on South Holliston Avenue, will bring together leading researchers and engineers from Amazon, Caltech, and other academic institutions to accelerate advances in quantum computing technology.

Led by Oskar Painter (MS '95, PhD '01), the John G Braun Professor of Applied Physics and Physics, and Fernando Brandão, Bren Professor of Theoretical Physics, the researchers already involved in the work of the center are aiming to develop more powerful quantum computing hardware and software, and to identify new applications for quantum technologies. Such technologies have the potential to drive transformative advances in areas such as data security, machine learning, medicine development, and sustainability.

A "Strange and Exciting" Step

Marion Nelson (née Movius, BS '74) was a member of Caltech's first class of undergraduate women, which entered the Institute 50 years ago, in 1970. Three years later, as a senior, she wrote an article about her experiences at Caltech that she submitted to Seventeen *magazine. Below is a condensed version of that piece. After Caltech, Nelson earned a master's degree in math and also pursued a teaching credential. She married Norm Nelson (BS '76) in 1975 and moved to San Diego, where she taught high school math and physics, raised their four children, and became, she says, "a pretty good tap and jazz dancer."*



Clockwise from above: Marion Movius Nelson at her 1974 Caltech graduation; in a photo taken for then-president Harold Brown's 1970 Christmas card, with Rudy Castro, Debra Dison Hall (BS '74), and Rik Smoody; performing with the San Diego Follies in 2017 at the Lincoln Performing Arts Center; and with her 8-year-old granddaughter Lucy.

How would you feel walking onto an all-male campus as one of the first co-ed freshman class? I took that strange and exciting step three years ago, and it turned out to be the best thing I could ever have done for myself.

Being conspicuous: that was what it was all about for a good part of that first year. I was fresh out of a normal public high school with a boy-girl ratio of about 1:1, and all of a sudden here it was more like 25:1.

I had my share of odd experiences. Too many times I found something as casual as a smile to a slight acquaintance could lead to him deciding he was in love with me.

But I certainly didn't come to Caltech just for the ego trip of being suddenly desirable and well known. It's a serious kind of place, and I came for a serious reason: to get the best possible education in my field.

I became interested in science at a very early age when my father taught me some astronomy.

I entered high school having pretty much decided I'd be working toward a career in math or science, so I took all the courses I could in those fields. Many people, students and teachers alike, showed skepticism at my interest in a "man's field," but I knew it was my thing.

Coincidentally, Caltech was going co-ed the same year I'd be starting college. I was shocked when Tech said they'd take me, but my friends were even more shocked that I would actually consider going there. They pictured a place where mad scientists work incessantly in their labs, where young Einsteins with thick glasses walk around spouting equations to each other. I did visit the campus before I committed myself, though, just to make sure they weren't right!

It was a long haul through that first year. I learned how to accept grades far lower than "A," even though I studied easily five or six hours a day. There were many times I wondered why I was torturing myself here when I could have been coasting along without any trouble at some other school. But I'd realize that there would be no point in that; I felt if I couldn't make it at the best place, I didn't belong in my field at all.

Well, I did make it. In a few months I'll have a Bachelor of Science degree in mathematics. Not only did I survive the ordeal of required courses like Chem 1, Physics 1, and Physics 2, but I managed to get some reasonable grades and to become a "mathematician."

I've done a lot of hard work to get where I am right now. I've been exposed to some of the top minds in the world on a personal level. But what's most special to me is having been a pioneer who made it all the way through. Now we have about 100 girls at Caltech, in all four classes, and they're here to stay.

Read the full article at **magazine.caltech.edu/post/marion-nelson**

Strength in Community

By the *Caltech* magazine staff
Illustrations by Aurélia Durand

Scientists and engineers share their experiences and perspectives on how to create a more inclusive Caltech

There is a phenomenon that occurs throughout the natural world, known scientifically and philosophically as emergence, in which individual entities (such as individual brain cells) come together to create a whole (such as a conscious human being) that is greater than the sum of its parts.

That concept is one that Caltech scientists and engineers embrace in their work, recognizing that scientific advances demand collaboration among people with diverse points of view. But this idea is equally important beyond the lab, in the Caltech community at large. The idea, of course, is that the more diverse and inclusive the individuals are who come to the Institute, the more exceptional the Caltech community will become.

"It is only when all scholars share fully in the privileges of the academy that we will realize fully the potential of science and engineering to transform society for the better," President Thomas F. Rosenbaum wrote in his letter marking the end of the 2019-2020 academic year. "Each and every person brings their own story that must be honored and valued as a contributing member of the Caltech community."

Creating that community, however, requires intentionality and efforts to overcome the historical social, political, economic, and sometimes physical barriers in the way of many individuals whose racial, gender, socioeconomic, and other characteristics are not among those of the majority. The difficult truth is that the scientific community has never and still does not reflect the society in which it operates.

As just one example: of the 919 individuals who received Nobel Prizes between 1901 and 2019, only 53 (not quite 6 percent) have been women. And the Nobel Prizes in Physics, Chemistry, and Physiology or Medicine have never, at the time of this writing, been awarded to a Black American scientist.

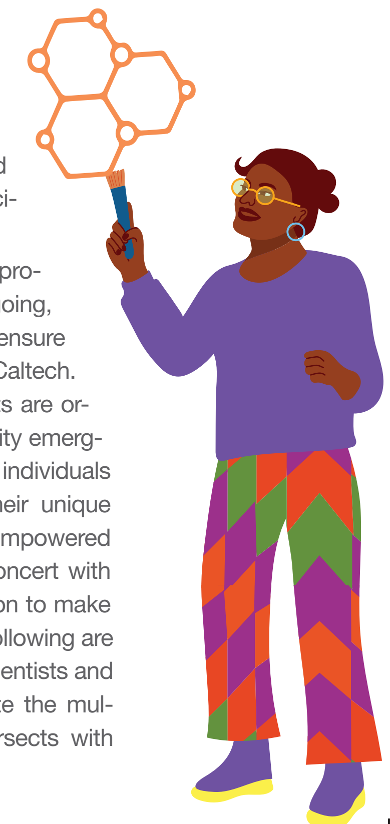
The Institute, in recognition of these inequities, has accelerated efforts to foster a more welcoming community, one that offers access and support to individuals whose diverse experiences and perspectives enable Caltech to advance its stated mission to "investigate the most challenging, fundamental problems in science and technology in a singularly collegial, interdisciplinary atmosphere, while educating outstanding students to become creative members of society."

Fifty years ago, the modern-day Caltech first admitted women to its undergraduate program; today, women make up 45.3 percent of the undergraduate student body, and 31.5 percent of graduate students. The Institute has also taken seriously its charge to bring to campus the best and brightest individuals from all backgrounds, with a steady increase in the number of students who belong to one or more underrepresented communities: African American / Black, Hispanic / Latin(x), Native Hawaiian, Pacific Islander, Indigenous People / Native American / First Nation. At the undergraduate level, in particular, the admissions office has implemented a holistic review process that considers in its decisions an individual's experience, interests, and ability in its decisions, and that prioritizes outreach efforts that expand awareness to underrepresented communities. These efforts have ultimately expanded representation of students in the applicant pool and fundamentally changed the makeup of Caltech's incoming classes; between 2010 and 2020, representation of undergraduate students who identified with one or more underrepresented groups increased from 9 percent to 22.7 percent.

At the graduate level, admissions offers are made by individual options; although Institute leaders recognize that the pace of progress must accelerate, this distributed system creates unique challenges. In the last decade, the percentage of graduate students from underrepresented groups hovered around 6 percent (ranging from 6.2 percent to 6.5 percent), with dips in between. To explore Caltech's opportunities for growth in recruitment and identify practices that better leverage the Institute's strengths, President Rosenbaum in September constituted a new campus advisory committee to examine existing recruitment efforts and issue recommendations for moving forward.

The goal of these efforts, according to Chief Diversity Officer, English Professor, and Vice Provost Cindy Weinstein, is to create a community where everyone feels like they belong and can reach their full potential as scientists and as human beings.

Through multiple centers and programs, some new and some ongoing, the Institute is making efforts to ensure that diverse individuals thrive at Caltech. The manner in which these efforts are organized recognizes that community emerges when creative and curious individuals have an opportunity to bring their unique experiences together, and are empowered to share ideas and to work in concert with one another and the administration to make sure their voices are heard. The following are stories of some of the Institute scientists and engineers whose efforts celebrate the multifaceted ways that identity intersects with STEM and with Caltech.



Krystal Vasquez

Chemistry Graduate Student
Co-Founder, Caltech Disability Coalition

Chemistry for a cleaner planet

"As someone who has grown up in Southern California, it's hard not to notice the poor air quality. I was always pretty curious why the mountains in the distance seemed to disappear some days. When I happened to take a class on the subject matter and learned that it was all a result of chemistry (my major in undergrad), I was fascinated and was told Caltech is a great place to go if I wanted to learn more. Now, my work focuses on how local and regional air quality is affected when urban pollution meets local biogenic (i.e., natural) emissions."

Disability is diversity

"I became chronically ill in the middle of grad school. Because it was such a lonely and isolating experience, I founded the Caltech Disability Coalition with the help of [fellow graduate student] Newton Nguyen (MS '19) so that disabled students, staff, and faculty at Caltech have a community to turn to. The Caltech Disability Coalition is also a space where allies can begin to learn about different disability issues and how to best advocate for their disabled colleagues. After all, disability is more than individual issues that certain students have to deal with; nondisabled people can play a huge role in breaking down the barriers that are keeping disability underrepresented in STEM. For example, though I don't usually need captions, I make sure to have captions in my presentations and have asked seminar series around campus to consider including captions, too. Allies can also make note of places in their labs or around campus that are inaccessible to people with mobility and sensory disabilities, and inform Caltech Facilities so that they can resolve these issues. Even though over 25 percent of the U.S. population is disabled, only 10 percent of scientists are disabled. Fewer still obtain PhDs in science-related fields. We need a wide array of voices to proactively make spaces accessible so that disabled people feel welcome and supported at Caltech."

Inclusion and Support

A variety of centers and programs at Caltech work to provide access and support to individuals with diverse experiences and perspectives as a way to foster community. While their focus varies, the overarching goal of these groups, many of which are student run, is to allow the broadest possible range of individuals to thrive at the Institute. The Caltech Center for Inclusion and Diversity (CCID; diversity.caltech.edu) serves as an umbrella organization for many of these affinity groups and provides education, advocacy, and allyship to create a "community of equity and inclusive excellence," says CCID senior director Hanna Song. The CCID offers access to information and resources as well as workshops and trainings, and provides inclusive spaces and skill-building opportunities for all members of the community to engage with issues related to their individual identities. To learn more about some of these individual initiatives, visit **magazine.caltech.edu/post/access.**

Far left: Krystal Vasquez. **Left:** Isha Chakraborty. **Above:** Namita Sarraf with co-founders of the Women in BBE group, Acacia Hori and Jess Griffiths.

Isha Chakraborty

Sophomore Majoring in Computer Science
Event Coordinator, Society of Women Engineers; Title IX Advocate

Supporting women in computing

"I remember being in a Java programming class early in high school, struggling a little with some classwork, when another student commented, 'This is why girls shouldn't code.' This kind of ignorant statement was really disappointing and frustrating to me. But, in a way, it kickstarted my passion for inclusion of women in computer science. I joined Technovation Girls Challenge, a global competition for app development, which is for anyone who identifies as a woman and is geared toward solving world problems. I ended up mentoring a team that built an app about interventional methods for autism, and the team ended up winning the national competition and coming in third overall in the world.

"In the future, I'm hoping to use my computer science skills to help kids with special needs. This interest has been lifelong for me. When I was volunteering with special needs kids in elementary schools, I was surprised that there was no equivalent of Google Translate for American Sign Language. I'm hoping I can be the one to create that. Computer science is about more than just programming; it's about what you can do for the community and for humanity."

Namita Sarraf

Bioengineering Graduate Student
Co-Founder, Women in BBE

On healthy social relationships

"I really believe that the more fulfilled you are, the better work you do in every aspect of your life: you're a better friend, a better scientist, you come up with better ideas. The best way to achieve fulfillment is to have solid supportive relationships. Fostering a healthy social environment can sometimes fall to the wayside at Caltech because people are so focused on lab work. I'm trying to promote people building social relationships and fostering a sense of community beyond one's specific lab. A lot of my good research ideas and collaborations come out of hanging out and chatting about work with someone who is in a totally different field. So I'm really passionate about creating spaces for social hours for grad students."

Telling women's stories

"I started Women in BBE along with [fellow graduate students] Acacia Hori and Jess Griffiths because there are a lot of implicit barriers to women being successful, even in today's day and age where we've made the most progress we've ever had. Having a community of women to discuss these issues and validate one another is really important. When women visit campus and see a strong community of women, it makes them want to come here. I'm also collaborating with other women across campus [Stacy Larochelle (MS '18) and Clare Singer (MS '20), Women in GPS; and Jacqueline Tawney (MS '20), Women in GALCIT] to host an event called Herstories: Lives and Lessons from Caltech Scientists, where female faculty talk about their professional and personal challenges and successes. Each of them has really incredible stories. We're hoping to have it in person once COVID is over."

David Cagan

Chemistry Graduate Student
Co-President, Diversity in Chemistry Initiative

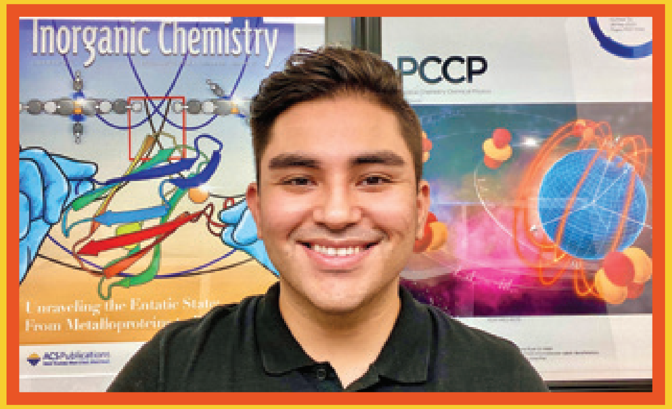
Discovering a love for chemistry

"I started at Pasadena City College as an art major. But after I took a required chemistry course, I remember thinking that chemistry was the most beautiful thing I'd ever seen. The deeper I dove into chemistry, the more I found it was a different kind of art itself, a new perspective for looking at the world. Science is such a creative thing, just like art. If you're going to answer the toughest questions in society today, you have to be open to different mindsets.

"I failed my first general chemistry exam. In moments like those, I questioned whether I was good enough, whether I was right for science, and whether science was right for me. But the people and mentors I've had in my life have pushed me to keep going; plus I love the field, so I push myself. I fully empathize with students who struggle, and I want people to believe in themselves and their capabilities. Even if they don't end up pursuing science, there is something to be learned. I ended up getting an award for organic chemistry. I'm very grateful to everyone who has supported and encouraged me."

Encouraging prospective scientists

"I fell in love with Caltech and the campus first through the WAVE program. Now, along with my fellow Diversity in Chemistry co-president Mary Arrastia, I'm thinking about ways to help underrepresented students build confidence in coming to Caltech and get them excited about science. Many programs like WAVE require you to have prior research experience, but how do you get that initial experience, especially if you're from an underprivileged background? My ultimate goal is to develop a one-month lab training workshop for local community college students, where they can build lab skills, learn techniques, and build their résumés as a kind of pipeline into WAVE."



Above, top: David Cagan with journal artwork he designed and created. **Above, bottom:** Lívia Hecke Morais with her mother at her PhD graduation. **Right, top:** Rebekah Loving (left, in blue top) with with her family in Hawaii. **Right, bottom:** Bil Clemons.

Lívia Hecke Morais

Postdoctoral Scholar
Founder, Diversity Committee of the Caltech Postdoc Association

A role model at home

"Support for my pursuit of science really started in utero, as my mom was getting her PhD in engineering in Brazil when she was pregnant with me. I was really privileged to have a role model at home. I wouldn't have made it this far if not for my mom's encouragement; she gave me freedom to try different things and stimulated my creativity. Science is a way that I express and think creatively."

Creating space for LGBTQA+ postdocs

"Postdocs are at a challenging crossroads, which has become a kind of bottleneck for women and other underrepresented people to reach the faculty level. As a postdoc at Caltech, I created the diversity committee of the CPA (Caltech Postdoc Association). One of the things that I care a lot about is to bring awareness to the issues that LGBTQA+ community face with their identities in the workspace. I have invested time to foster a sense of belonging for LGBTQA+ postdocs and students to our workspace and community at Caltech by organizing social and professional events. It's our goal to understand the needs of the LGBTQA+ postdoc community and help postdocs become comfortable with diverse identities in the workspace."

Rebekah Loving

Biology Graduate Student
Member, Black Scientists and Engineers of Caltech

Finding a passion for human health

"There are certain things, health-wise, that are really underserviced in the broader Oceania community. As a Native Hawaiian and Pacific Islander, seeing disease and physical impairments affect my family members and friends, I was really influenced to work at the intersection of health and biology.

"I initially applied to undergrad as a nursing major because I thought that would be the best way to give back to my community. But I realized that I really enjoyed the computational and mathematical sides of things, and I could use this to answer questions in systems biology, which would allow me to aid in decreasing health disparities facing Pacific Islanders. When I first came to Caltech as part of the WAVE program, I worked with Lior Pachter [Bren Professor of Computational Biology and Computing and Mathematical Sciences] on a method for combining single cell and bulk RNA sequencing analyses that could be applied to cancer research. After that, I knew I wanted to come back to Caltech for graduate school."

Building home away from home

"My adviser and my fellow students both in and out of the WAVE program made me feel like I belonged. Even though I wasn't the same as anyone else, I felt like Caltech was a place where nobody needed to be the same. It's the first place I've felt at home outside of my family. Caltech provided an intellectual and personal home, and I searched and found part of my Christian family near Caltech as well. Through involvement with Caltech, my Christian family, and my community, I was able to build a home while at Caltech. In Oceania, family ties are really important, culturally. I chose Caltech because I knew that my adviser would be supportive of how important family is to me."

Bil Clemons

Professor of Biochemistry
Chair, President's Diversity Council

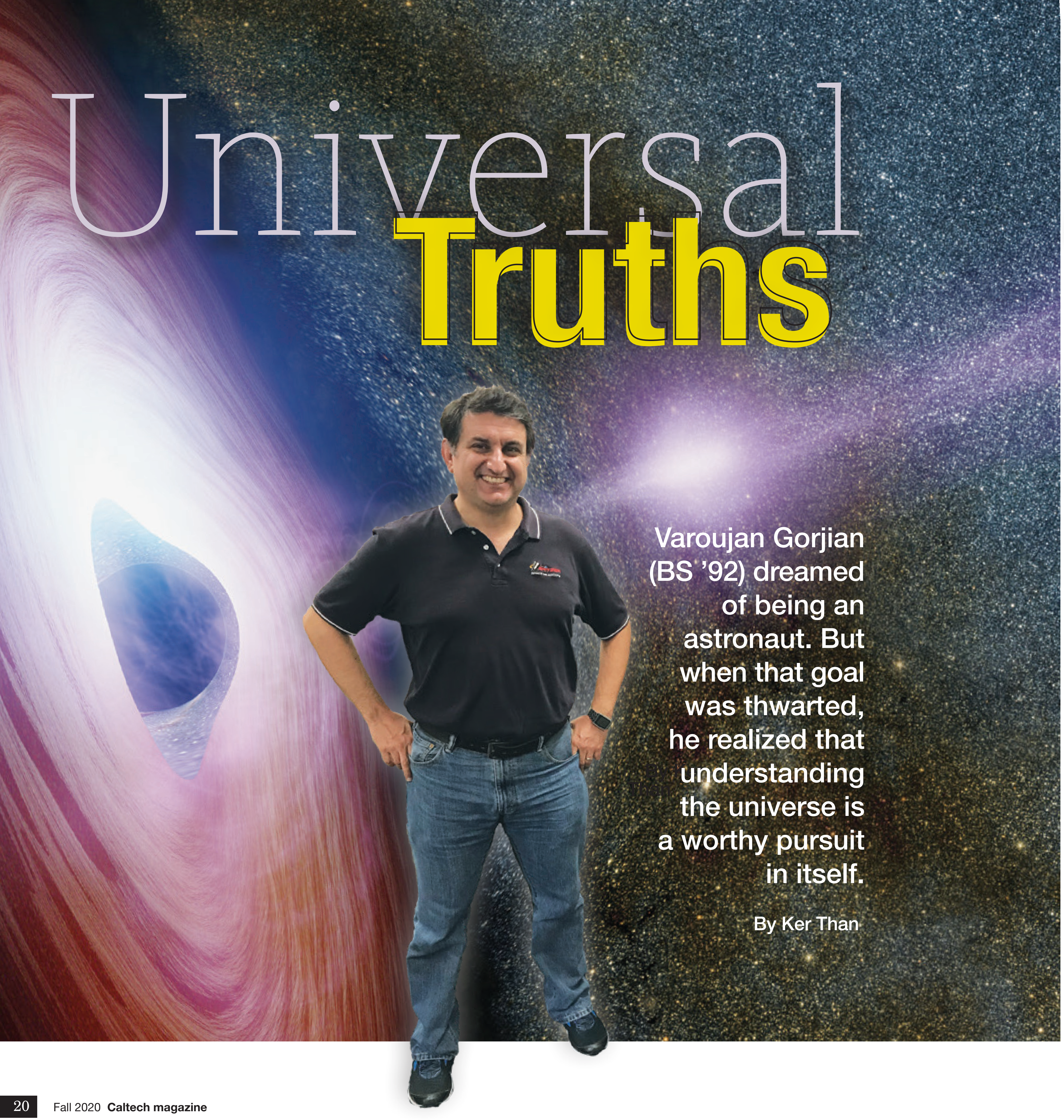
An early love for the scientific process

"I don't remember ever not being a scientist. I was always curious and wanting to know how things worked, to take things apart and understand. I didn't have any scientific role models growing up, but a teacher in elementary school encouraged me to participate in a marine biology program at the local aquarium in Waikiki. That was a very transformative experience that set me on a lifelong love of marine biology."

On being Black in academia

"I never had a Black lecturer or professor during my undergraduate and graduate education. It's crazy that I am probably one of the only Black faculty members my students will have. But we're in a very active moment right now. Caltech is asking itself: Where are we now? Where are we going? How do we enable, engage, and get resources to accomplish our diversity, equity, and inclusion goals?

"I would love for Caltech to be able to endow our DEI [Diversity, Equity, and Inclusion] efforts and provide administrative structure to accomplish concrete goals of building resources and programs. We've demonstrated our commitment to these goals with a plan, but our next priority is to get the financial resources to make the plan a reality. Caltech is already a beacon for academics and research, and we want to be a beacon for inclusivity as well."



Universal Truths

Varoujan Gorjian (BS ’92) dreamed of being an astronaut. But when that goal was thwarted, he realized that understanding the universe is a worthy pursuit in itself.

By Ker Than

A profound truth about the universe stares each of us in the face every night, says astronomer Varoujan Gorjian (BS ’92). It’s accessible to everyone, no telescope required, and to experience it, one need simply look up.

“You can know a lot about the universe by going out at night, looking up at the night sky, and seeing that it’s dark,” says Gorjian, a research scientist at JPL, which Caltech manages for NASA.

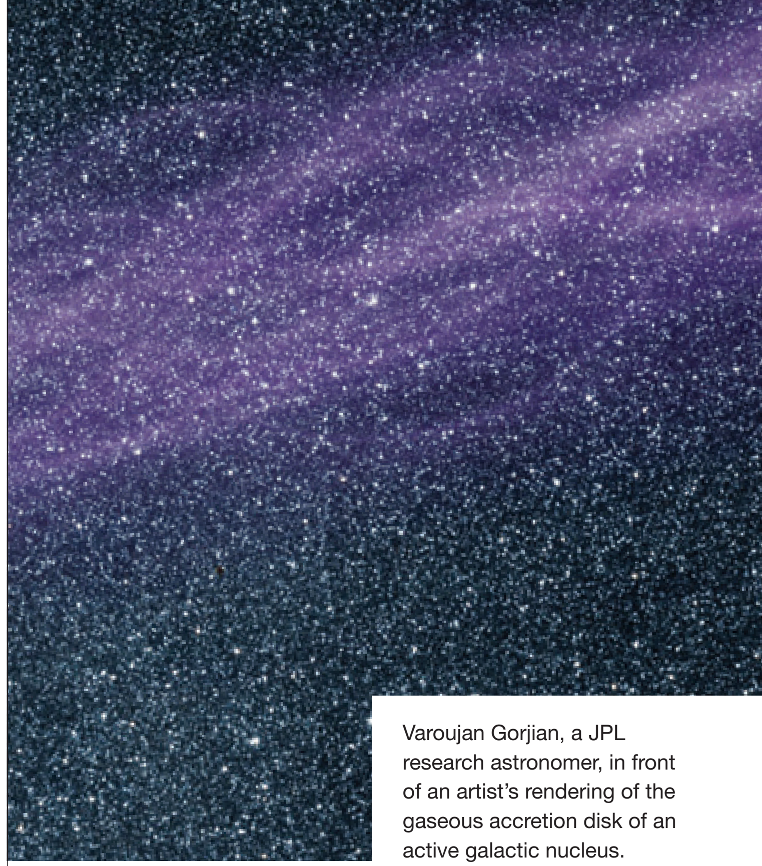
That darkness, Gorjian explains, is a powerful clue that the universe cannot be both infinitely old and infinitely large. It is not, in other words, the eternal, ever-present universe, unbounded and populated by limitless stars as imagined by astronomers of old. If the universe were infinitely old and endless, filled with never-ending uniformly distributed stars, then the light from even the most distant bright objects would have reached Earth already. As a result, the night sky would be a blazing wall of glittering starlight. (An analogy is standing in a dense, never-ending forest; turn to look in any direction and there will be trees in your line of sight.) The fact that what greets us instead when we look up at night is speckled darkness tells us that one of these assumptions is wrong.

This observation is known as Olbers’ paradox, named after the 17th-century German astronomer Heinrich Wilhelm Olbers. “Scientists now think that the universe is likely infinite in extent,” Gorjian says. “Therefore, given the paradox, it must be that the universe is not infinite in age, which tells you that there must have been a Big Bang. There must have been a beginning.”

Gorjian likes to bring up Olbers’ paradox when he introduces the wonders of space and science to laypeople, an area in which he is unusually talented. This gift is on full display in a *Wired* video in which Gorjian was challenged to explain black holes to individuals with a wide range of expertise, including a 5-year-old.

“[Gravity is] what keeps us on the earth,” Gorjian tells the child. “The main thing about black holes to remember is, [just like] how the earth holds you down, the black hole pulls you in as well.”

Gorjian’s fascination with space traces back to childhood. As a boy, he recalls “bouncing off the walls” after a family visit to the London Planetarium. Perhaps not surprisingly, the young Gorjian was also a Trekkie. An Armenian born in Iran, he would watch old episodes of *Star Trek* dubbed in Farsi with his older brother, Zareh. The siblings called the show “Mr. Spock,” or the “Spock show,” after their favorite character. Gorjian says he was drawn to Spock because of the character’s scientific bent and also because, being half human and half Vulcan, Spock was an outsider. Gorjian empathized with this aspect of Spock, especially after his own family moved to Los Angeles when he was 10 following the Islamic revolution in Iran.



Varoujan Gorjian, a JPL research astronomer, in front of an artist’s rendering of the gaseous accretion disk of an active galactic nucleus.

“This merged character was what I was,” recalled Gorjian in a NASA interview. “I was this mesh of cultures. Spock has these two sides to him; for me there were even more sides.”

Because of his love for space, the young Gorjian longed to become an astronaut. “Lots of kids want to be astronauts, but most sort of grow out of it. I never quite did,” he says with a laugh.

This dream drove Gorjian to major in astrophysics at Caltech, where he made friends he is still in touch with today. “There are five of us, and we recently got together to mark the 30th anniversary of when we all started at Caltech together,” he says.

Gorjian credits his participation in Caltech’s Summer Undergraduate Research Fellowships (SURF) program with giving him his first real taste of science. He worked with astrophysicist George Djorgovski to study the evolution of galaxies and cosmologist Tony Readhead to investigate the cosmic microwave background, the faint cosmic background radiation that is the leftover heat signature from the Big Bang.

“I was most impressed by Varoujan’s enthusiasm and dedication. We accomplished a lot in that first summer,” Readhead says.

"… every person you talk to has a different background and a different set of either misconceptions or outdated conceptions, so you have to account for that when you're communicating."

Varoujan Gorjian explains black holes to a 5-year-old in a 2018 *Wired* video.

After Caltech, Gorjian received his PhD in astronomy and astrophysics from UCLA. It was in graduate school that he began to study active galactic nuclei. An active galactic nucleus (AGN) is a super-energetic variant of the supermassive black holes that nestle in the hearts of most galaxies. The energy from an AGN is generated by gas spiraling into a supermassive black hole and heating up as it falls in, a process called accretion. In a subset of these AGNs, powerful twin jets of particles erupt from the poles of the black holes and stretch for light-years into space. The oldest and most energetic AGNs are known as quasars.

During his grad-school studies with Matthew Malkan (PhD '83) at UCLA, Gorjian screened images taken by the Hubble Space Telescope for clues about how AGNs were fueled. "AGNs became my regular, everyday kind of science," Gorjian says.

After he earned his PhD, Gorjian was finally ready to reach for his childhood dream and apply to NASA's astronaut corps to become a mission specialist, a class of astronauts reserved for scientific, engineering, and medical experts. By then, however, his eyesight, never perfect to begin with, had fallen below the requirements and disqualified him. Gorjian, however, was not especially dismayed by this turn of events.

For one thing, he was eager to get on with the rest of his life. "I had just spent six years getting my PhD. If my application had been accepted, it would have meant moving to Houston for another seven years for astronaut training before getting to fly into space. So, I thought, 'You know, I'm OK with this,'" Gorjian says.

Gorjian had also come to discover that what he had considered a means to an end, studying astronomy, had become a worthwhile end in itself, one that brought him joy. "Had I been accepted, I would have done it," Gorjian says. "But this way, I could delve into pursuing astronomy and continue doing something that I enjoyed."

So, Gorjian stayed in California and accepted a job offer as a postdoctoral researcher at JPL working with Michael Werner, project scientist for what would later become NASA's infrared Spitzer Space Telescope. "My specialty had become infrared astronomy," Gorjian says. "At the time, JPL and Caltech, through IPAC and the Spitzer Science Center, were both ramping up in this area."

After two years as a postdoc, Gorjian was hired fulltime at JPL as a Caltech employee. "That was in 2000," he says. "This year marks my 20th year as a Caltech employee. I have my 20-year pin and everything."

Gorjian has spent most of that time studying AGNs using Spitzer, which completed its primary mission in January 2020. "Every galaxy seems to have a supermassive black hole, and an AGN phase seems to be a vital aspect of that, so AGNs connect you to the galaxies themselves," Gorjian says. "It seems to me that they are at the nexus of a lot of interesting concepts."

At JPL, Gorjian has found himself working alongside Caltech professors who taught him as an undergrad. One of those mentors-turned-collaborators is Readhead, whose lab Gorjian had worked in. "We are studying a most peculiar 'blazar' [a rapidly varying quasar] that has baffled astronomers for the past four decades," says Readhead. "It seems to be located in a spiral galaxy, but its blazar properties are those of a quasar in an elliptical galaxy."

Gorjian also has another close connection at JPL: his brother, who was already a 10-year veteran at JPL by the time Gorjian joined. Zareh is a programmer and computer-graphics artist with JPL's Science Data Visualization Group, where, among other things, he helps convert data gathered by probes around Mars and Venus into cinematic flyovers across those planets' surfaces. "We see each other fairly often," Gorjian says. "For a brief amount of time, our offices were actually on the same floor. When we were younger, some people thought we looked alike, so they would start conversations with me thinking I was him."

Watch the *Wired* video at **wired.com/video/watch/astronomer-explains-one-concept-in-5-levels-of-difficulty**

For the past 15 years, in addition to his astronomy work at JPL, Gorjian has also been closely involved with the NASA/IPAC Teacher Archive Research Program, or NITARP. The 13-month program connects high school science teachers and their students from across the country with professional astronomers like Gorjian to collaborate on original research projects.

"Many science teachers have learned science but are not trained in the process of doing science. Most of them have never been to a scientific meeting," observes Gorjian, who is NITARP's deputy director. "This is like having people who have studied basketball, but have never played basketball, teaching basketball to kids."

Most years, NITARP's teachers and scientists first encounter one another at the annual meeting of the American Astronomical Society, one of the premier conferences in the field. "These meetings are where science is communicated, where scientists are interacting, and where critical new information is being presented," Gorjian says. "We show the teachers what a science meeting is like, in particular what poster sessions are like, and then afterward we write a proposal for a project of our own. This is not a toy project; it's real science."

As part of the program, the teachers and the students are invited to Caltech for four days to work directly with the scientists on their projects. This trip also includes a visit to JPL. Gorjian says a critical lesson that he and fellow research scientist Luisa Rebull, NITARP's director, try to impress on the teachers and students is that science is not just about the answer at the end of the book. "One time, a teacher turned to me as we were analyzing data and asked, 'Is this right?' I said, 'I don't know. If I already knew it was right, I wouldn't be doing it!'" Gorjian recalls. "The idea of delving into data, applying various techniques to learn more about some physical phenomenon … that whole process is what I want them to come away with."

"One time, a teacher turned to me as we were analyzing data and asked, 'Is this right?' I said, 'I don't know. If I knew it was right, I wouldn't be doing it!'"

NITARP's longevity, and testimonies from the teachers themselves, suggest the program is a success. "The collaboration with Varoujan and Luisa has really helped me find ways to work with students to help them engage with data in a more open-minded and nuanced way," says David Strasburger, a high school physics teacher at Lawrence Academy in Groton, Massachusetts, who has participated in the program twice.

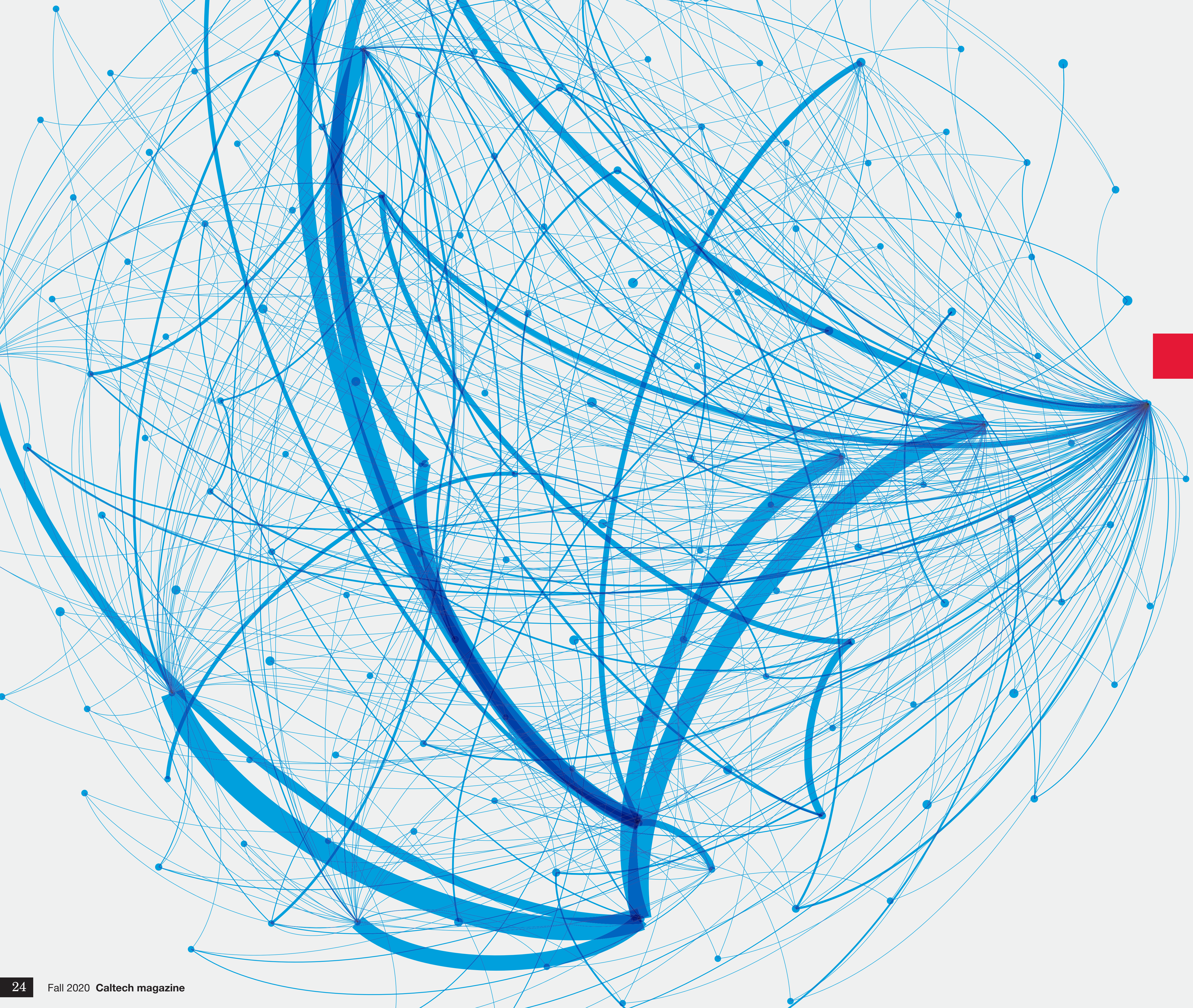
"One of the things that makes the NITARP program a really vibrant experience for teachers is its authenticity," Strasburger adds. "These are not canned projects. Varoujan's attitude is, 'We're going to try this, and I hope it works. But if it doesn't work, that's research.' For my students, that's mind-blowing. It helps them realize that doing science is really different from taking science classes."

It also helps, Strasburger says, that Gorjian has a knack for conveying complex scientific concepts to teachers and students alike in a respectful way. "He is impressively able to talk to people at different levels. He meets them where they are and doesn't talk down to them."

Gorjian says science communication is a skill he has purposefully cultivated over the years. "It's like most things: repetition makes you better," Gorjian says. "In this case, it's not repetitions of the same thing, because every person you talk to has a different background and a different set of either misconceptions or outdated conceptions, so you have to account for that when you're communicating."

Gorjian views science communication as a personal responsibility that comes with being someone with the great fortune of being paid to understand the universe. "That's a place of extreme privilege, and to treat that as an ivory tower that only the worthy can come to understand just seems personally wrong to me," Gorjian says. "The vast majority of what we do is taxpayer funded. I feel there is a real responsibility to help the public understand what they're paying for. That part of it has always motivated me."

It also helps that most people are inherently interested in space. "Of all the science topics out there, there are two that everybody is interested in: dinosaurs and space," Gorjian says. "If we as astronomers can help people feel a connection to the greater universe, I think that is a very worthwhile thing to do." [C]



How to Make Sense of Data

Caltech scientists and engineers are designing the sensors that gather data and the algorithms that translate data to communicate and work together in a process they call Sensing to Intelligence (S2I).

By Andrew Moseman

In April 2017, a group of observatories scattered across the face of the earth, from Spain to Hawaii, turned their attention to one object: a black hole called M87 that lies around 55 million light-years away. The radio instruments that make up this global network of observatories, known as the Event Horizon Telescope (EHT), gathered data about M87 throughout an entire night of observation; EHT researchers then fed that mountain of information into algorithms that processed it, adjusted for the changing sky and the distances between telescopes, and finally created the historic first image of a black hole.

Kathryn L. Bouman, who worked on that black hole image before joining Caltech as assistant professor of computing and mathematical sciences, electrical engineering, and astronomy, now collaborates with a team to create the Next-Generation Event Horizon Telescope (ngEHT) that will bring more black holes into view and increase the understanding of these bizarre cosmic phenomena. To realize such an instrument, which will include Caltech's Owens Valley Radio Observatory, the scientists plan to reverse their typical process: rather than simply building a bigger network of observatories and asking a new generation of algorithms to make sense of the data, Bouman and colleagues plan to use their algorithms to find weak spots in the current data and find the optimal places to build new telescopes and thereby enhance their ability to see black holes. The machine-learning side of EHT is not only interpreting data, it is informing the design and operation of the sensors themselves. "The goal is to try to combine sensing and intelligence," Bouman says, "to no longer separate them, but to think of this as a whole pipeline."

Sensors and machine learning lie at the forefront of research across the sciences. At any given moment, billions of sensors around the world, ranging from something as simple as a motion detector for a home to something as complex as the LIGO (Laser Interferometer Gravitational-wave Observatory) detectors, generate a pile of information whose size increases exponentially. Sensors allow seismologists, climate change experts, and gravitational-wave hunters to amass enormous data sets, while computer algorithms and human researchers work unceasingly to sort the signal (the true information) from the noise in this data stream. These two fields are typically seen as distinct, but the ngEHT is one example of how sensing (the hardware) and intelligence (the software) can converge to create networks of sensors that are intelligent in their own right.

This convergence powers a new research thrust at Caltech: Sensing to Intelligence, or S2I, an initiative that unites researchers from across interests and disciplines with a focus on co-designing sensors and learning algorithms. The researchers are, in other words, building the two sides to communicate and collaborate from the outset as they envision new ways to refine earthquake prediction, visualize distant cosmic phenomena, and find signals about a person's health in the molecules found in their breath.

Left: Kathryn L. Bouman
Right: In 2019, the Event Horizon Telescope (EHT) captured the first-ever picture of a black hole and its shadow by imaging the one at the center of M87, a galaxy 55 million light-years from Earth. The EHT's successor could reveal the black hole at the heart of the Milky Way.

"We have a unique opportunity at Caltech to transform the way we connect the information world with the physical world," says Azita Emami, the Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering and one of the leaders of the S2I initiative. "That can lead to a whole new generation of smart devices and instruments."

Breath Biomarkers

"Think about breath analysis as another version of a blood test," says Alireza Marandi, assistant professor of electrical engineering and applied physics. A person's breath abounds with information, with biomarkers that have the potential to inform doctors about different aspects of that patient's health. But to isolate and identify the various molecules in a cloud of vapor requires sophisticated technology that would be problematic to downsize into a device compact enough for people to use at home. For example, Marandi says, picture a breath analyzer small enough to attach to a smartphone so that users could easily track health data over time simply by exhaling into the device. He seeks to make such technology possible by advancing the sensing and intelligence sides of the problem simultaneously.

Marandi's lab investigates how nonlinear photonics, a field of optics in which light (usually a laser) emerges with different frequencies and properties after passing through a material, could be used in sensing applications to accomplish tasks no other technologies can accomplish. For example, Marandi's team has found that laser pulses in the mid-infrared range have just the right resonant frequency to cause molecules they touch to "jiggle." Those excited molecules emit information that acts as a fingerprint, which theoretically would allow researchers to identify a particular molecule's presence in a cloud of gas, like an exhaled breath from a person's lungs. The sensing challenge, however, is that most lasers work in the visible light or near-infrared parts of the spectrum, and so most of the backbone technologies needed for that kind of a breath sensor are focused only on those ranges, too. To make use of these affordable and available tools, Marandi starts with laser light in the visible or near-infrared range and transforms his beam into the mid-infrared range in which it is most effective.

The most straightforward way to find out what molecules are inside a a person's breath could be spectroscopy, a long-standing technique in which researchers look at which frequencies of light are absorbed as the beam passes through matter. However, building a perfect spectrometer would add weight and complexity to the device, and it is not necessary in this case since Marandi does not need to identify every molecule in a person's breath. Instead, he is working to develop a sensor that works only in the mid-infrared range and can ID certain noteworthy molecules that a user might need to track. The machine-learning element would extract only the relevant data and leave behind the extraneous information. To Marandi, his solution is an example of when the perfect is the enemy of the good. "You actually want to think about not having a very clean set of information but being able to get bits and pieces," he says.

Such a device would not only be more accurate than a sensor that tracks every molecule in a puff of air, but it would also be smaller and more efficient, allowing it potentially to be scaled down for consumer use. "I don't have to spend a lot of time making a full-fledged spectrometer," Marandi says. "I just need to make something from which I can extract the right information. That is one of the themes of S2I."

Join Marandi for a lecture and discussion on his work at the November 11 Watson Lecture. events.caltech.edu

The Body and the Brain

A microscopic sensor, a single tiny chip, floats through the body, protected by a thin but porous layer of platinum. Glucose and oxygen molecules can squeeze through the holes in this layer, but the body's immune cells, which would seek to destroy such a synthetic intruder, cannot pass. Once past the platinum, glucose reacts with an electrode on the surface of the chip to generate a small electrical current. This tiny chip amplifies that current and digitizes it into data representing the level of glucose in the bloodstream. The sensor then embeds these data within a radio signal to send to a receiving device outside the body, thereby providing a measurement of a person's blood sugar.

Azita Emami holds a large-scale model of her implantable health monitor. Such a device could track a person's blood glucose level without the need for daily needle pricks and could talk to machine-learning algorithms that help the sensor capture a more complete picture of a patient's health.

This glucose sensor, which takes the place of the frequent needle pricks diabetic patients typically must endure, was built by Azita Emami and Axel Scherer, Caltech's Bernard Neches Professor of Electrical Engineering, Applied Physics and Physics. Their device, which has been tested in mice, demonstrates the ability of low-power, implantable, tiny medical devices to become flexible technology platforms that can be adapted to a wide variety of medical uses. At the same time, algorithms can help those devices adapt to each individual's unique biomarkers and baseline health data. Feedback from this intelligence side of the system may tell the sensors to change what they measure inside the body or how they measure it.

"Imagine a two-way flow of information, not just from the sensors to the software but from the algorithm side back to the sensor," says Emami, who also serves as an investigator in the Heritage Medical Research Institute. "If you design these two together, you can create systems that are far more efficient and have better performance. Perhaps then we will be able to see things that could not be seen before."

Emami is also trying to apply S2I to perhaps the most complicated part of the body in which to put an implantable device: the brain. Caltech researchers and others have built brain–machine interface devices that can read the neural activity that occurs when a person tries to move a limb, for instance. In this way, patients with spinal-cord injuries can learn to move prosthetic devices with nothing but their thoughts. The problem, however, is that the brain is a busy environment, and it is difficult to isolate a person's intention to move a limb in a certain direction from among the myriad other neural signals. "We have huge amounts of data recorded by small electrodes in the brain, and they vary over time because of small movements by the electrodes," Emami says. "To address that, we are using algorithms that provide a more robust prediction of the intention of the patient."

Frontiers Large and Small

M87, the subject of the momentous black hole image by Bouman and colleagues, is a behemoth. It contains 6.5 billion times as much mass as the sun. Because the black hole is so vast, the light orbiting M87 requires longer to complete an orbit than it would to circle a smaller black hole. The upshot is that M87's appearance in the night sky changes relatively slowly. If it went too much faster, the EHT's sensors and algorithms, already pushed to their limits, would not have been able to capture a true image of the black hole, says Bouman, one of Caltech's Rosenberg Scholars. The next-generation Event Horizon Telescope, designed through an S2I approach in which algorithms optimize the locations of new observatories, could have enough data-gathering and processing power to image another black hole: the one at the center of the Milky Way galaxy, which is far smaller and evolves much faster than M87.

Black hole research is only one example of computational imaging, a cross-disciplinary approach that creates images from data sets rather than by gathering visual light through a lens or other filter. Its practical applications are already familiar to many: ultrasounds, CT scans, and other forms of medical imagery create pictures by processing data in various wavelengths. But computational imaging can visualize subjects from the astronomical to the microscopic. For example, one of Bouman's postdoctoral researchers, Aviad Levis, looks inside clouds via tomography, the same kind of X-ray technology at work in CT scans. "Clouds may be the most important part of climate models," Bouman says. "If you want to have accurate climate models, you have to understand clouds and their microphysics." Because of clouds' complexity, researchers like Levis rely on machine learning to help them process data taken from multiple angles into a realistic model of a cloud.

Another of Bouman's students, Angela Gao, collaborates with Zachary Ross, assistant professor of geophysics, and Yisong Yue, professor of computing and mathematical sciences, on machine learning to help build a better picture of earthquakes. Often, earthquake analyses build upon a simulated model of the ground (its structure, materials, and faults) that has been computed from earlier quakes but may not be accurate for smaller quakes, Bouman says. Gao seeks to use data from a quake to build a new, better model.

Computational imaging also can lead scientists to new advances at smaller scales. Changhuei Yang, Caltech's Thomas G. Myers Professor of Electrical Engineering, Bioengineering, and Medical Engineering, applies the power of machine learning to microscopy and medical imaging. For example, when pathologists look through a microscope they are trained to look for particular cells, such as cancer cells. However, an image contains far more information; the problem is how to know what to look for. That is where machine learning enters the picture. Yang feeds microscope images to a neural network, a kind of artificial intelligence based loosely on the brain. Because he does not label the parts of the picture or tell the AI what to look for, the system is forced to figure out how to make sense of the images and find patterns within them without the cognitive bias of a human scientist who has been trained on what to look for. "The idea here is that it's possible to build a system that can optimally collect information even if the information is not collected in such a way that a human eye can readily interpret it," Yang says.

"Imagine a two-way flow of information, not just from the sensors to the software but from the algorithm side back to the sensor."

A major challenge of machine learning, however, is that while the algorithms can process far more data than a person can, and might find patterns a human would not notice, AI cannot explain how it "thinks" or how it interprets information; and of course it is important for researchers to learn why the algorithm focused on a particular element or whether that element is important to a person's health.

Here again, Caltech researchers see the opportunity for the algorithms to inform the sensors. In the case of medical microscopy, Yang might have the neural network study certain locations within an image and then tweak the sensors (in this case, the microscopes) to match. "It's like talking to somebody who might have difficulty communicating," Yang says. "You can pay attention to where that person's eyes are focused, and that will give you some glimpse into what is going on in the person's thought process. Similarly, we can optimize the collection system to suit what the machine learning is focusing on."

Across Caltech, interdisciplinary projects of this nature that fall under the S2I framework will begin to help humanity make sense of the modern-day data deluge. "We have these two isolated domains, the sensors and the algorithms, but we believe that this is not sustainable," Emami says. "We have dealt with the exponential growth in the data from different sensors in a very blind way. It will be completely different if we co-design sensing and algorithms so that it is all done in a more intelligent way." [C]

Caltech science exchange *introduces*

The **Election** Experts

As millions of American voters cast their ballots this November, Caltech political scientists, historians, computational social scientists, and data scientists examine the systems, policies, and technologies that underlie elections and other democratic processes. On the Caltech Science Exchange, an online public resource that brings expert insight to the scientific questions that define our time, these researchers provide insights on the impact of local politics and the historical implications of voting rights legislation. They also shed light on the mechanics of polling (including why it is so difficult to accurately forecast a presidential election) and emerging threats to election security and fairness.

Here, faculty within the Institute's Division of the Humanities and Social Sciences share their perspectives on critical topics in the runup to the 2020 U.S. presidential election.

Learn more about voting and elections at **sciencexchange.caltech.edu**

Especially in a presidential election year, **media** and **public attention** seem to be focused on **national politics.** What should voters know about local politics?

I study urban politics, so I think one thing that often gets overlooked is the importance of state and local politics. Many people think that the way to engage in politics is to vote every four years at the federal level. As I show in my work, and as other urban historians have shown, it's at the state and local level that you see legislation with the most direct impact on people's lives and where people have more power to effect change. People often feel demoralized when the national election doesn't go their way, but I think they can feel more empowered and more like they live in a democracy when they are invested in state and local politics. It's also important to remember that cities and states are often used as laboratories for various policies or programs. Many federal policies began at the state and local level, where you can get a sense of the larger implications of a policy by seeing how it functions at a smaller scale. Similarly, voters can get a sense of how a party is thinking about things by looking at what's being done at the state and local level. And remember, voting is just one tool of political engagement. We can't understand it as the be-all and end-all of politics.

—**Danielle L. Wiggins,** assistant professor of history

As a professor of history, **what responsibility** do you believe you have to **inform policy?**

Let me tell you how I got started in voting rights cases. My doctoral dissertation was on the disfranchisement of Blacks and poor whites in the South in the late 19th and early 20th centuries. In about 1979, a lawyer who was cooperating with the ACLU [American Civil Liberties Union] in Birmingham, Alabama, called me up—I didn't know who he was—and he said, "Do you have an opinion about whether section 201 of the Alabama constitution of 1901 was adopted with a racially discriminatory purpose?" I said, "I do. I've studied that. I think it was adopted with a racially discriminatory purpose."

Writing expert witness reports and testifying in cases are exactly like what I have always done as a scholar. I have looked at the racially discriminatory effects of laws; I have looked at the racially discriminatory intent of laws. I have examined them by looking at a lot of evidence. I write very long papers for these cases. They are scholarly publications, and whether they relate to something that happened 100 years ago or something that happened five years ago or yesterday doesn't really, in principle, seem to make any difference.

—**Morgan Kousser,** professor of history and social science, emeritus

What makes presidential elections so **difficult** to **accurately forecast?**

As a statistician or researcher conducting a survey of a population, I want to define that population and then take a representative sample. When working with populations for which there's a census, for example U.S. households, that's easy. In contrast, a fundamental problem with election polling is defining the population. Not everyone votes, and turnout fluctuates between election cycles. There's no census, or defined population, of voters to sample from.

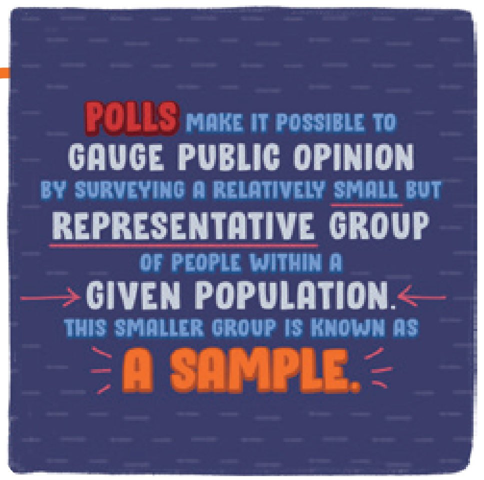
Pollsters have different strategies for getting around this problem. For example, in most states you can get a list of registered voters, and some polls will sample from that list in what are called registered voter samples. The problem here is that not all registered voters vote. So, to get a representative sample, I'm going to have to create a statistical model to help predict how likely it is that a given individual will, in fact, vote. The challenge is that reasonable statisticians can have different views on what a reasonable voter model is.

That's problem one: we can't define the population that we want to sample from. We're going to have to make some assumptions, and different pollsters make different assumptions.

The second problem in forecasting presidential elections is that a poll represents a snapshot of public opinion today, but what we really care about is what happens on the first Tuesday after the first Monday in November. Things change quickly, even in a relatively brief space of time, and, clearly, the farther out we are from Election Day, the more uncertainty we have to accept.

The third problem is, in general, that response rates to surveys are way down. It used to be, back when Gallup was the only business in town, people were more willing to participate in surveys. Today you might see low-quality polls with a 3 percent or 4 percent response rate. Now you, as a researcher, have to make heroic assumptions about the people you could get on the phone versus the people you couldn't. There are statistical fixes, but, again, those fixes add another layer of assumption about which reasonable people might disagree. And it turns out, how you disagree can have profound impacts on your polling results.

—**Jonathan N. Katz,** Kay Sugahara Professor of Social Sciences and Statistics



Why does it seem to be **taking longer** to **finalize election results**, even with new voting technology?

We've seen an evolution of procedures and technologies, mostly aimed at expanding the franchise—providing more and better opportunities for people to register to vote and express their opinions on Election Day. But as we continue to see an evolution of technology, procedures, and administrative practices, we're also going to see some challenges. Remember that we're talking about a very complicated process.

One of the things we've come to appreciate in our research with the Caltech/MIT Voting Technology Project is just how much goes on behind the scenes to get people registered to vote; to verify and record their registration information; and then to provide voters the opportunity to securely, and in an accessible and simple manner, cast their ballots.

Once you vote, your ballot will likely end up in a securely sealed ballot box. When polls close, election officials at the polling place will break those seals and conduct an initial examination to reconcile all the ballot materials they've received. The ballots will then be securely transported to a central location. Some will go by car. Some may be delivered by law enforcement. Some, if they are coming from a remote location, may go by helicopter.

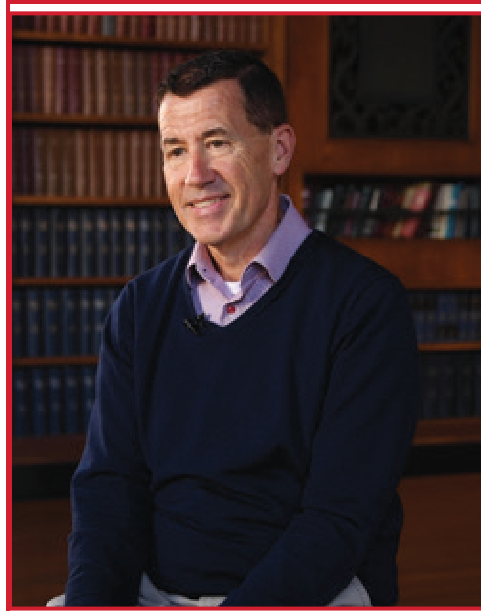
Many of those ballots are tabulated immediately. If you voted in person on Election Day or earlier, your vote is probably going to be tabulated that night or early the next day.

However, mail-in ballots that arrive later, or ballots that are cast provisionally on Election Day, will take longer to count. Staff at the election office will confirm whether the voter is registered in their jurisdiction and that they haven't cast another ballot elsewhere. If those conditions are met, the ballot will be included. If those conditions aren't met, officials will investigate further.

That's one of the reasons it takes so much time. Election officials, especially here in California, are committed to making sure that all the ballots that are eligible to be counted are, in fact, counted.

In a related phenomenon, known as "blue shift," it has become increasingly common for vote totals to shift in favor Democratic candidates after polls close. This is, in part, because Democratic-leaning voters are likelier to vote by mail and to cast provisional ballots.

It is not unusual to see final results change, sometimes significantly, as legitimate ballots continue to be counted after Election Night.

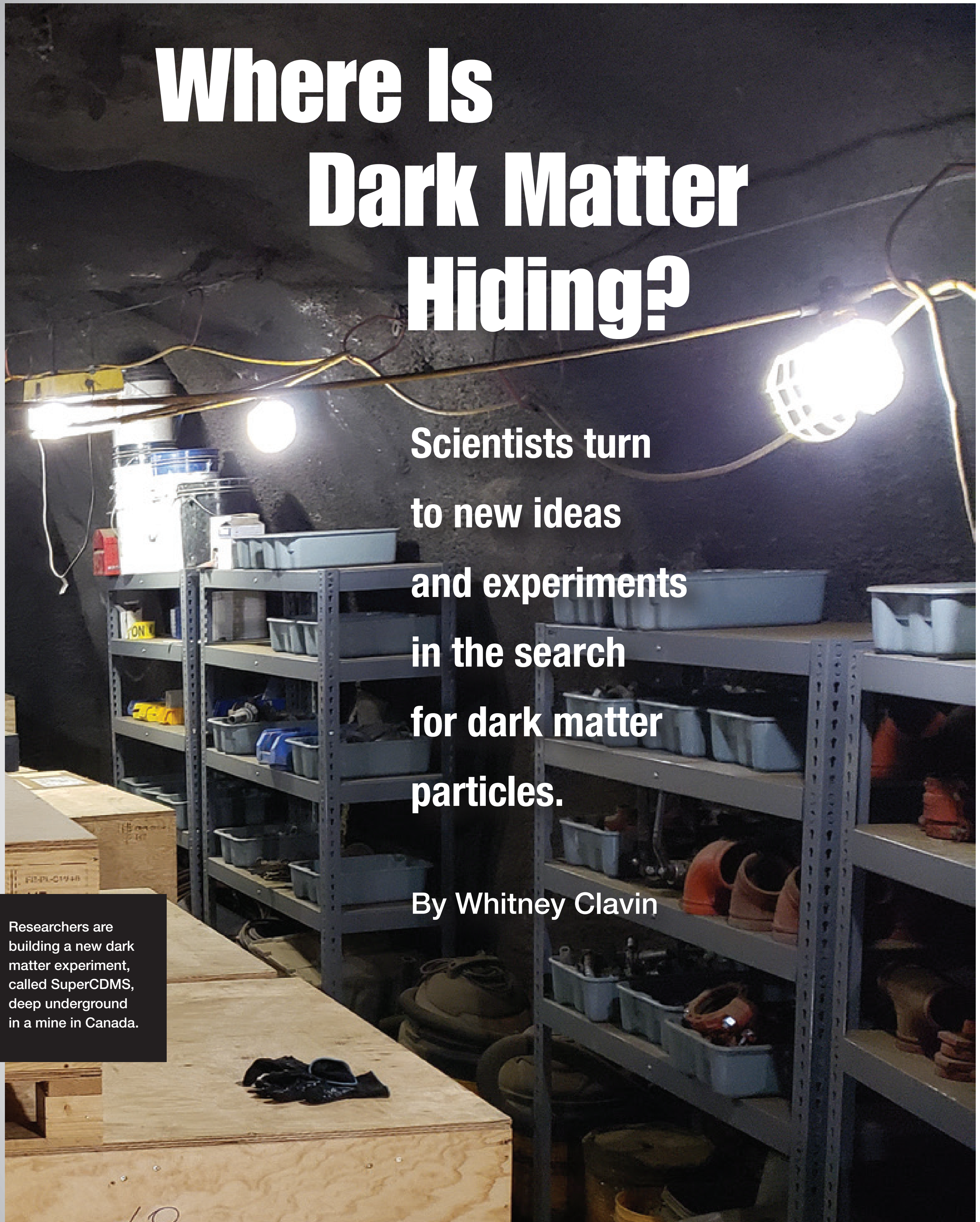


—**R. Michael Alvarez,** professor of political and computational social science

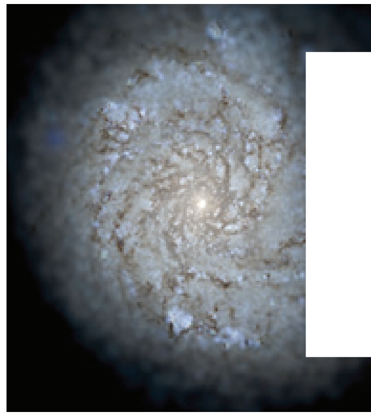
Where Is Dark Matter Hiding?

Scientists turn to new ideas and experiments in the search for dark matter particles.

By Whitney Clavin



Researchers are building a new dark matter experiment, called SuperCDMS, deep underground in a mine in Canada.



Every second, millions to trillions of particles of dark matter flow through your body without even a whisper or trace. This ghostly fact is sometimes cited by scientists when they describe dark matter, an invisible substance that accounts for about 85 percent of all matter in the universe. Unlike so-called normal matter, which includes everything from electrons to people to planets, dark matter does not absorb, reflect, or shine with any light. It is … dark. But if we cannot see dark matter, how do scientists know it is there? The answer is gravity. Astronomers indirectly detect dark matter through its gravitational influences on stars and galaxies. Wherever normal matter resides, dark matter can be found lurking unseen by its side.

The first real evidence for dark matter came in 1933, when Caltech's Fritz Zwicky used the Mount Wilson Observatory (see article on page 7) to measure the visible mass of a cluster of galaxies and found that it was much too small to prevent the galaxies from escaping the gravitational pull of the cluster. Something else, concluded Zwicky, was acting like glue to hold clusters of galaxies together. He named the substance *dunkle Materie*, or dark matter in German. In the 1970s, Vera Rubin and Kent Ford, while based at the Carnegie Institution for Science, measured the rotation speeds of individual galaxies and found evidence that, like Zwicky's galaxy cluster, dark matter was keeping the galaxies from flying apart. Other evidence throughout the years has confirmed the existence of dark matter and shown how abundant it is in the universe. In fact, dark matter is about five times more common than normal matter.

"The universe is hitting us over the head with evidence of dark matter," says Phil Hopkins, professor of theoretical astrophysics at Caltech. "Whether it is the motion of galaxies, or the fact that dark matter bends light, or the expansion of the universe, or the growth of structures in the universe, there are many different types of measurements that have been made and every single one of them fits the same paradigm of dark matter."

Yet, despite its preponderance, scientists have not been able to identify the particles that make up dark matter. They know dark matter exists and where it is but cannot directly see it. Since the 1990s, scientists have been building large experiments designed to catch elusive dark matter particles, but they continue to come up empty-handed. What some still consider the leading candidate for dark matter, called WIMPs (weakly interacting massive particles), have not been found in any of the data collected so far, nor have particles called axions; both WIMPs and axions are hypothetical elementary particles proposed to solve outstanding theoretical mysteries in the widely accepted model of particle physics, called the Standard Model, which classifies all known elementary particles and describes three of the four known fundamental forces (the electromagnetic, weak, and strong interactions, leaving out gravity). Additional dark matter candidates include particles called sterile neutrinos, along with primordial black holes. Some theorists have proposed that modifications to our theories of gravity might explain away dark matter, though this idea is less favored.

In the past decade, another set of dark matter candidates has emerged and is growing in popularity. These candidates collectively belong to a category known as the hidden, or dark, sector. At Caltech, hidden-sector ideas are in full bloom, with several scientists cultivating new theories and experiments.

"When you look beyond WIMPs and axions, a whole range of observational consequences open up," says Kathryn Zurek, a professor of theoretical physics at Caltech and one of the pioneers of hidden-sector theories. "The WIMP and axion paradigms are great because they are very predictive and led to the building of direct-detection experiments. Now we can leverage this beautiful technology to look for hidden-sector dark matter."

Hidden Valleys

In 2006, Zurek and colleagues proposed the idea that dark matter could be part of a hidden sector, with its own dynamics, independent of normal matter like photons, electrons, quarks, and other particles that fall under the Standard Model. Unlike normal matter, the hidden-sector particles would live in a dark universe of their own. Somewhat like a school of fish who swim only with their own kind, these particles would interact strongly with one another but might occasionally bump softly into normal particles via a hypothetical messenger particle. This is in contrast to the proposed WIMPs, for example, which would interact with normal matter through the known weak force by exchanging a heavy particle.

A key feature of hidden-sector particles is that they would be much lower in mass and energy than other

Kathryn Zurek is a theoretical physicist and one of the pioneers of hidden-sector theories of dark matter.

Hidden-sector dark matter is thought to range in mass from about one-trillionth that of a proton to 1 proton.

proposed dark matter candidates like WIMPs. Hidden-sector dark matter is proposed to range in mass from about one-trillionth that of a proton to 1 proton. Technically, this translates to masses between milli- and giga-electron-volts (eV); a proton has a mass of about one giga-eV.

“We are moving to a new frontier of lighter dark matter,” says Zurek. “At first, we called these particles hidden valleys because the idea was that you would climb a mountain pass and look down to very low-energy particles.” But now, she says, the phrase hidden valley has morphed into hidden, or dark, sectors.

Sean Carroll, research professor of physics at Caltech, and his colleagues also wrote an early paper, in 2008, on the idea that dark matter might interact just with itself. Similar to the hidden-sector ideas, the team proposed that, “just like ordinary matter couples to a long-range force known as ‘electromagnetism’ mediated by particles called ‘photons,’ dark matter couples to a new long-range force known (henceforth) as ‘dark electromagnetism,’” Carroll wrote in his blog, Preposterous Universe, in 2008.

“Now, years later, scientists are in a phase of ruling out more and more models,” says Carroll. “Our dark photon models are still possible but less likely than other models like Kathryn’s.”

So how does one go about finding a hypothetical particle less massive than a proton? Zurek and others have proposed tabletop-size experiments much smaller than other dark matter experiments, which can weigh on the order of tons. Although hidden-sector particles are thought to only rarely and weakly interact with normal matter, when they do, they cause disturbances that could, in theory, be detected. Zurek and her team have proposed a way to detect a disturbance caused by the hidden sector using a type of quasiparticle called a phonon. A specialized sensor would be used to catch the phonon vibrations, indicating the presence of dark matter. (A quasiparticle is a collective phenomenon that behaves like a single particle.)

Zurek is also developing other methods to help in the hunt for dark matter, including gravitational-based techniques that measure how clumps of dark matter in the cosmos affect the timing of flashing stellar remnants called pulsars. Like many scientists in the field, she feels that it is important to take a multipronged approach to the problem and look for dark matter with different but compatible methods.

Mark B. Wise, the John A. McCone Professor of High Energy Physics, who, in 1982, was among the first to propose that axions could be the missing dark matter particles, says dark matter could be axions, hidden-sector particles, or something else entirely. Wise made his proposal along with John Preskill, Caltech’s Richard P. Feynman Professor of Theoretical Physics and director of the Institute for Quantum Information and Matter (IQIM), and Frank Wilczek of MIT. “We look where we can and where nature tells us to look,” Wise says. “As a theoretical physicist, I am humbled by the universe. We should be embarrassed at some level about how little we know, but this can also be an opportunity to learn more.”

Deep Underground

About 6,000 feet underground, in a working nickel mine in Ontario, Canada, a dark matter experiment is taking shape. Unlike the small experiments proposed by Zurek and others, this one is a massive undertaking. Scheduled to begin operations in 2022, SuperCDMS (Super Cryogenic Dark Matter Search) is designed to find lighter WIMPs than those sought before, with masses of 1 giga-eV, which is close to the mass of a proton. Because SuperCDMS is looking for lower-mass particles, it also has the ability to find lighter hidden-sector particles.

“When you enter the lab, it’s an interesting process,” says Sunil Golwala, professor of physics at Caltech. “You go down the mine elevator, sometimes with the miners, and then you walk about a kilometer in mine clothes: full-body mine suit, hard hat, boots, and all that. And then when you get to the lab entrance, you take all that off and take a shower. Then you put on a bunny suit and go into a lab, all of which is kept as a clean room. So, the lab is kept extremely clean even though it’s sitting in the middle of a dirty mine.”

“I am humbled by the universe. We should be embarrassed at some level about how little we know, but this can also be an opportunity to learn more.”

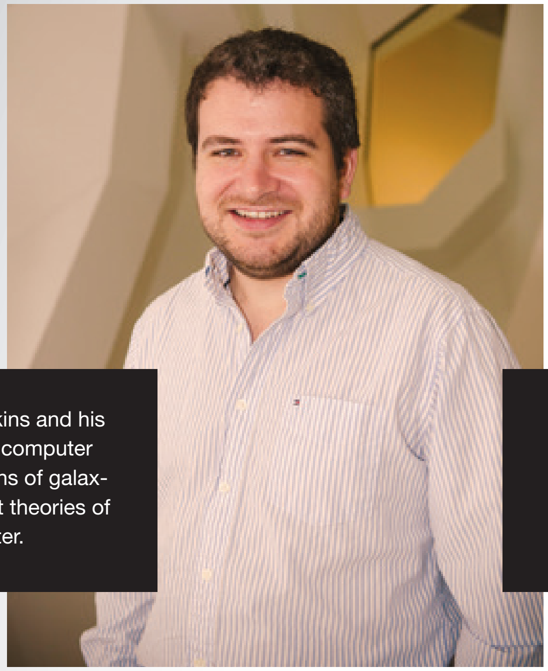
-Mark Wise

Golwala helps manage the fabrication of the detector assemblies for SuperCDMS; the detectors are being built at the SLAC National Accelerator Laboratory, which leads the SuperCDMS project. Golwala explains that most dark matter experiments searching for WIMPs and hidden-sector dark matter are performed underground, often in mines, in order to shield the instruments from cosmic rays that could mask the dark matter signals.

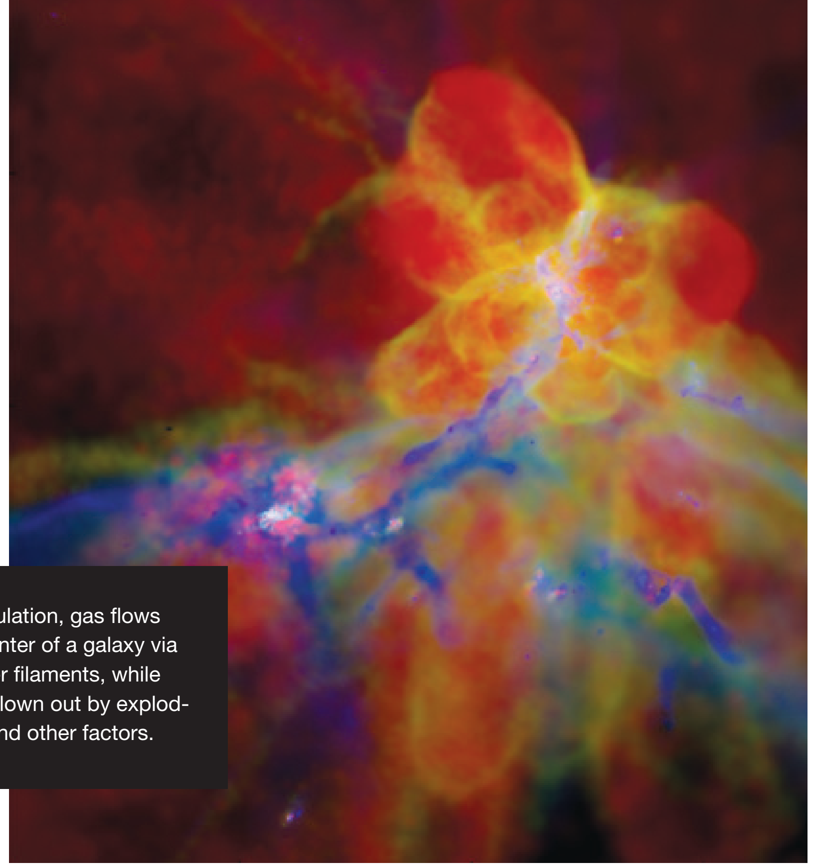
WIMPs were proposed in the late 1970s and early 1980s based on the idea that heavier hypothetical particles than those in the Standard Model, with a mass of more than 100 protons, could explain mysterious features of the model and, importantly, would just happen to be produced in the early universe in the amount needed

A new underground dark matter experiment looking for WIMPs may also detect hidden sector particles.

Sunil Golwala is an experimental physicist working on SuperCDMS, seen here coming together in a cleanroom inside a mine in Canada.



Phil Hopkins and his team run computer simulations of galaxies to test theories of dark matter.



In this simulation, gas flows into the center of a galaxy via dark matter filaments, while matter is blown out by exploding stars and other factors.

to explain the dark matter abundance. In addition, a theory known as supersymmetry (which states that every particle has a partner with a complementary spin) predicts partner particles, one of which could be a WIMP. But, over the years, evidence for supersymmetry has failed to materialize.

"There had been hope for many years that if we saw dark matter it would be a hint that supersymmetry exists, but people are getting less and less convinced. Kathryn is one of the people who has strongly advocated for looking at other models, given that supersymmetry has not turned out to be discovered yet," says Golwala. "That's been one of the big motivations for wanting to look down at the mass range that we're looking at. Twenty years ago, if you told someone you were looking for dark matter at 1 giga-eV, they might say, 'Why are you doing that? There's no supersymmetric particle down at 1 giga-eV.' And now, 20 years later, as far as we know, there's no supersymmetry, so we had better pay attention to these other models. The nice thing about SuperCDMS is that we are looking for WIMPs and the hidden sector."

By adding dark matter physics into computer simulations of galaxies, researchers can make predictions about features that telescopes might observe in the future.

In addition to contributing to SuperCDMS, Golwala is working on tabletop experiments specifically designed to uncover the hidden-sector particles. He says he pays close attention to Zurek's guidance on what types of interactions to look for between dark matter and normal matter. "Kathryn is a theorist, and I am an experimentalist. She says, 'This is the thing you should build in order to look for this model of dark matter.' I take her ideas and say, 'OK, we are going to build an experiment that can do that.'"

Just Add Dark Matter

Outside the lab, there are other ways to probe the hidden sector. Phil Hopkins and his team have embraced the various new dark matter ideas and folded them into their computer simulations of galaxies and the universe. Like baking a batch of cookies, researchers can mix and match cosmic ingredients in a computer simulation and see what arises. If a resulting galaxy looks like the real thing, then scientists know they are closer to understanding its ingredients.

"If you assume that most matter in the universe is dark matter, and that dark matter interacts only with gravity, then it is actually pretty simple to set up your computer simulation," says Hopkins. "You have one force, gravity, and you let everything evolve from there."

Recently, Hopkins and his students have refined this simple simulation to include hidden-sector physics. He says his research serves as a bridge between that of Zurek and Golwala, in that Zurek comes up with the theories, Hopkins tests them in computers to help refine the physics, and Golwala looks for the actual particles. In the galaxy simulations, the hidden sector dark matter is "harder to squish" because of its self-interacting properties, explains Hopkins, and this trait ultimately affects the properties of galaxies. The team's computer creations allow them to make predictions about the structure of galaxies on fine scales, which next-generation telescopes, such as the upcoming Vera C. Rubin Observatory, scheduled to begin operations in Chile in 2022, should be able to resolve.

"You can imagine a whole dark universe or this hidden sector where all sorts of things are happening underneath normal matter or 'under the hood,' as you might say. What we have tried to do is ask, 'What are the astrophysical consequences?'" says Hopkins.

Several other Caltech researchers are also on a quest to uncover the nature of dark matter, including cosmologists who study its effects on vast scales that span the history of the universe, as well as particle physicists who search for dark matter candidates produced in high-energy colliders such as CERN's Large Hadron Collider, or LHC. Cristián Peña (MS '15, PhD '17), a Lederman Postdoctoral Fellow at Fermilab and a research scientist with the High Energy Physics group and INQNET (INtelligent Quantum NEtworks and Technologies) at Caltech, was among the first, in 2016, to attempt to discover dark matter in high-energy proton-proton collisions at the LHC. Those searches for dark matter were made with data collected by the Compact Muon Solenoid instrument.

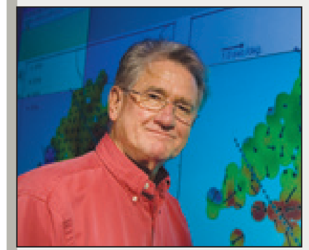
Now, Peña is developing quantum-sensing experiments to detect dark matter. The state-of-the-art sensors he is using are being developed as part of a quantum internet project involving INQNET in collaboration with Fermilab, JPL, and the National Institute of Standards and Technology, among others. INQNET was founded in 2017 with AT&T and is led by Maria Spiropulu, Caltech's Shang-Yi Ch'en Professor of Physics. A research thrust of this program focuses on building quantum-internet prototypes including both fiber-optic quantum links and optical communication through the air, between sites at Caltech and JPL as well as other quantum network test beds at Fermilab. The optimized sensors developed with JPL for this program are also well-suited to detect very-low-mass dark matter and, as Peña says, any "feeble interactions" of hidden-sector states beyond the Standard Model of particle physics.

"Quantum sensing is an emerging research area at the intersection between particle physics and quantum information science and technology," he says.

While most researchers agree that finding dark matter is a long shot, they feel confident that the pursuit, and all the science and technology that has been and will be acquired along the way, is worth the journey. After all, we know that dark matter exists and, as Carroll says, it is "not really all that mysterious." When Carroll explains dark matter to the public, he has them imagine that our moon is made of dark matter and thus invisible. "We would still experience the moon's tides on Earth even though we couldn't see the moon. We know dark matter is there, we just can't see it." [C]

In Memoriam

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



Donald V. Helmberger 1938-2020

Donald V. Helmberger, who ran the Caltech Seismological Laboratory from 1998 to 2003, passed away on August 13 at the age of 82. Helmberger joined the Caltech faculty as an assistant professor in 1970 and was named Smits Family Professor of Geophysics in 2000. His primary research interests involved seismic-wave propagation and the use of waveforms to recover information about earthquake characteristics as well as the earth's structure.

Masakazu (Mark) Konishi 1933-2020

Masakazu (Mark) Konishi, the Bing Professor of Behavioral Biology, Emeritus, passed away on July 23. He was 87 years old. Konishi was renowned for his work on the neuroscience underlying the behavior of owls and songbirds. His team worked extensively on the auditory systems of barn owls, which use their acute hearing to home in on prey on the ground, even in total darkness. He also theorized and then showed experimentally how the brains of songbirds learn and produce song.

James (Jim) Morgan 1932–2020

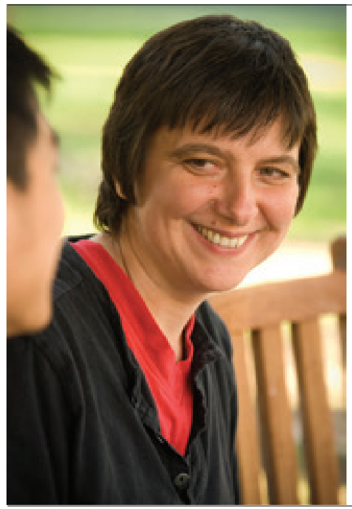
James (Jim) Morgan, the Marvin L. Goldberger Professor of Environmental Engineering Science, Emeritus, at Caltech, who previously served as dean of students and later as vice president for student affairs, passed away on September 19 at the age of 88. Morgan, who joined Caltech's faculty in 1965, focused his research on the chemistry of aquatic environments and water treatment, and in particular on the scientific bases for establishing criteria and standards for water-quality protection.

Endnotes

Which female mentor or role model inspired you during your time at Caltech?

Nai-Chang Yeh was the first female professor in physics when she joined Caltech in 1989. It's a real blessing to be under her mentorship as she adds a powerful and wise philosophy on approaching both physics and life in general. Nai-Chang has taught us to be versatile and bold when facing tough problems in our research enterprise.

Deepan Kishore Kumar (BS '15)
PASADENA, CA



I SURFed with the incredible **Matilde Marcolli.** Her understanding of math and physics is remarkably deep *and* diverse, but even more important to my experience that summer was the genuine warmth and care she showed for her students.

Adam Ball (BS '16)
SOMERVILLE, MA

I am inspired by my graduate adviser, **Dianne K. Newman.** Her boundless optimism and perpetual encouragement were an integral part of my success in graduate school. She inspired me to think independently and nurtured in me a sense of academic and intellectual freedom.

David Basta (PhD '19)
PASADENA, CA

A major influence on my career, **Barbara Wold** took me into her research lab as a freshman and taught me to look at problems in a new light. She instilled in me to question assumptions and always fostered my unending curiosity.

Lawrence Schaufler (BS '94)
DENVER, CO

Shirley Marneus was a great role model as director of TACIT. We learned about teamwork, conflict resolution, and the value of working long hours with true passion. She saw potential where we did not, and her vision was (and always will be) an inspiration to us all.

James Gleeson (BS '99)
LIMERICK, IRELAND

Anneila Sargent (MS '67, PhD '77) was a fine role model as vice president for student affairs. She combined being a formidable scientist with a passionate attention to student concerns. And all this was communicated in her delightfully lilting Scottish voice.

Sean McKenna (BS '17)
SANTA MONICA, CA

Azita Emami is an amazing teacher and enthusiastic supporter of her students. In both of her classes that I took, she took care to involve her students and make sure they had the resources to understand their work. I am sure that she will help many more women like me feel equipped for their future male-dominated workplaces.

Suzannah Osekowsky (BS '17)
SEATTLE, WA

Eleanor Helin ("Glo" to friends and colleagues) was a planetary scientist at JPL. She led a program to find near-earth asteroids long before this was a hot topic. She was my SURF mentor for two years and the first female boss I ever had. She showed me what a woman leader really looks like: authority plus love.

Celina Mikolajczak (BS '91)
RENO, NV

Jenijoy LaBelle was Caltech's first female professor, hired in 1969. A professor of English at Caltech, she fought for tenure for a decade and finally got it in 1979. She was a hero for all of us women students.

France Córdova (PhD '79)
SANTA FE, NM

Alas, since I am in the class of 1963 there were no women classmates. However, **Olga Taussky-Todd** was an inspirational member of the faculty.

Barry McCoy (BS '63)
STONY BROOK, NY

Hands down, **Prof. [Katherine] Faber!** She was my PhD co-adviser, and she always gave comments to guide us to the right answers ourselves instead of telling us what to do or try.

Wei Lin Tan (PhD '19)
SINGAPORE

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

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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 to be enjoyed from the comfort of home: from author interviews to faculty musicians to a live play about living with diabetes (see item on page 6).

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

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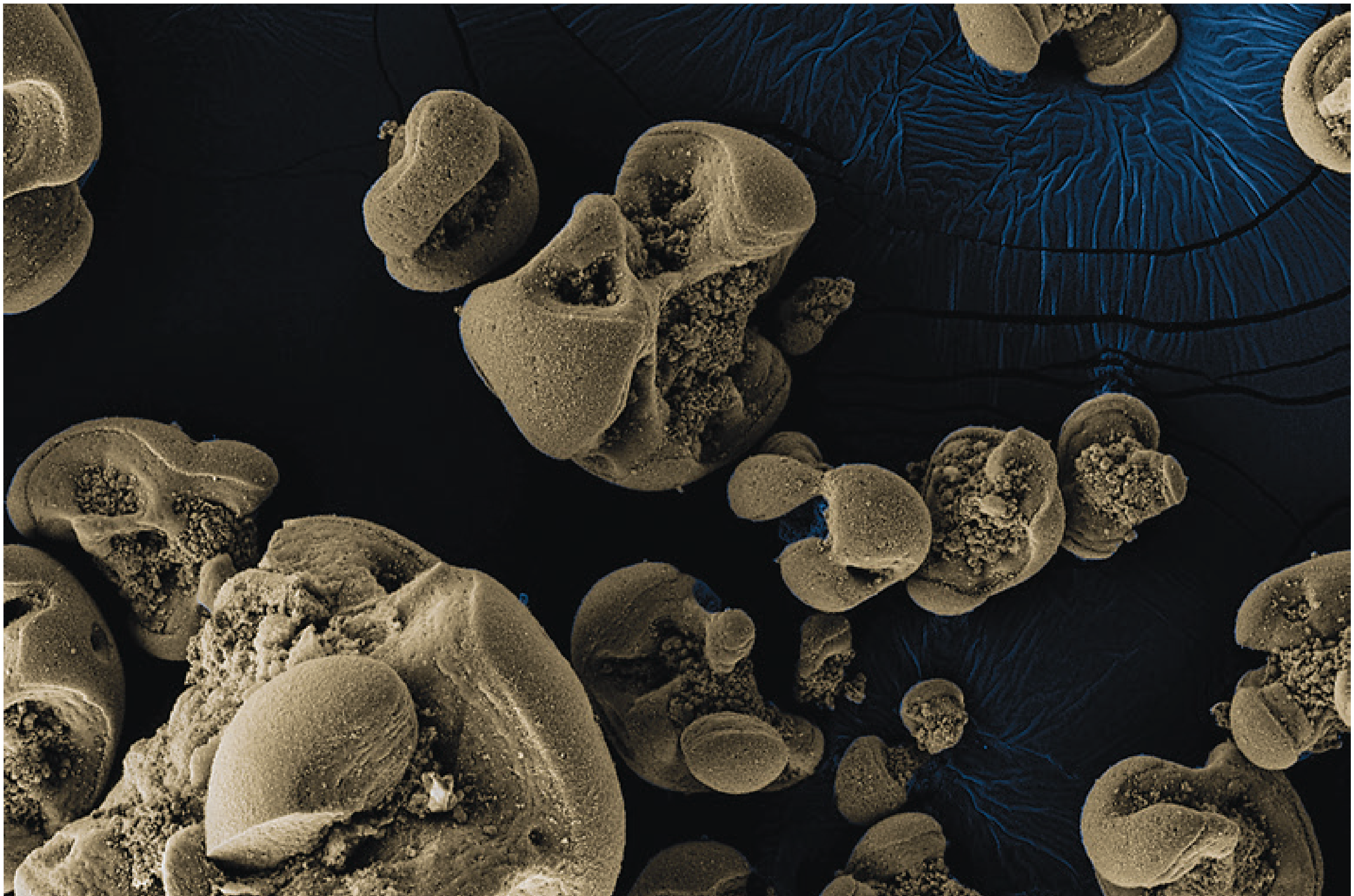

Metal-Eating Microbes

Caltech microbiologists have discovered bacteria that feed on manganese. “These are the first bacteria found to use manganese as their source of fuel,” says Jared Leadbetter, professor of environmental microbiology, who made the discovery with postdoctoral scholar Hang Yu (MS ’13, PhD ’17). Leadbetter found the bacteria after performing unrelated experiments using a light chalk-like form of manganese. He had left a glass jar soiled with the substance to soak in his Caltech office sink before departing for several months to work off campus. When he returned, the jar was coated with a dark material that tests revealed to be oxidized manganese generated by newfound bacteria that had likely come from the tap water itself. Further research revealed that these bacteria can also use manganese to convert carbon dioxide into biomass. Previously, researchers knew of bacteria and fungi that could oxidize manganese, but they had only speculated that microbes might be able to harness the process to drive growth.

Find out more at **magazine.caltech.edu/post/metal-eaters**