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Engineering & Science

VOLUME LXXV, NUMBER 3, FALL 2012

California Institute *of* Technology

On the cover and to the left: Regarded as one of the most distinctive image makers working today, Bulgarian-born artist Luba Lukova has held solo exhibitions at UNESCO in Paris, DDD Gallery in Osaka, La MaMa in New York, and the Art Institute of Boston. She is the author of the critically acclaimed *Social Justice* poster portfolio containing visual reactions to many of the pressing issues of our time. The portfolio has been exhibited widely in the United States and around the world and was recently included in the permanent art collection of the World Bank. Lukova's new book, *Graphic Guts* (Clay & Gold), featuring her social-commentary art, will be published later this year.

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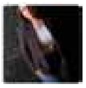

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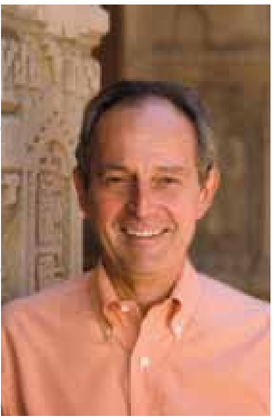
FROM THE PRESIDENT

Dear alumni and friends of Caltech,



The impact of the work done in Caltech's laboratories, in its classrooms, and, sometimes, at the Red Door Café reaches far past the boundaries of campus and Pasadena. It reaches into corporations, hospitals and homes, farms and airports; it reaches, as I recently witnessed from the control room at JPL, to Mars and beyond. This commitment to the world outside our academic buildings is, in fact, right there in our mission statement: *The mission of the California Institute of Technology is to expand human knowledge and benefit society through research integrated with education.*

This issue of *E&S* describes just a few of the ways in which Caltech's science and engineering efforts have expanded human knowledge and benefited society. It looks at the pioneering efforts of the Institute's environmental scientists, whose basic-science inquiries into the chemistry of air pollution have made a visible difference in the air we breathe today. It considers the knockout punches being delivered to the human immunodeficiency virus by some of the most committed and talented biologists in this country. And, as we head into the home stretch of the 2012 presidential election, it examines the factors each of us might be weighing as we decide who we will pull the (now mostly metaphorical) lever for.

We believe Caltech has a responsibility to be a leader both locally and in the global community, which is why we actively participate in the world beyond our campus. In addition to its being a source of education, discovery, and knowledge creation, we believe that a research university should be a hub of innovation and entrepreneurship where impact is measured in terms of job creation and our ability to graduate students ready to compete globally. We believe that basic research can—and should—result in both ideas and inventions, and that all this comes in addition to our commitment to supporting and nurturing our exceptional students.

"In addition to its being a source of education, discovery, and knowledge creation, we believe that a research university should be a hub of innovation and entrepreneurship where impact is measured in terms of job creation and our ability to graduate students ready to compete globally."

I hope that by the time you turn the last page of this issue, you will agree.

Yours in discovery,

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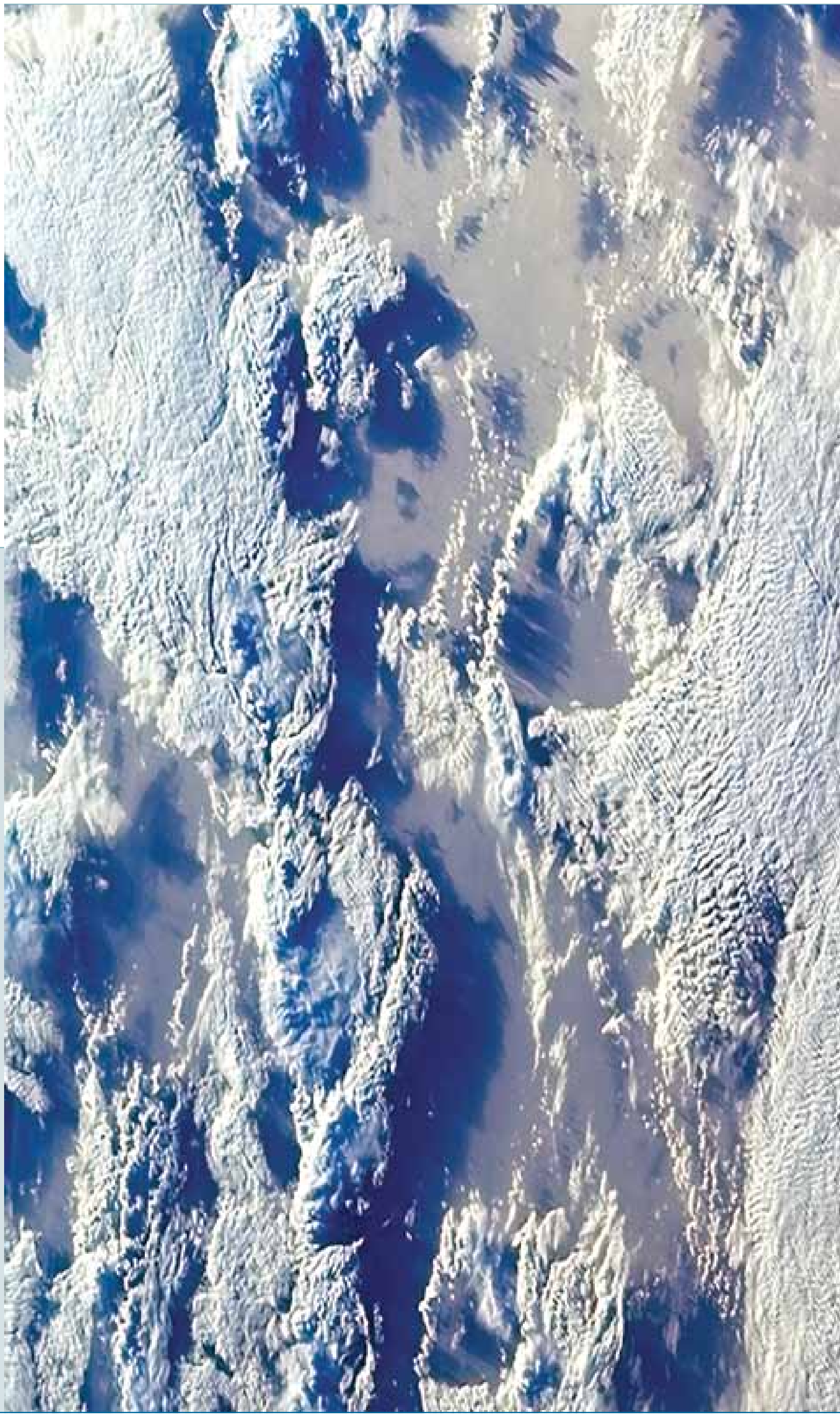
Random



The effect of low clouds on temperature is well known to scientists—and to anyone who has experienced "June gloom" in Southern California. When such clouds roll in, the temperature drops. What scientists don't know is how future changes in global temperature might, in their turn, affect the production and behavior of those clouds. And that's important: since low clouds reflect sunlight without adding substantially to the greenhouse effect, the presence of more low clouds would reduce future warming, while fewer would add to any uptick in the global thermostat.

To address the question of future changes, Tapio Schneider, the Frank J. Gilloon Professor of Environmental Science and Engineering at Caltech, and JPL's Joao Teixeira (a visiting associate at Caltech) are developing very high-resolution simulations of the behavior of low clouds and using the results in global climate models, which in turn inform the cloud simulations. "The hard part is making the connection between the very small-scale dynamics that we can now simulate pretty well and the large-scale conditions of the environment in which these clouds live," Schneider says. "That's where I think what we're doing is really new."

Schneider expects to have a "much better model of what clouds do" within the next five years. And that, he says, is not just pie-in-the-sky—or clouds-in-the-sky—thinking. *—KF* e&s

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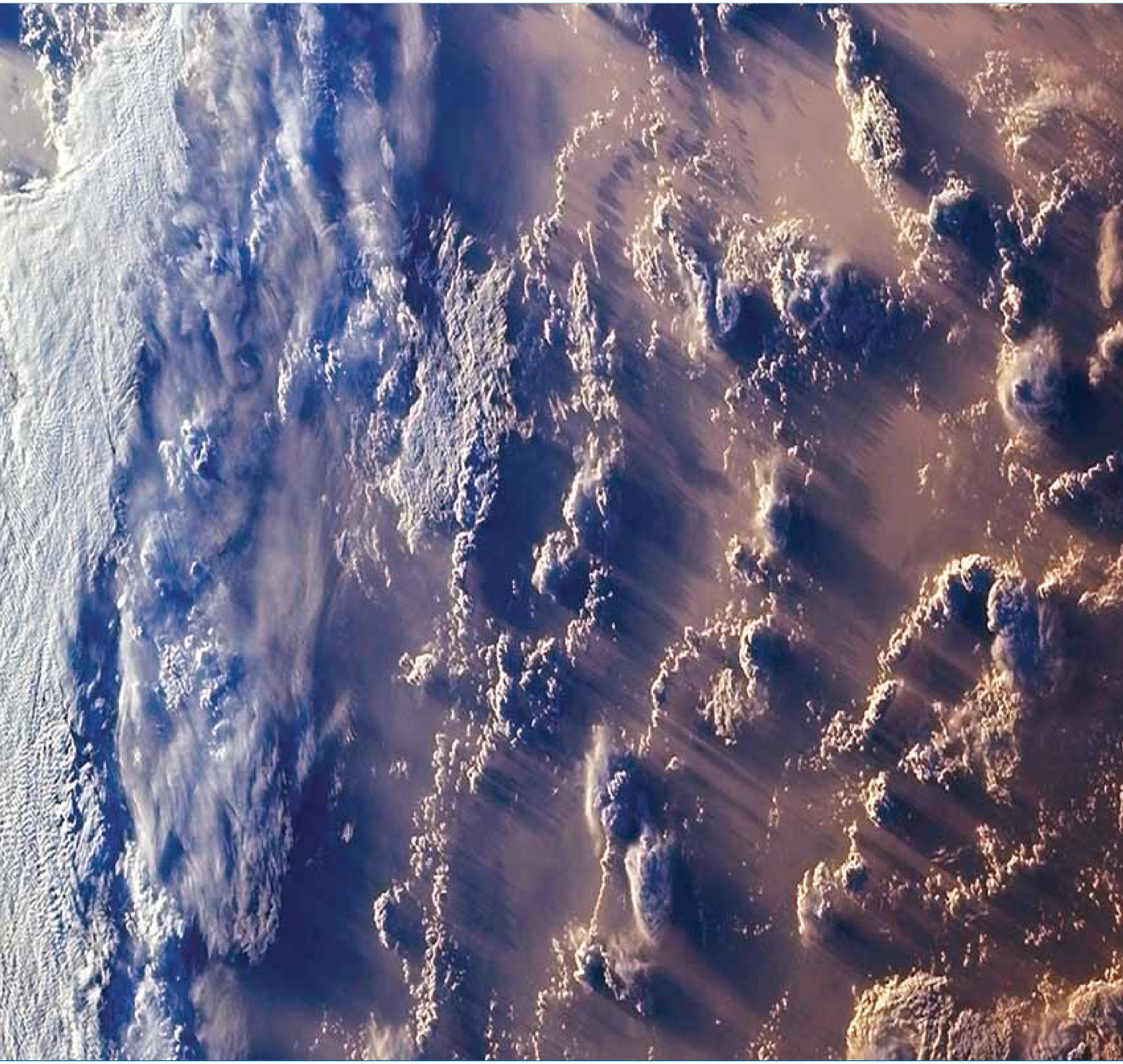
Walk

THINGS THAT CAUGHT OUR EYE . . .



SHHHHH!

WE'RE TRYING TO WORK HERE

Military jets may be powerful and highly maneuverable, but they're also deafeningly loud; on takeoff, jets routinely subject flight-deck personnel to roars of 150 decibels or more (at just 85 decibels, factories must institute hearing protection programs). The Navy, understandably, is keen to reduce jet exhaust noise.

That's where mechanical engineer Tim Colonius comes in. He and his team have been building models to understand how jet engines generate noise and the Office of Naval Research recently awarded Colonius funding to develop a better way to control the din. The goal: devices that that can be switched on to reduce noise levels during takeoff and then turned off afterward so they don't reduce thrust or otherwise affect the performance of the jet.

There are many sources of noise on an aircraft—from the landing gear to the internal engine. But the loud roar associated with military jets actually comes from turbulence in the jet plume *behind* the engine. The turbulent eddies generated in that flow are "kind of like little supersonic bullets flying through the air," says Colonius. Each of these structures causes something similar to a mini sonic boom. "Because they're supersonic with respect to the ambient air, they make little shock waves, and that's the sound that you hear."

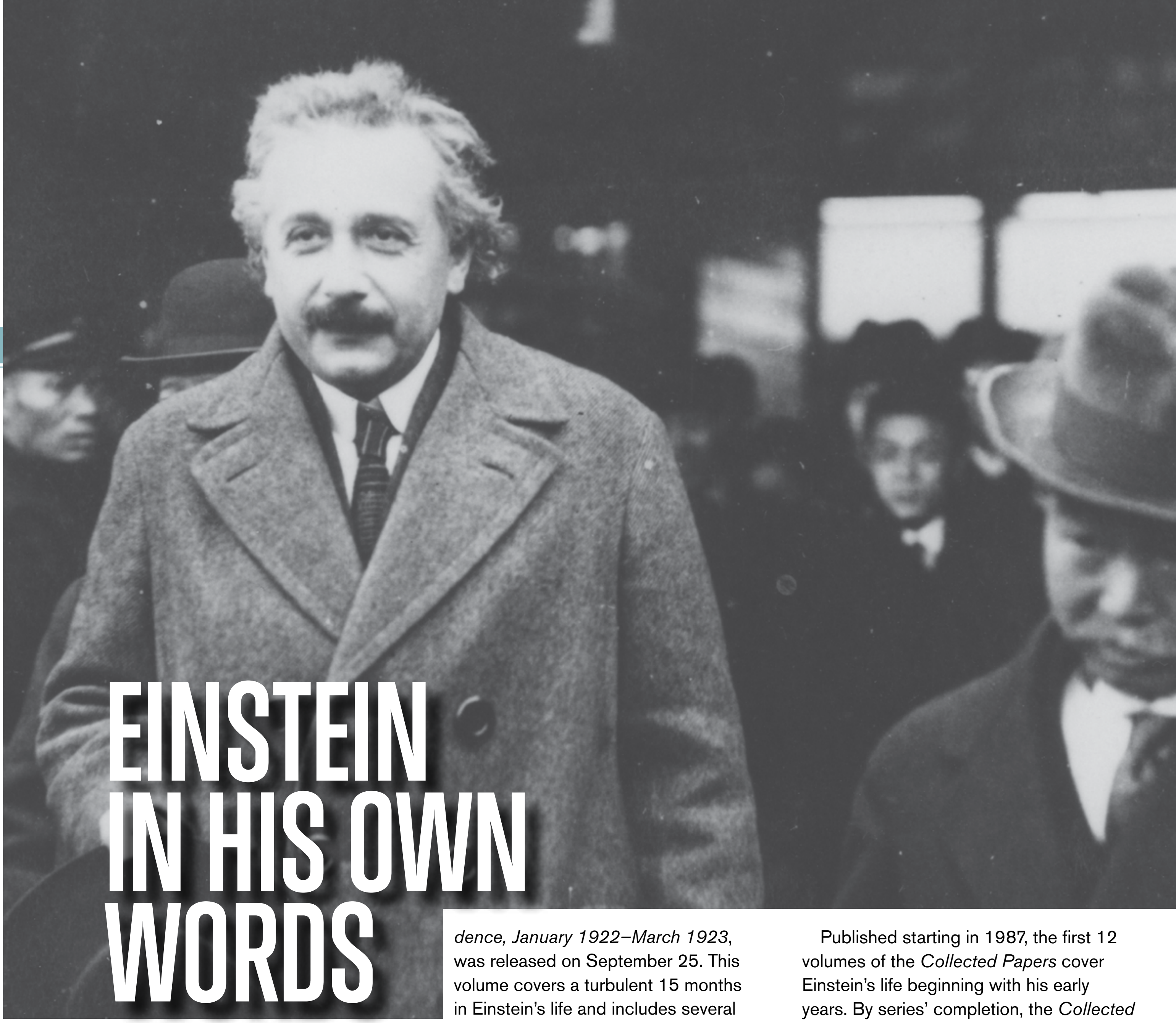
By controlling the properties of those bullets of air as they propagate downstream, Colonius and his colleagues hope to significantly dampen the deafening roar.

Colonius and his group have recently developed a new mathematical model for analyzing the turbulent structures trailing a jet. Working with partners at the United Technologies Research Center in East Hartford, Connecticut, they fed the model data gathered from hundreds of microphones positioned around a jet inside a sound-absorbing chamber.

"Now we are getting a much more detailed picture of the actual mechanism by which the turbulence makes the sound," Colonius says.

Using the new model, Colonius and his partners plan to figure out exactly where to introduce small disturbances—perhaps by injecting puffs of air near the jet nozzle. By positioning the disturbances in just the right spots, and puffing at just the right time, they hope to modify the turbulent eddies. It's all about limiting the number of those pesky supersonic bullets of air. —*KF* E&S

Top of page: A view into a jet surrounded by a rotating array of microphones in a test chamber at the United Technologies Research Center. Tim Colonius and colleagues will use a setup like this one to study the turbulent structures that emanate from jets and determine how they can modify those structures to decrease jet noise.



EINSTEIN IN HIS OWN WORDS

Thanks to a massive undertaking by editors and historians at the Einstein Papers Project, the life of one of science's most notable figures is quite literally an open book. *The Collected Papers of Albert Einstein* offers readers a never-before-seen perspective on Einstein's life. More than 80,000 documents—including Einstein's scientific writings, correspondence, articles, lecture and research notebooks, book reviews, and patent applications, as well as accounts of his lectures, speeches, interviews, and other oral histories—tell the story of this brilliant, and sometimes controversial, physicist.

The latest edition, *Volume 13: The Berlin Years: Writings & Correspondence, January 1922–March 1923*, was released on September 25. This volume covers a turbulent 15 months in Einstein's life and includes several hundred previously unpublished and unknown letters and articles that express his desire for "a normal life." Einstein's writings convey a feeling of restlessness and a strong desire to escape the demands of his increased fame and heightened visibility. Diary entries chronicle his six-month sea voyage to and from Japan for a series of public lectures, and they paint a vivid picture of an Einstein who, fearful for his safety following the assassination of his friend, the German foreign minister Walter Rathenau, decided to leave his home in Berlin and contemplated leaving academic life entirely. Einstein's winning of the Nobel Prize in Physics in 1922—after having been nominated for more than a decade—also figures prominently into this period of his life.

Published starting in 1987, the first 12 volumes of the *Collected Papers* cover Einstein's life beginning with his early years. By series' completion, the *Collected Papers* will comprise nearly 30 volumes. Caltech professor of history Diana Kormos-Buchwald serves as general editor of the series and director of the Einstein Papers Project. In addition to support from Caltech, the Einstein Papers Project is sponsored by the Hebrew University of Jerusalem and Princeton University Press and receives funding from institutional and individual contributors. —*AA* e&s

Above: Einstein at the Orio railway station in Kitakyushu in southern Japan as he prepares to travel from Moji to Hakata in December 1922. Accompanying him on his travels is surgeon Hayari Miyake (right), a renowned member of the Japanese scientific community.

WORDY WORMS

Lurking in the crevices of our planet are millions and millions of microscopic worms. They live in soil, plants, water, ice, wildlife, and sometimes even humans. In fact, nematodes—also known as roundworms—are among the most abundant and diverse animals on Earth, where they play a variety of roles.

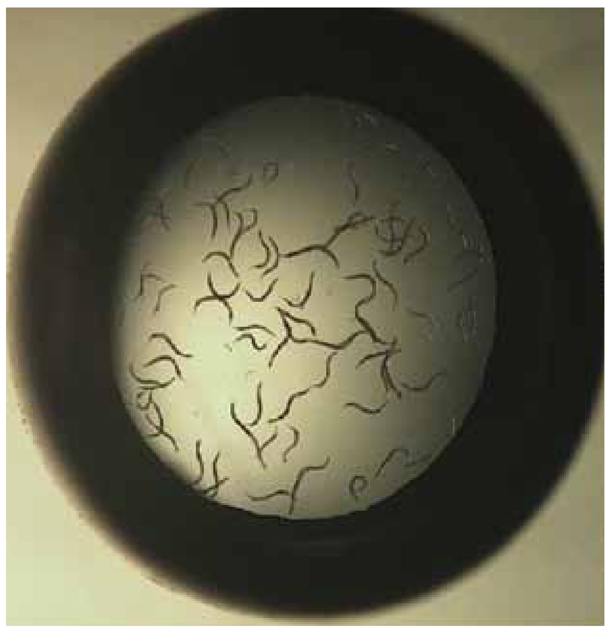
For the past 25 years, Paul Sternberg, the Thomas Hunt Morgan Professor of Biology at Caltech and a Howard Hughes Medical Institute investigator, has been studying the development and behavior of these creepy-crawly creatures and has recently uncovered important clues about how the worms communicate.

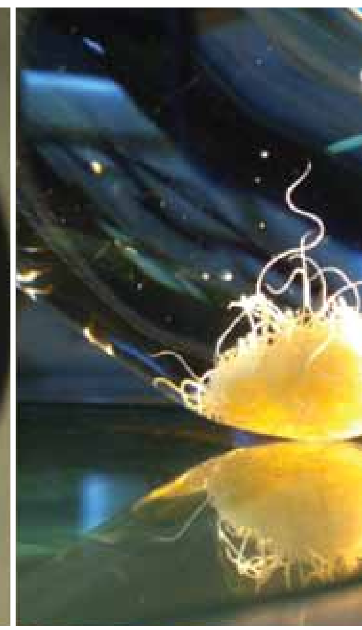
"We can now say that many—maybe all—nematodes are communicating by secreting small molecules to build chemical structures called ascarosides," says Sternberg. This makes sense, he notes, since his research group and collaborators previously found that at least one type of nematode secretes ascarosides both as a sex attractant and a social aggregation cue. "It's really exciting and a big breakthrough that tells us what to look for and how we might be able to communicate with this entire phylum of animals."

The ascarosides appear to represent a complex "language" in which the worms combine different chemicals into compounds, building a molecular library of signals that can be used to regulate behavior. To see if a similar chemical alphabet existed among other nematodes, Andrea Choe, formerly a graduate student (PhD '11) and now a postdoctoral scholar in biology, gathered up a bunch of nematode species—from nasty hookworms to harmless pests.

"For a long time, I turned a section of Paul's lab into a parasite zoo," says Choe. "People were both intrigued and terrified to come back there." At times it also resembled a kitchen, since in order to culture a certain plant parasite, she had to cut small, very sterile disks of carrots. "On some days, people would see me with a kitchen apron on, slicing carrots and then flaming my knife," she recalls.

Once the researchers had cultured a number of different nematode species, they bathed the creatures in a liquid solution dubbed "worm water." This worm water was used to collect the chemicals given off by the nematodes; the chemicals were then analyzed using a mass spectrometer—a tool used to deduce the chemical structure of molecules.



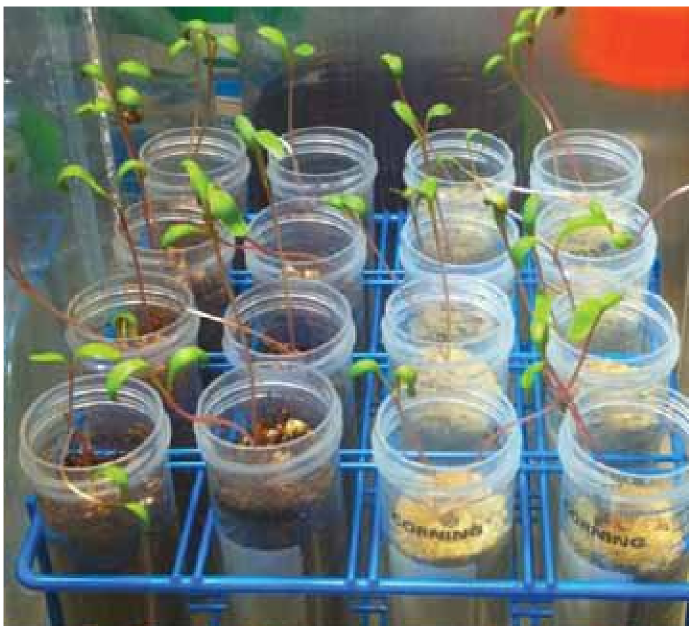


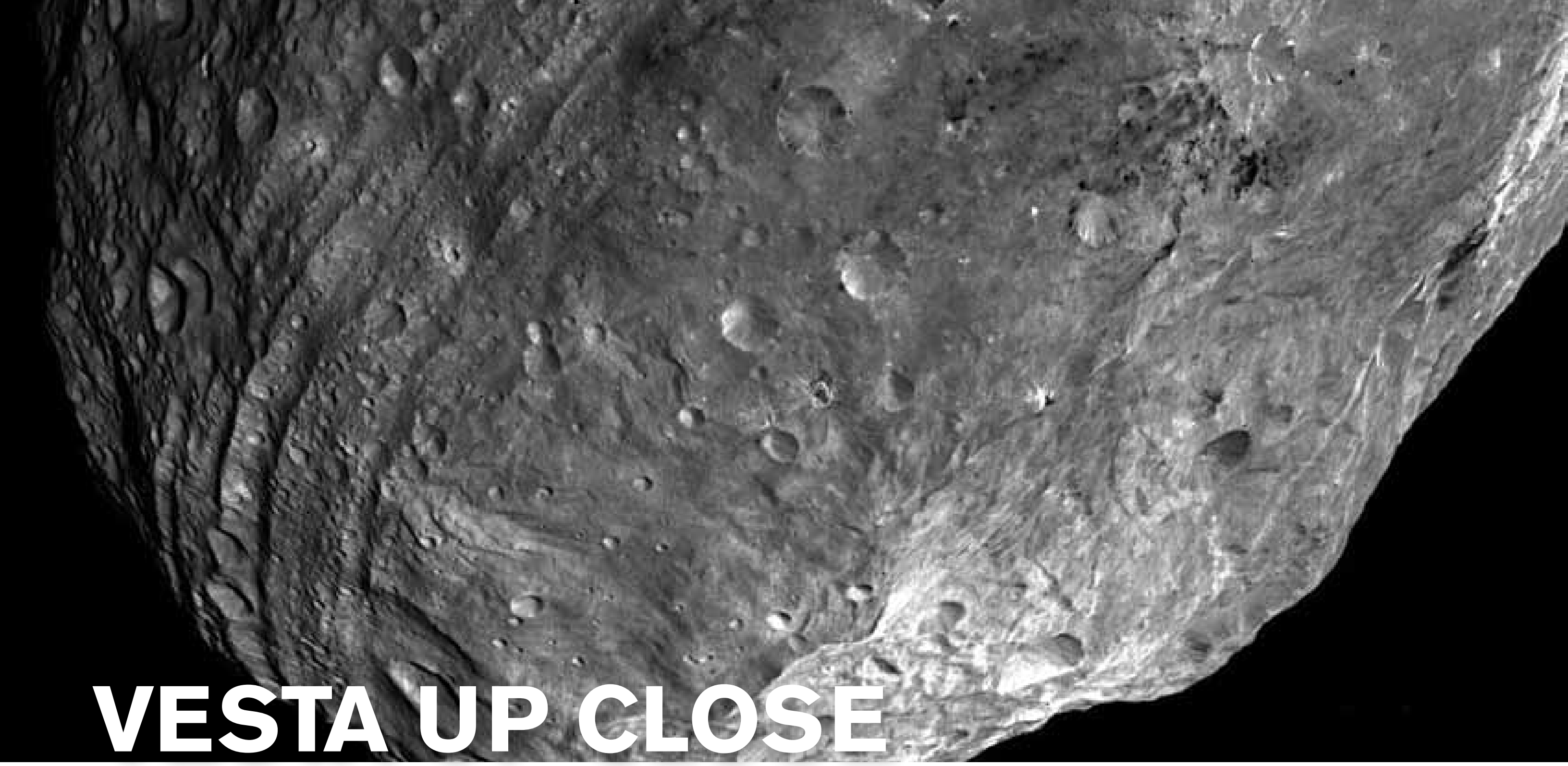
Below and below opposite: Many species of nematode were found by the Sternberg lab to communicate using the same types of chemical cues. Here, samples from the lab show some of the different shapes, sizes, and colors these creatures come in, as well as a few of the environments they inhabit.

"When the results came back showing that the same ascarosides were present in all the worm-water samples, I thought that we had made a mistake," says Choe. It was, she says, a *very* surprising finding. "A mistake seemed more plausible than stumbling upon a shared code between nematodes that had evolved millions of years apart and now live where they would never encounter each other."

"It really does look like we've stumbled upon the letters or words of a universal nematode language, the syntax of which we don't yet fully understand," adds Sternberg. For example, he wonders, what combinations of how many different chemicals are needed to "say" food, or mate, or attack?

If the team can crack the code in terms of what different blends of ascarosides mean to different species, Sternberg says, they can begin to interfere with the actions of the nematodes that wreak havoc across the world. And that might lead to more effective eradication of plant pests, as well as human and animal parasites. Maybe early *words* can catch worms, too. —*KN* E&S





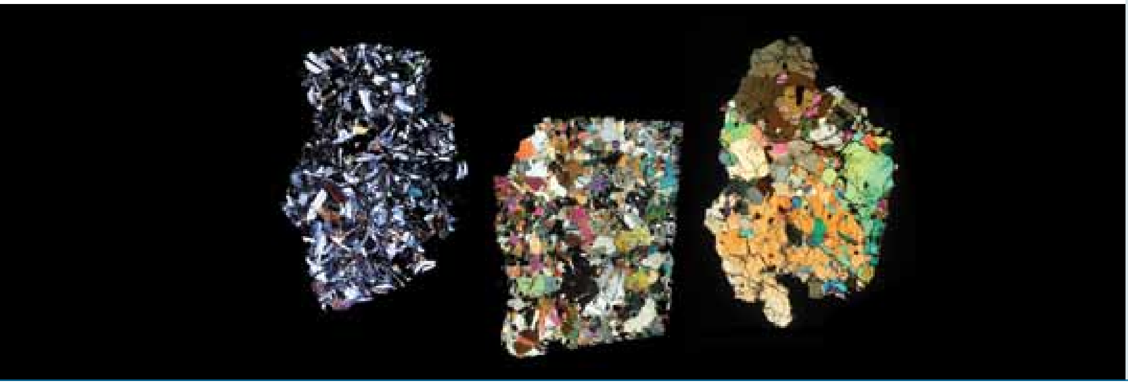
VESTA UP CLOSE

Out between Mars and Jupiter lies the rubble of planets that never quite formed. Although the asteroids date to the birth of our solar system, our closest looks at them have been glimpses—from spacecraft whizzing by en route to the glamorous outer solar system. That changed last July, when Dawn slipped into orbit around Vesta, the asteroid belt's second-most-massive member. Dawn, managed by Caltech's Jet Propulsion Laboratory (JPL) with UCLA's Christopher Russell as principal investigator, has now mapped about 80 percent of Vesta in 3-D. In May, a set of six papers describing the Dawn team's initial findings were published in *Science*.

The headline news is that Vesta has a substantial nickel-iron core, just like Mercury, Earth, and Mars—a radical notion first proposed in 1970 by Dawn coinvestigator Tom McCord (MS '66, PhD '68). McCord (then at MIT), his postdoc Torrence Johnson (PhD '70), and JPL's John Adams took detailed spectra of Vesta's surface and discovered it was entirely basalt, a type of frozen lava. If Vesta had gotten that hot, they reasoned, its heavy elements would have melted and sunk to the core in a process called differentiation—a key step on the road to planethood. In fact, jokes JPL's Carol Raymond, Dawn's deputy principal investigator, "We like to call Vesta 'the smallest terrestrial planet.'" Raymond's gravity data put the core at about 18 percent of Vesta's mass, or proportionally about two-thirds as massive as Earth's.

Dawn's mapping spectrometer has verified an even wilder conjecture from the 1970 paper: Vesta is indeed the source of the howardite-eucrite-diogenite (HED) meteorites found on Earth and Mars. The Dawn team thinks the HEDs came from an impact basin the team has named Rheasilvia, after a vestal virgin. Counting the craters within Rheasilvia gives it an age of about one billion years, surprisingly recent for something so big. At 500 kilometers in diameter, Rheasilvia is nearly as large as Vesta itself—the result of a collision that stripped away most of the crust from the southern hemisphere, baring Vesta's interior like a clumsily peeled orange. "Vesta likely came close to shattering," says Raymond, noting that the blow left concentric sets of troughs—fracture lines—around Vesta's equator.

Rheasilvia doesn't represent Vesta's only near-death experience. Dawn found a second basin, nearly as big and a billion years older, sticking out from under Rheasilvia. This basin, named Veneneia (for another vestal virgin), is also a potential source of HED meteorites. —*DS* E&S



Above: Vesta used to be round—until it got hit by something nearly one-tenth its size. The resulting impact basin, named Rheasilvia, fills most of this image, taken from some 5,200 kilometers away. Vesta's south pole lies in the mountains at lower right, while the parallel grooves at left (also created by the impact) run roughly along the equator.

Below, left: Cross sections of a eucrite meteorite found in Antarctica (at left); a diogenite (at right), also from Antarctica; and a howardite (center) from North Carolina. The eucrite's very fine crystals formed during the rapid cooling of Vesta's upper crust; the diogenite's crystals had time to grow bigger while Vesta's inner crust slowly solidified. Howardite is a mishmash of eucrite and diogenite shards, born in the impact that blew them sky-high.

Meet graduate student Julia Cosse, PhD ’14. Your gifts to the Caltech Fund have helped provide Julia with the financial freedom and stability—through resident associate and teaching assistant positions—to pursue her passions. In partnership with vice provost and professor of bioinspired engineering Morteza Gharib, PhD ’83, Julia is working to improve wind energy efficiency by developing flexible wind-turbine blades.

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THE FIGHT OF THE CENTURY

By Katie Neith

BIOLOGISTS AT CALTECH SEEK TO DELIVER A KNOCKOUT BLOW IN THE BATTLE AGAINST HIV, ONE OF THE WORST EPIDEMICS IN THE HISTORY OF THE WORLD.

Despite over 30 years of educational and behavioral approaches designed to prevent human immunodeficiency virus (HIV) infections, the disease continues to spread at an alarming rate. The development of drug cocktails has made the virus manageable for those with access to medication, yet less than half of the approximately 34 million people living with HIV are receiving these live-saving drugs, according to the World Health Organization.

"Cumulatively, more than 60 million people have been infected over the past three decades and the epidemic continues to grow," says physician-scientist David Ho (BS '74), scientific director and chief executive officer of the Aaron Diamond AIDS Research Center in New York. "There is no way we can treat our way through this epidemic. We have to find a way to slow the spread of HIV."

When HIV first made headlines in the early 1980s, scientists, clinicians, and activists in California took on key roles in diagnosing and treating infected individuals, as well as in influencing the health-care policies that sprang up around the epidemic. Indeed, some of the very first cases of what was then referred to as human T-lymphotropic virus-III—now simply known as acquired immunodeficiency syndrome, or AIDS—were identified and studied in Los Angeles. Today, HIV cure and prevention research continues both in Los Angeles and across the globe. As a world-class research institution with the resources to make a huge impact in human health, Caltech is among the leaders in developing new approaches to defeating HIV.

BEATING THE COUNT

Caltech structural biologist Pamela Bjorkman is working to beat the virus at its own game—not by preventing HIV from spreading, but by trying to slow down, or block entirely, the virus's ability to infect cells once it has entered the body. She does this by employing highly potent neutralizing antibodies—a version of the two-armed proteins that she and others in her lab have designed specifically to knock out, or neutralize, most strains of HIV.

"We know that in the case of HIV, our own bodies' antibodies are generally not very effective against the virus," says Bjorkman, who was a 2006 recipient of the L'Oréal-UNESCO Award for Women in Science for her pioneering work in understanding the immune system. "I thought we could use what we knew structurally about antibodies to design something that is better than a natural antibody."

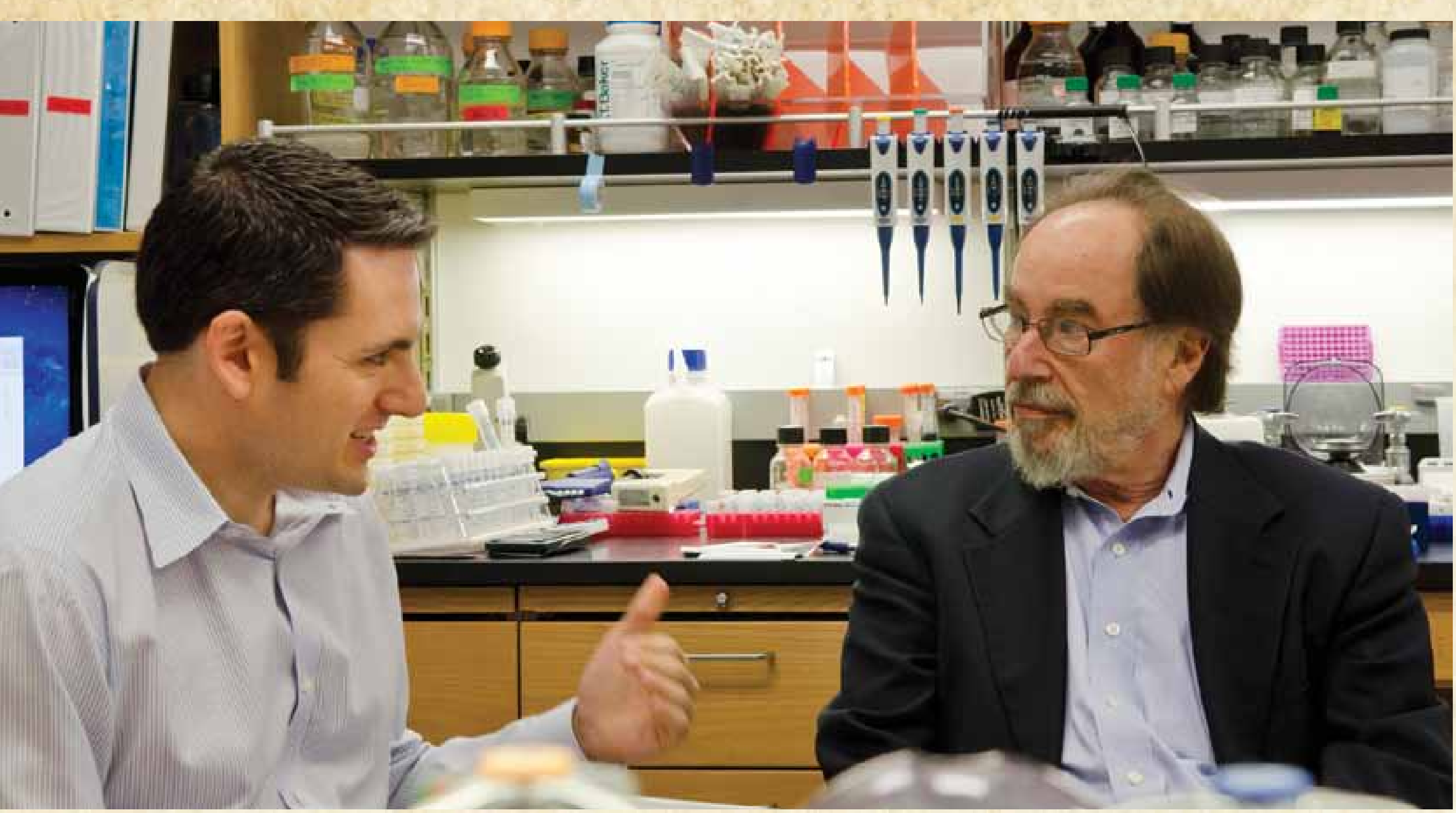
Like a nimble boxer who adjusts to the fighting style of his competitor, HIV is able to mutate in order to escape most antibodies—both those produced by the human immune system and the ones scientists have developed thus far.

"No matter what you do to the virus, it figures out a way to get around it," says Bjorkman. "So we're studying the viruses that have mutated to be able to bypass our antibodies, and designing new types of antibodies that stop the virus from taking each of those particular paths."

The good news is that, in response to some antibodies, it appears that HIV mutations make the virus less fit. So if you can create antibodies that are strong enough to keep forcing the virus to mutate in ways that harm it, the virus may eventually cripple itself to the point that it's not a threat to the body any more.

Which is just what Bjorkman and her colleagues are seeing. Their most recent experiments on one of their newest antibodies showed that it could target and neutralize up to 97 percent of viral strains it was tested against. The study was led by Ron Diskin, a senior postdoctoral scholar in Bjorkman's lab, and was published in the December 2, 2011, issue of the journal *Science*.

"The first one we made a year ago was a remarkable improvement over a natural antibody, and this one is even better," says Bjorkman. "We think that our whole approach works, and we think that we can keep improving the



antibodies. I think that this could be used for a cure—I really do."

And she has evidence to bear that out. In a 2005 clinical trial, Swiss researchers tested early versions of neutralizing antibodies in HIV-positive individuals who volunteered to go off their antiretroviral drugs. Normally, when patients stop taking these drugs, their viral loads skyrocket; what the researchers found was that an injection of the neutralizing antibodies significantly delayed—although did not prevent—that increase in viral load.

Those antibodies, says Bjorkman, were orders of magnitude less powerful than the ones she has today. That's why she's now hoping to find both the funding and the clinical partners to allow her to repeat that trial using her new, more effective antibodies.

"We have failed to come up with a protective vaccine after nearly three decades of research," points out Ho, who coauthored a study of naturally occurring neutralizing antibodies with Bjorkman last year. It described a group of novel antibodies isolated from HIV-infected individuals using a new cloning approach. "We have to think of alternative strategies, and one of them is passive immunization, or giving the body antibodies instead of provoking it to make its own. The kind of antibodies that Pamela is coming up with are so potent in blocking HIV infection—at least in test tubes and in experimental animal models—that they hold promise of being protective against HIV in humans, too."

Top: Alex Balazs (left) and David Baltimore discuss their novel approach to HIV prevention: a method for delivering neutralizing antibodies, which protect against HIV infection in mice. A video detailing their work can be found on the Caltech YouTube channel in the "Research & Science" playlist.

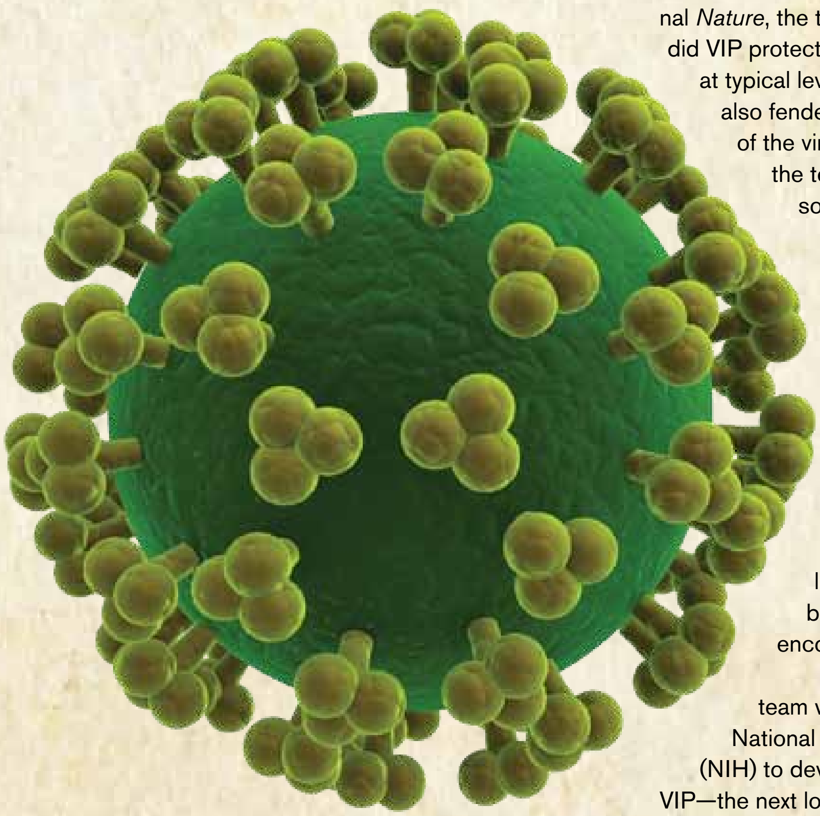
Right: This illustration of HIV's surface shows spike proteins sticking out from the body of the virus. These proteins, which give the virus the ability to enter and infect a cell, are the target of the neutralizing antibodies Pamela Bjorkman is building and David Baltimore is working to deliver.

INSIDE FIGHTER

While Pamela Bjorkman is focusing on designing better antibodies, biologist David Baltimore is testing a way to deliver those tiny virus-fighting proteins to both infected and uninfected populations—with the latter being given the antibodies in the hopes that, should they come into contact with HIV, they'll be ready and able to fend off the virus.

"It first became a thought to us in the early 2000s that you might be able to make antibodies and use them for protection against HIV infection," says Baltimore, who won the 1975 Nobel Prize for discovering the DNA-building enzyme reverse transcriptase. In retroviruses like HIV, reverse transcriptase is essential for viral reproduction and is the target of some of the antiretroviral drugs used to treat the disease. "But it wasn't until Alex Balazs, a postdoc in my lab, suggested we switch the way we deliver the antibodies that we began to see real success. He showed that his delivery method could work and has directed that whole program ever since."

Instead of injecting antibodies directly into the body, this new approach—called VIP, or vectored immunoprophylaxsis—uses a benign human virus called adeno-associated virus (AAV) to deliver the punch. The scientists simply replace the genes in that virus with the genes that encode for the antibody they want the body's cells to produce.



When tested in animal models, the AAV transport mechanism worked. "We injected the virus into the muscle of a mouse, and the muscle cells became a factory for antibody production in the animal," explains Balazs. "In fact, the secreted antibody was present at a high enough concentration to prevent a subsequent infection by HIV."

The VIP method is a bit of a new approach to HIV prevention. Traditional efforts to develop a vaccine against HIV have centered on stimulating an immune response—either in the form of antibodies to block infection or T cells to attack infected cells.

"With VIP, we bypass the immune system because we deliver the specific genes for the antibody we would like as the final product," says Balazs. "In doing so, we can direct an immune response that may be difficult to achieve using traditional vaccine approaches that stimulate immune responses."

In describing their results in a paper in the January 5, 2012, issue of the journal *Nature*, the team noted that not only did VIP protect mice against infection at typical levels of HIV exposure, it also fended off much higher levels of the virus. In fact, although the team expected that, at some dose, the antibodies would fail to protect the mice, that never happened—even when researchers gave mice 100 times more HIV than would normally be needed to infect seven out of eight mice. "All of the exposures in this work were significantly larger than a human being would be likely to encounter," Balazs says.

At press time, the team was in talks with the National Institutes of Health (NIH) to develop a human trial for VIP—the next logical step after such a successful animal trial. Balazs says that although the process is slow going, he has every reason to think it will get done—and has every hope that it will be successful.

"I have always felt that HIV research was the most frustrating thing in the world," says Baltimore, "because no matter what you did, you didn't seem to get any closer to affecting the disease in human beings. Because of VIP, that whole perspective has changed for me. And that's incredibly satisfying."

THE ONE-TWO PUNCH

It might seem as if a vaccine, or a vaccine-like approach, shouldn't be necessary when there are already so many proven behavior modification methods of HIV prevention, such as safer-sex practices and needle-exchange programs. And yet, Balazs says, it's still critical; behavioral changes just don't work well enough to end the epidemic.

"Educational approaches, such as teaching people to use condoms or abstain from sex, have a very important role, and clearly they've been very effective in reducing HIV transmission," says Balazs. "But ultimately we think you're going to need an intervention that doesn't require a schedule or maintenance—something in which compliance will not be a factor." It's hard, after all, to get people to adhere to a restrictive behavioral regimen or to take complicated combinations of medications on a daily basis.

That's why Balazs thinks vaccines are the only way to go. "Vaccines have been one of the few ways that we have to actually eradicate diseases," he says. "We need a vaccine, or vaccine-like approaches, to really make an impact on HIV."

Vaccines are also important for those populations whose members cannot control whether or not they become infected. Bjorkman points out, for example, that infants born to HIV-positive mothers can't do anything to prevent themselves from becoming infected with the virus. Behavioral methods of prevention are also not an option for victims of sexual abuse or women in certain cultures who do not have a voice when it comes to sexual rights. Not to mention that there are millions of people worldwide who do not know they are carriers of the virus.

"If we had an effective prevention method, we could drive the virus down to very low levels," says Baltimore. "In principle, you could extinguish it and put the genie back in the box. That would be a super cure because it would eradicate HIV from the face of the earth. But it will require a very good vaccine or widespread use of something like VIP."

ON THE ROPES

As in any tough fight, the struggle to achieve that "super cure" is chock-full of challenges. One of the biggest of these challenges, from a biological point of view, is the virus's ability to mutate at will. "The mutation abilities of this virus are just terrible and, of course, deliberate on the part of the virus," says Bjorkman.

Still, she says, trying to gain support for her research can be almost as daunting as trying to counter the virus's structural slipperiness.

"I would—more than anything else—like to do a clinical trial right now with our antibodies and I don't have the money, which is incredibly frustrating to me," she says. "We are completely stuck between the findings and the application of those findings—and this needs to be done."

Baltimore agrees that finding funding can be a constant struggle for any scientist, particularly when trying to move bench research into human clinical trials.

"If *we*'re talking about VIP as a piece of medicine, then it's got to pass FDA certifications and that's going to be a challenge in itself," he says. "To do a large enough trial to convince people that it's safe and efficacious could cost tens of millions of dollars, and perhaps even hundreds of millions of dollars."

The flip side to those challenges, notes David Ho, is the rather unique opportunities offered by a culture like Caltech's—which gives researchers the ability to explore beyond the traditional confines of their own fields.

"It is intellectual freedom—the ability to roam within the scientific space—that has produced so many great results over the decades," says Ho. "Basic research is crucial for an epidemic like HIV/AIDS, and not just in terms of adding to incremental knowledge, but to fundamental breakthroughs."

Baltimore agrees, citing Caltech's "laissez-faire" atmosphere as the reason he's been able to pursue collaborative efforts with outside medical schools. Recently, for instance, he's been working to grow the Joint Center for Translational Medicine, a partnership with UCLA, which he codirects.

"I hope the center will reinforce the viewpoint that basic researchers should work toward moving their findings from the bench to the bedside," says Baltimore. This collaboration, he notes, has received over $7 million in funding thus far and has an increasing number of researchers who are working under that support, including Bjorkman.

While such partnerships are indeed crucial, Balazs believes that being at an institute that focuses solely on basic research allows Caltech's scientists to approach problems from different angles.

"For example, we can look at something from an engineering perspective, as we did in our VIP work," he says. "We decided we wanted to engineer immunity rather than simply trying to provoke the immune system. This is not something that is typically done and may not have come up in a different environment. I think that despite the fact that we are 'only' a basic-science campus, we have an important role in bringing new ideas to the table."

BATTLE TO THE BELL

Which is why Baltimore and Bjorkman continue to study and improve upon the ideas they see as winning approaches to beating HIV. Indeed, for Baltimore, the challenge of eradicating the virus is a sort of ethical obligation.

"One of the things we said in the first report I wrote on the epidemic was that the existing research community of people interested in retroviruses ought to be focusing on this problem," he recalls. "I believed people had a moral responsibility to turn their research—or at least some of it—toward AIDS."

Pamela Bjorkman delivers a talk about her neutralizing-antibody research at the 2011 TEDx Caltech event. For a video of her full presentation, visit the conference's website at www.tedxcaltech.com. This past summer, Bjorkman volunteered in India with Vatsalya (www.vatsalya.org), an organization that provides assistance to HIV-positive women and children.

IT'S CRUCIAL TO STAY IN THE FIGHT BECAUSE—DESPITE PERCEPTIONS IN THIS COUNTRY TO THE CONTRARY—THE VIRUS HAS NOT BEEN TAMED.

Since cowriting that initial HIV-research agenda in 1986, he has focused a small but significant part of his laboratory on the virus.

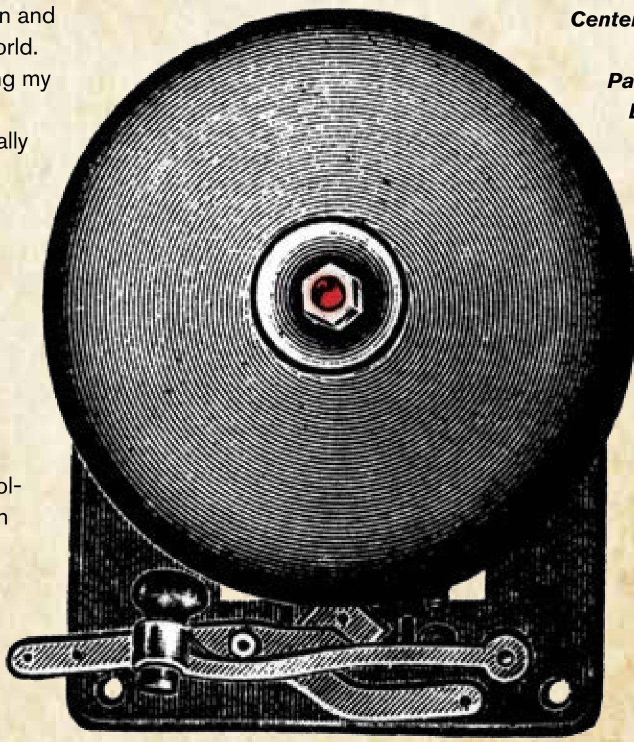
"We've made a lot of discoveries and done some important things along the way, but the epidemic continues on in spite of all of our interest," says Baltimore. "So, when the possibility of giving VIP a try came up, I put a lot of horsepower behind it."

For Bjorkman—whose early research focused on topics that were not directly medically relevant—HIV research has a different feel.

"This is a global health problem that we really need to fix. I recently had the opportunity to visit a program to educate sex workers in India about HIV and was able to see the effects this virus is having on women and families in the developing world. So I feel good about devoting my time to this," says Bjorkman. "Basic research is always really fascinating and interesting and wonderful to do—but it's more rewarding when there's a problem that might be helped through what we're doing."

She doesn't only feel that urgency in the lab; in recent years, she has incorporated learning about HIV into the Principles of Biology course, so that freshmen will understand why research into preventing HIV is absolutely critical for today's world. "People are still getting infected and dying from this disease, so we've got to have some way of preventing it," she says. "Ultimately, that means we have to have some form of a vaccine."

Indeed, Baltimore says, it's crucial to stay in the fight because—despite perceptions in this country to the contrary—the virus has not been tamed. "The fact of the matter is, there are 50,000 new HIV infections in the U.S. every year and we're not seeing a diminution," he notes. "People are not listening to messages about how to protect their health. So it's up to the scientific community to keep fighting to end this epidemic. And now I think we have a shot at it." E&S



Alejandro Balazs is a postdoctoral scholar in the Division of Biology whose work is supported by a postdoctoral fellowship from the Foundation for AIDS research (amfAR).

David Baltimore is president emeritus of Caltech and the Robert Andrews Millikan Professor of Biology. His HIV research is funded by the Bill & Melinda Gates Foundation, the National Institutes of Health, and the Caltech-UCLA Joint Center for Translational Medicine.

Pamela Bjorkman is the Max Delbrück Professor of Biology at Caltech and a Howard Hughes Medical Institute (HHMI) investigator. Her HIV research is funded by the Bill & Melinda Gates Foundation, HHMI, and the Caltech-UCLA Joint Center for Translational Medicine. Support for structural biology at Caltech is provided by the Gordon and Betty Moore Foundation.

DECISIO 20

By Marcus Y. Woo

As Election Day nears, what factors are you weighing while you ponder your vote? The issues, the economy—or how the candidates look?

The story is one of style over substance, of youthful charisma over sweaty awkwardness. On September 26, 1960, John F. Kennedy, the young senator from Massachusetts, faced off against Richard Nixon, the sitting vice president, in the first-ever televised presidential debate.

Kennedy, with the benefit of full makeup and a tan from campaigning in California, stood in stark contrast to Nixon. The vice president, who had been in the hospital with a knee infection just a few weeks before, had declined makeup, leaving his pale face sweating under the glaring hot stage lights. Kennedy wore a dark suit while Nixon wore gray, blending into the background.

It was nearly unanimous that Kennedy trounced Nixon—on TV, at least. A poll found that those who had listened to the debate on the radio thought Nixon had done just as well as Kennedy, suggesting that Kennedy's debate victory—and eventual election win—was primarily due to his television performance.

N MAKING
12

The now oft-told tale came to symbolize a new era in American politics—an era in which image became paramount. Even though some scholars later found the radio poll data to be unreliable—meaning the assumption that style trumped substance might have been exaggerated—there's little doubt Kennedy's appearance played a big role in his win.

What about today's voter? As Election Day approaches, what factors are you weighing while you ponder your vote? Will you be charmed by a candidate's charisma and appearance—as many Kennedy voters supposedly were? Will you focus on the candidates' qualifications and stances on the issues? Just what will go into your decision-making process?

That's the question that Caltech's economists and political scientists and even its psychologists and neuroscientists are asking. And while they've had some success—gleaning insight into how the economy affects election outcomes, for instance, or what role emotions play in the process—no one really knows how you or your neighbor will actually vote, says Caltech political scientist Erik Snowberg. "Ultimately, we just know how people voted and what stimuli they might have been exposed to as part of their decision-making process," he says. "It's kind of a black box."

Which is why Caltech neuroscientists have been looking directly into the brain in the hope of homing in on just how people make these kinds of decisions—and, in particular, whether electability really is in the eye of the beholder.

FACING THE CANDIDATES

Do looks really matter in elections? The answer may surprise you. Take, for example, a 2005 study in which volunteers were asked to compare headshots of congressional election winners and runners up. After discounting any candidates they recognized, the participants—who didn't know the outcomes of the elections in question—were asked to pick the candidate who looked more competent. In more than 60 percent of the races, the chosen person was indeed the actual winner.

"This result is not necessarily something you would predict if democracy was really run primarily on the issues," says Michael Spezio, a neuroscientist at Scripps College and a visiting associate at Caltech. "It turns out that candidate appearance matters. But we don't know exactly *what* about their appearance matters."

The lead author of that original study—Princeton's Alexander Todorov—joined Spezio, Caltech neuroscientist Antonio Rangel, and other Caltech researchers to try to answer that very question. They conducted a similar experiment—except this time they put the test subjects in a functional magnetic resonance imaging (fMRI) machine.

An fMRI machine measures blood flow in the brain, which serves as a proxy for neural activity—the busier a part of your brain is, the more oxygen (and thus blood) it needs. By looking at where the blood is going, researchers can map the active regions of the brain while a subject does a particular task—in this case, evaluating candidates' faces.

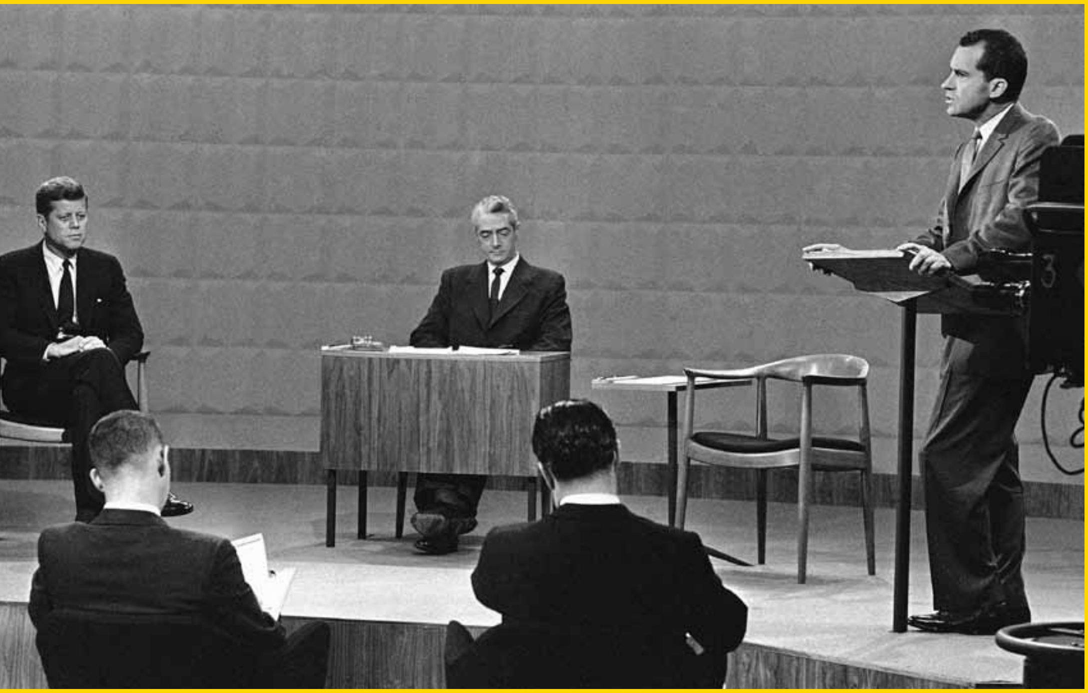
In all of these experiments, the researchers controlled for both race and gender by using images of white males—who make up the majority of candidates—running against each other. Otherwise, Spezio says, the effects of race and gender would likely swamp any influence facial features might have.

In the first part of this two-part experiment, Rangel asked volunteers to pick the candidate they would vote for based on appearance. When he and his colleagues analyzed the fMRI data, they found that when the participants were looking at their ultimately chosen candidate, there was no consistent pattern of neural activation. But when the subjects looked at the candidate they voted *against*, two regions in their brains lit up: the ventral anterior cingulate cortex (an area associated with valuation and decision making) and the insula (which evaluates faces and emotion and is known to be especially active when processing negative reactions, such as disgust).

In the second part of the study, led by Spezio, the volunteers went through pairs of candidates and chose which candidate in a pair looked more threatening, competent, attractive, or deceptive. Comparing these results to the actual election outcomes, the researchers replicated the results of Todorov's first study—i.e., they found that the candidates who were rated in the laboratory as looking more competent tended to be the winners of their elections in the real world. They also discovered something new: the candidates who lost real elections tended to appear more threatening than those who won their elections.

Interestingly, the fMRI data showed that the same two brain regions—the ventral anterior cingulate cortex and the insula—had the strongest response when subjects were looking at the candidate they thought looked more threatening. The data also showed that brain response was more consistent among people who were processing negative characteristics of appearance than positive ones. The researchers say that these results, which were published in *Social Cognitive and Affective Neuroscience* in 2008, make evolutionary sense, since failing to identify who poses a threat could easily mean injury or death. And they're in line with findings by political scientists that people tend to vote *against* someone, rather than *for* a particular candidate.

We also could be adapted to recognize negative traits because those tend



Above: In the first-ever televised presidential debate, John F. Kennedy—young and charismatic—sported a tan and wore a dark suit. Richard Nixon, on the other hand, declined makeup, leaving his pale face sweating under the hot stage lights, while his gray suit blended into the background.

Right: Asked to choose a candidate based on appearance, volunteers reproduced the actual election results when judging a full headshot (top), just the candidate's face (middle), and, surprisingly, even photos with the face cut out.

to be more genuine, explains Caltech neuroscientist Ralph Adolphs, a member of the research team. Usually, people don't *try* to look threatening. But if an insincere smile or furled eyebrow makes them look a little untrustworthy or hostile . . . well, then maybe they are.

"It's a real honest signal they can't hide," he says. "It's a plausible evolutionary scenario, and it fits with lots of data both in psychology and neuroscience." Research has shown, for example, that aggression can manifest itself in facial characteristics—such as the width-to-height ratio of a face, or prominent cheekbones—that tend to be triggered by the presence of extra testosterone in the body.

In a follow-up study, Spezio and Caltech graduate student Laura Loesch, Frédéric Gosselin of the University of Montreal, Kyle Mattes (MS '05, PhD '08) of the University of Iowa—who wrote his thesis at Caltech on negative campaigning—and Caltech political scientist Michael Alvarez tried a similar experiment. But this time they used photos that either showed only faces (no hair or shoulders) or photos that showed hair and shoulders but had the faces cut out (as shown at right). Again, participants were asked to go through each pair and pick which candidate they would vote for, which one appeared more competent, and which one looked more threatening. The laboratory results were then compared with election outcomes in the real world.

The researchers expected the experiment to simply confirm that voters take candidates at face value, so to speak. And indeed, when looking only at faces, the participants were quite good at picking out the losing candidate by deciding who looked more threatening—although they were less effective at picking the winner based on how competent he looked.

But what was really surprising was what happened when the participants looked at images *without* faces. The candidates they picked as more competent tended to be the winners—and the candidates who appeared more threatening still tended to be the losers. This predictive power, remember, came from nothing more than cues like face shape, hair, clothing, or posture.

These results, published earlier this year in the journal *Political Psychology*, suggest that nonfacial features could be just as crucial as facial features when we're judging candidates, Spezio says. The importance of these nonfacial features, which a candidate has more control over than, say, having a big nose—it's easier to get a haircut than a nose job—gives Spezio hope. "It does indicate we can be a little more optimistic about how candidates can help present themselves," he says, "and not necessarily be prisoners of the face they were born with."

Of course, most of us don't deliberately place our votes based on whether or not a candidate looks the part. "The million-dollar question is how big a role this actually plays in real life," Adolphs says. "When you vote for someone, you certainly don't only look at a 100-millisecond flash of their face."

Still, says Spezio, the idea that appearance might play any role at all is worrisome. "Any evidence that our deliberative democracy is determined even in part by elements that have to do with a person's physical appearance is profoundly challenging for the health of our electoral system. But perhaps the best way to counteract these influences is to become an informed voter, since data show that people who know a lot about the candidates and the issues are less influenced by candidate appearance than voters who are ill informed."

IT'S THE ECONOMY, GENIUS

Twenty years and thirty-two days after Kennedy's milestone television performance, Jimmy Carter squared off against Ronald Reagan in their one and only debate. In his now-famous closing remarks, Reagan posed a question to viewers: "Are you better off than you were four years ago?" He cited high unemployment to argue that he was a better choice than Carter, the incumbent. A week after the debate, Reagan won the White House.

Just a couple of years earlier, Caltech political scientist Rod Kiewiet had been studying this very topic, and had showed that while a good economy favors the incumbent, a bad economy bodes well for the challenger.

To Kiewiet, it seemed as if Reagan had taken a page straight from his research paper. "It was interesting how explicit he was," Kiewiet recalls.

Before Kiewiet had published his findings, conventional wisdom held that voters cared only about how the economy affected their individual lives. But after sifting through more than a century's worth of presidential election results and economic data, such as unemployment and inflation rates—and looking at data from surveys dating back to the 1950s, asking voters who they voted for and what they thought about the economy—Kiewiet learned that, when voting, people seem to consider the state of the economy as a whole.

"If you think about it, it just means voters are sort of sensible," Kiewiet says. "Their own economic fate is largely driven by a very large number of factors the government doesn't have anything to do with, while the general direction of the economy is more easy to connect with the management of the incumbents."

Still, while Reagan's question was astute, Kiewiet says his time frame was off. Political scientists have found that voters have short memories when it comes to the economy. The real question that people ask themselves is whether they're better off than they were six to nine *months* ago, not four years ago.

"Even though in the last three years we have had this hideous recession, and there's a lot of argument about whose fault it is—was it Bush's fault or Obama's fault—that doesn't really matter," Kiewiet says. "By election day, it's all forgotten." As to whether that's good for Obama or not, Kiewiet's not making predictions; he's just analyzing the past.

So what *is* important to voters? Unemployment, he says, calling it the best economic predictor of elections. Not the absolute percentage of out-of-work voters, mind you, but whether that number is rising or falling—even by just 1 percent. An incumbent should therefore hope that unemployment rates drop in the months leading up to Election Day, while a challenger might (quietly) root for the opposite.

Of course, it may not all be about how the economy is actually doing so much as your perception of the economy that matters. Recently, Erik Snowberg found that most people seem to base their impressions of unemployment on their own economic situations. For example, young people and minorities—groups whose members are more likely to be among the unemployed—believed unemployment was higher than the actual rate. People who have jobs, or are in positions of more economic security, were more likely to underestimate unemployment.

Despite the connection most of us make between the economy and the Oval Office, experts say our commander in chief really doesn't have as much influence as we might think; after all, our democracy is set up with many checks and balances, and other politicians feel free to challenge the president's decisions. "I would say the typical president does not feel like he has any real control," Kiewiet says. "What can you do? You're not running the Fed. You're not running Congress." And in today's global economy, he has even less control, since he definitely doesn't have a say over European or Asian markets.

In more authoritarian countries, however, economies seem to be affected by a leader's every breath. In 1997, for example, rumors of the late Indonesian president Suharto's failing health sent an already-falling Indonesian stock market into an even steeper decline.

Still, Kiewiet says his research shows that despite the president’s lack of control, making voting decisions based on the economy isn’t a bad strategy. At the very least, it provides an incentive for the president to do whatever he can to make things better—even if any direct authority he might have is just a matter of perception.

EMOTIONAL INFORMATION

So, if our decision-making process is fraught with complexity, uncertainty, and—as the face experiments show—potential unwitting biases, what are we to do? We need to learn about the issues, says Mike Alvarez. “I think all the research we do indicates that there are places where voters can be better informed,” he notes.

Becoming informed is especially challenging when we’re talking about smaller elections or ballot measures, which generally lack the high-profile campaigns and media coverage of presidential contests. For those, we voters usually have to rely on the thick, text-heavy voter-information booklets that our state election boards mail out—and they’re not exactly a good read.

“They’re really stuck in the 19th century,” says Alvarez, who has been studying voter-registration and voting-technology issues since 2000 as one of the founders of the Caltech-MIT Voting Technology Project, of which he is a codirector. “I’m an expert, and very rarely do even *I* read through those in their entirety. And, when I do, I wind up confused.” Instead, he says, we need to take advantage of our 21st-century technologies—like apps for tablet computers and smart phones—to convey nonpartisan information in clear, digestible doses.

Still, even if we become as well informed as humanly possible, it doesn’t mean we should vote only with our heads and not with our hearts—or that we can. Political campaigns aim to stir your angers, fears, and hopes; a leader’s job isn’t just to govern, but to inspire.

“Politics is an inherently emotionally laden process,” Alvarez says. “Emotions are always going to factor into it.” If you feel good about a candidate, then you will be more confident that he or she will be able to overcome unexpected crises that will inevitably arise. “People use emotions to ease their uncertainty and alleviate their concerns about making a decision that has very important consequences for the future,” he adds.

You probably already know who you’re going to vote for in this presidential election; after all, the fraction of undecided voters in this kind of big race is relatively small, ranging from 10 to 20 percent of registered voters, Alvarez says. “Campaigns are really competing for a very thin segment of the electorate,” he notes. But, if you are among the undecided, know that voters like you can swing an election—and your decision may be crucial. Will you vote by evaluating the economy, or are there other issues that are important to you? Maybe your decision will be more emotional, based on whether you feel inspired by a candidate—or whether he looks threatening.

In the end, Snowberg says, to vote is to be part of something greater than yourself. “I’m really glad that people want to vote,” he says. “And I’m really glad that I get to vote. It makes me feel good about myself, and it makes me feel engaged in a very big and complex society.”

***Ralph Adolphs* is the Bren Professor of Psychology and Neuroscience and professor of biology, and is the director of the *Caltech Brain Imaging Center.* His research is supported by the Gordon and Betty Moore Foundation and the National Science Foundation.**

***Michael Alvarez* is a professor of political science. His research is funded by the James Irvine Foundation and the Carnegie Corporation of New York.**

***Rod Kiewiet* is a professor of political science and the dean of undergraduate students.**

***Erik Snowberg* is a professor of economics and political science.**

***Michael Spezio* is a visiting associate in psychology at Caltech and an assistant professor of psychology at Scripps College. His research is supported by the Caltech Brain Imaging Center, the National Science Foundation, and the John Templeton Foundation.**

I can see (mor cl

e) early now

By Kimm Fesenmaier

Sitting in his office on an average Pasadena afternoon, atmospheric chemist John Seinfeld can glimpse the San Gabriel Mountains, a commanding reminder of the geological cards the L.A. Basin has been dealt. When he arrived at Caltech in 1967, there would have been few days when he would have been able to take in such a view—at that time, a pall of brownish-gray smog would have often obscured the mountains.

"If you were here in the late 1960s, the smog was pretty thick, and this was a calling card for Los Angeles," Seinfeld says. "Had I gone to another university as a faculty member, I probably never would have gone into this field." In fact, having recently completed his doctorate in chemical engineering at Princeton University, the young Seinfeld had never dabbled in environmental studies.

But when he arrived on campus, Caltech was already home to several leading researchers in the air-quality field who had been shaking things up—fighting industry and, in some cases, policy makers for a decade or more. (See "The Award Goes To," page 29.) After talking with some of them, Seinfeld joined the effort—and he's never looked back. Today, he and Caltech scientists such as Richard Flagan, Paul Wennberg, and Mitchio Okumura are carrying the air-quality torch forward, providing insight into the atmosphere and the ways human activities affect it.

Indeed, it would be no exaggeration to say that the air we breathe today would be very different if not for the work that Caltech researchers have engaged in since the late 1940s. They have helped build the scientific foundation that has led policy makers to adopt everything from the first statewide air-quality standards and the original Clean Air Act, to that act's more recent revisions and to ever-stricter controls on factory and vehicle emissions.

A 30-BILLION-TON REACTOR

Before Caltech biochemist Arie Haagen-Smit started working on the air-pollution problem in 1948, no one even knew what smog was. Through a series of investigations, he showed that two of the products that come out of the incomplete combustion of gasoline in cars—volatile organic compounds and oxides of nitrogen—combine in the atmosphere in the presence of sunlight to produce ozone and other nasty by-products. He estimated that to make significant improvements to L.A.'s smog situation, nitrogen oxide emissions would need to be reduced by about 90 percent.

"It was a good starting point, but there is much more to the problem than he knew at the time," says Flagan, another chemical engineer whose research focuses on the control of air pollutants. "The basic chemistry gives you some clues as to what you need to do, but to know how far you need to go, you need to fill in the gaps in the science and then build models. Caltech's huge impact has been that of going beyond the science to the engineering of air quality—to actually understanding it well enough that you could start tweaking the system to start cleaning up the air."

It was this push toward a deeper understanding that led to Seinfeld becoming fascinated with the idea of the atmosphere as one big chemical reactor. It was also how he decided to start building a mathematical model of the air above Los Angeles—one that would incorporate emission levels and sources, as well as the details of the chemistry that was taking place, the atmospheric circulation patterns . . . the whole shebang. With his training as a chemical engineer, Seinfeld had plenty of experience describing what transpires in reactors. So he tapped into that experience to begin writing equations to describe the fundamental physics and the chemical reactions that take place in L.A.'s atmosphere.

It was Glen Cass (PhD '78), another young Caltech researcher at the time, who ended up doing the grunt work of determining everything that might contribute to emissions throughout Los Angeles—from oil refineries and factories to diesel trucks and automobiles. Chemical engineer Sheldon Friedlander worked out a way to verify those inventories—determining where smog was likely to be coming from based on existing data about atmospheric chemical composition.

Seinfeld combined all of their efforts and everything that was known of atmospheric chemistry into the first model of an urban atmosphere—the grandfather of the models that all states are required by the federal Clean Air Act to use today in planning for air-pollution control.

Even before the modeling work truly began, Seinfeld, Friedlander, and their colleagues knew they would need to bring more depth to the pool of existing knowledge about atmospheric chemistry. Take aerosols, for example. In the early 1970s, only basic size and composition information was known about these suspensions of minuscule particles in the air, which are largely responsible for the obscuring haze of smog. Today, researchers know that aerosols are harmful to human health, affect global climate by reflecting solar radiation, and are incredibly complex. "The particles everywhere on Earth are little microscopic chemistry laboratories," Seinfeld says. "They contain a kitchen sink of chemicals."

Aerosols fall into a couple of categories—those emitted directly into the atmosphere and those, called secondary aerosols, that form after emissions react chemically with oxidants like the hydroxyl radical and ozone in the atmosphere. Secondary organic aerosols, a subclass of secondary aerosols, form when oxidized organic gases glom onto particles. These carbon-containing compounds make up roughly half of all aerosols in the atmosphere, yet researchers are still trying to work out all of the molecular details and the life cycle of these particles.

From the beginning of their efforts, Seinfeld and his colleagues knew that in order to investigate aerosols, they needed to find new experimental methods to study what was actually happening to particles in the air. "You can't study the chemistry of the air when it is flowing by," he says. "You measure it at one point, and then it is gone."

Above: Caltech biochemist Arie Haagen-Smit, known as the father of air-pollution control, in the lab.

Below: John Seinfeld, Richard Flagan, and their colleagues inside the new atmospheric chamber in the Linde + Robinson Laboratory.

And so he began using an outdoor reactor created by Friedlander—an atmosphere in a bag, if you will. For about 15 years, Seinfeld, Flagan, and their students ran experiments on the roof of the Keck building to determine the chemistry of trapped particles. Pumping huge Teflon bags full of carefully selected gases, they exposed the bags to sunlight and studied the chemical changes that took place over time.

Later the outdoor experiments were enclosed, and the group spent a decade using that facility on the roof of the Keck building, jump-starting the chemistry with artificial sunlight. Today, these so-called chamber experiments have a shiny new home in the Linde + Robinson Laboratory, and multiple researchers use the technique to study atmospheric chemistry.

This approach may be commonplace now, but it was Seinfeld and his colleagues who were first to use these chamber experiments, which also allowed them to become the first to reveal the mechanism by which some volatile organic compounds—those that evaporate quickly and easily at regular temperatures—become less volatile and condense onto atmospheric particles. More recently, his team has been investigating organic compounds called alkanes, which are emitted in combustion processes. The team is trying to trace the various chemical pathways that these alkanes and their oxidized products follow so as to end up as aerosols.

WHERE DOES HE GET THOSE MARVELOUS TOYS?

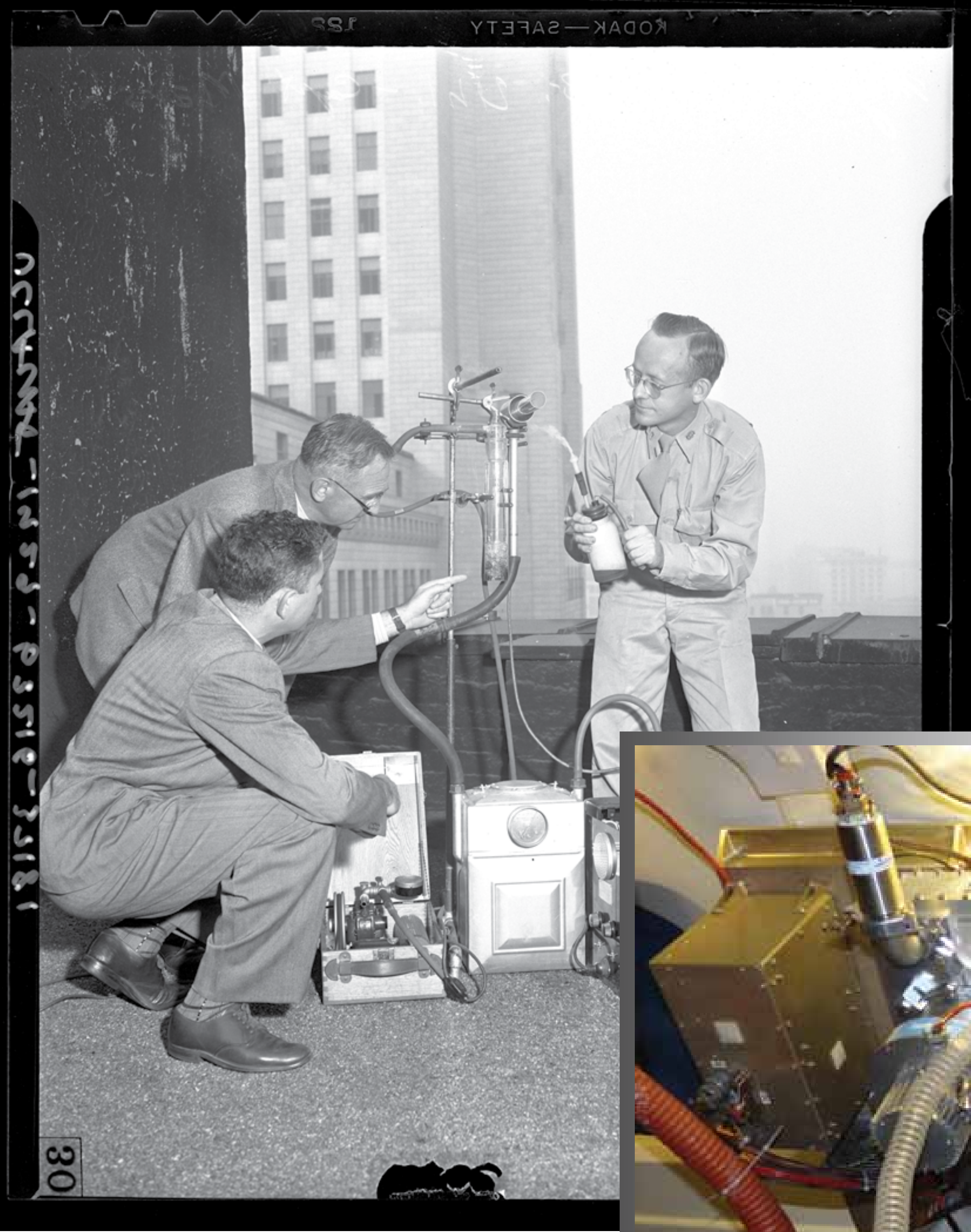
To track the molecular details of the reactions that take place in chambers or in the atmosphere, researchers need quality analytical tools. Making and improving such devices is the forte of Flagan and environmental scientist Paul Wennberg.

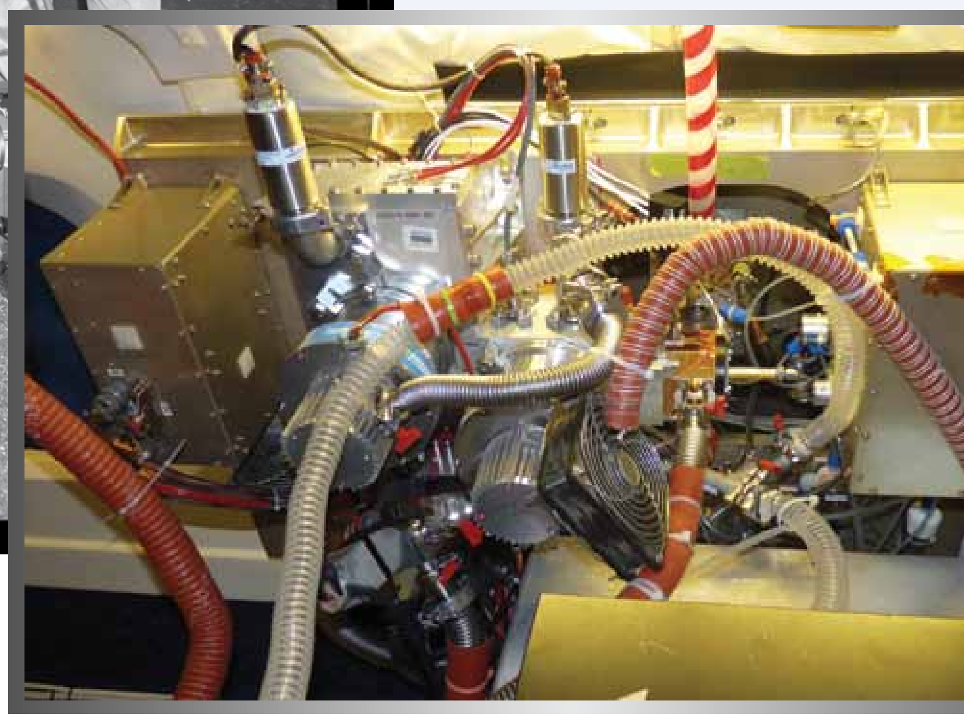
"Much of what I've done over the years has been focused on questions of getting data where we couldn't get it before," Flagan explains. He devised the first scanning mobility particle sizer (SMPS)—an instrument that measures minute aerosol particles in the air—while teaching an aerosol-measurements laboratory course at Caltech in the mid-1980s. "One day I gave my students a lecture on an instrument that didn't exist," he laughs. "I had them using it two weeks later." Today, the SMPS and its descendants are used by researchers around the world.

For their part, Paul Wennberg and his students have been building specialized mass spectrometers to analyze the chemistry of the atmosphere both in chamber experiments and out in the field. They are able to charge, or ionize, fragile gas molecules in the air, rather than needing high-energy electrons, which is the norm for mass spectrometry. "If we used the standard technique on these atmospheric gases, we'd end up with an uninterpretable mess," Wennberg says.

Wennberg and Seinfeld have used the mass spectrometers to study isoprene—the most abundant nonmethane hydrocarbon in the atmosphere, which is only emitted by plants. The chemistry of isoprene and related compounds is responsible for the haze and pollution of Atlanta and other cities in the Southeast. Using the new analytical methods developed in Wennberg's laboratory, the researchers discovered that the cascade of chemical changes triggered by the oxidation of isoprene in the atmosphere leads to the formation of epoxides. Chamber experiments revealed that these epoxides act as nature's glue, sticking to particles and producing secondary organic aerosols.

This summer, one of Wennberg's mass spectrometers was deployed on a National Science Foundation/NASA survey to look at air chemistry in the southeastern United States. His group has also deployed instruments in California's Sierra Nevada to study the air upwind of Sacramento. As Wennberg explains, this kind of fieldwork is one of three legs of atmospheric chemistry research: "First, you do a series of





controlled laboratory experiments. Then you plug your findings into a large model of the atmosphere and the chemistry within it. Finally, you go into the field to test if your description of the chemical environment is accurate."

Chemical physicist Mitchio Okumura uses ultrasensitive laser techniques in laboratory experiments that quantify key steps in the individual chemical reactions included in large models of the atmosphere. He and his colleagues also use quantum chemistry techniques to ensure that they understand the detailed molecular basis for each reaction. "That way," he says, "it's not just that we measure a number but that we know *why* it's that number."

In a study published in 2010, Okumura and his JPL collaborator Stan Sander (MS '75, PhD '80) were able to use these techniques to characterize the different pathways nitrogen dioxide and the highly reactive hydroxyl radical can take in the atmosphere. They examined a key reaction that produces nitric acid, a relatively stable molecule that essentially takes its reactants—i.e., the hydroxyl radical and nitrogen dioxide—out of play in the atmosphere. It's an important reaction in terms of reducing air-pollution levels because, left to their own devices, hydroxyl radicals and nitrogen dioxide are critical molecules in the reactions that create ozone.

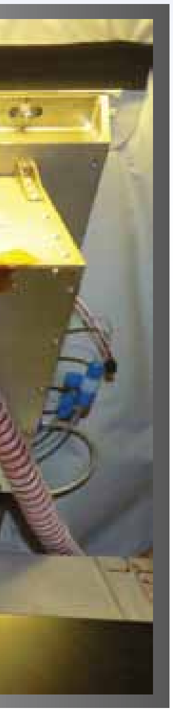
Okumura and Sander used an advanced chemical reactor at JPL to measure the rate of the reaction. At Caltech they used a relatively new analytical method, called cavity-ringdown spectroscopy, to observe the products as they were being formed. They could then measure how the amounts of nitric acid stack up against a less-stable product of the reaction of nitrogen dioxide and the hydroxyl radical, called HOONO (pronounced WHO-no). Rather than removing the reactants from the ozone cycle, HOONO dissociates and puts the reactants back *into* the atmosphere. The scientists determined how much HOONO was being produced but not accounted for by then-current models, suggesting that the models used to predict air quality could have been underestimating ozone levels by between 10 and 15 percent for the most polluted areas of Los Angeles on the most polluted days.

IT'S A SMALL WORLD, AFTER ALL

The combined product of these and many other efforts on campus has been the piecemeal creation of a much clearer picture of the atmospheric dynamics in the Los Angeles Basin.

That is not to suggest the air-quality problem is now solved. Take Los Angeles, for instance. It consistently earns top billing on the list of cities with the filthiest air. And the California Air Resources Board estimates that about 9,000 Californians die prematurely every year due to exposure to fine particles in the air.

But to be fair, Los Angeles is at a significant disadvantage. It has all of the necessary ingredients to whip up a particularly bad batch of air, what with its sunshine and its position in a basin that's shaped something like a bowl with an inversion layer for a lid, trapping smoggy air up against those commanding mountain ranges. Still, it's not all about geography: the iconic Angeleno obsession with cars and with shipping goods is also part of the recipe.



That said, Los Angeles is still a great example of how far we've come as a country in terms of air quality. Back in the 1940s, for instance, the air in Los Angeles was toxic, and air-quality standards were unheard of. Factory and refinery emissions were just starting to be regulated. People burned garbage in their backyards. No one knew that the exhaust spewing from tail pipes contributed to smog. What people *did* know was that the air made their eyes water, smelled slightly of bleach, ruined cherished views, damaged plants, and seemed to eat holes in rubber. Ah, the good old days.

By 1976, the first year for which detailed ozone air-quality data are available, the South Coast Air Quality Management District reported that ozone measurements exceeded health advisory levels on 166 days. There was obviously room for improvement: By 2010, there was not a single day when the ozone reached such levels.

Today, Caltech's air-quality researchers know they can't rest on their laurels; they also know they no longer have the luxury of focusing solely on the Los Angeles Basin.

"Back in the days of Haagen-Smit, one thought of air pollution as being confined to a city," Seinfeld says. "We've learned over the years that the atmosphere is in a sense one big backyard. Emissions from Asia are routinely sensed crossing the west coast of the U.S., and likewise emissions from the U.S. can be tracked in Europe. So we have had to broaden the focus of our research accordingly."

The global focus is especially important when looking at the link between air particles and global climate. After all, water droplets condense on particles in the air to form clouds. In fact, if our atmosphere were devoid of particles, Earth would have no clouds. And since clouds reflect about 20 percent of incoming solar radiation, both the planet and its climate would be drastically different without them.

Scientists still don't understand precisely how particles and clouds—those diaphanous, ever-changing players in the water cycle—interact with one another, nor how that intricate dance influences climate. What will happen to Earth's clouds, for instance, if more particles enter the atmosphere as a result of human activity?

One hypothesis holds that a higher number of particles will yield smaller cloud droplets, and that those smaller droplets will produce clouds that are more opaque and reflect more sunlight than clouds made of larger droplets.

Seinfeld and Flagan have seen this cloud-brightening effect from their flying laboratory, a Navy-owned plane now managed by the National Science Foundation. In a series of experiments, they collected samples of low-lying clouds—some visibly being fed exhaust from the smokestacks of large container ships and some not. Using a collection

Above: A 1945 demonstration of an electrostatic precipitator—a device once known as a "smog catcher."

Below: A chemical ionization mass spectrometer developed by Paul Wennberg's group. This instrument measures atmospheric acids and peroxides.

THE AWARD GOES TO . . .

It was inventor and long-time Caltech trustee Arnold Beckman (PhD '28) who originally pulled Arie Haagen-Smit—the biochemist known today as the father of air-pollution control—into the study of smog. Beckman, then chairman of the L.A. Chamber of Commerce's scientific committee, reached out to Haagen-Smit because of his skill in microchemical analysis, the study of minute concentrations of chemicals—a skill he developed working in plant physiology.

Beckman later said he felt guilty about pulling Haagen-Smit away from his research to work on the smog issue—but it was Haagen-Smit who couldn't walk away from the problem. As he said then, "The fly has trapped the fly paper." Once he figured out the chemical recipe for smog and determined that the mighty automobile was a major contributor to L.A.'s ever-dirtier air, he became embroiled in a battle with the oil and car industries, which tried to discredit his work. The plan backfired; he became more motivated to produce new and better scientific evidence, which eventually convinced first the state and then the federal government to establish air-quality standards and set controls for motor-vehicle emissions.

For his work, Haagen-Smit was honored in 1974 with the first Tyler Prize for Environmental Achievement, an honor regarded as the highest distinction in environmental science, environmental health, and energy research. In 1995, Caltech geochemist Clair Patterson won the Tyler Prize for his work in investigating mineral isotope concentrations and his recognition that lead from man-made sources had been contaminating Earth's air, land, and water since the Industrial Revolution. That work, and his many testimonies to policy makers, led the United States to ban leaded gasoline in 1986, despite the vociferous objection of industry proponents.

This year, John Seinfeld became the third Caltech faculty member to receive the Tyler Prize. "When I began doing research on the atmosphere, I read Haagen-Smit's early papers and got to know him," Seinfeld says. "I never would have imagined at that time that the work I would do would someday lead to my recognition with the same prize that both Haagen-Smit and Patterson received for their work." E&S

of onboard analytical instruments, they measured everything from aerosol size and composition to the size, concentration, and chemistry of each cloud's droplets. Their results showed that the exhaust-filled clouds are usually brighter than the others, but not always—a testament to the maddening complexity of cloud physics.

Such studies are needed to inform global climate models, where the magnitude of global cooling from aerosols remains a focal point. To understand why it's so important, consider that the concentration of aerosols in the atmosphere has increased two or three times since the Industrial Revolution but has leveled off in recent decades. Since no one knows how large a cooling effect to attribute to aerosols, it's hard to say how global climate will respond in the future if they remain at roughly the same levels while greenhouse-gas emissions rise.

"We've come from something that was a regional issue and fairly exclusively a chemical problem—smog in L.A.—to one that is global and involves other disciplines like fluid dynamics, microphysics, and biology," explains environmental scientist Tapio Schneider, who directs the Ronald and Maxine Linde Center for Global Environmental Science. "As a result, we have to be much broader in our studies than in the past. We all have to work together to ultimately reduce uncertainties about climate and how it works."

Caltech is well equipped to do such interdisciplinary work, he says, noting that these problems are naturally appealing to researchers—not just because the science is fascinating and complex, but because it addresses important issues we can all relate to on some level.

"How can we improve the air we breathe? How much does cloud cover increase or decrease as Earth's climate warms? These are important problems that matter for society," he says. "And with the analytical instrumentation, computational tools, and satellite data that are now available, we, unlike past generations, have a good chance of solving them."

Schneider has good reason to feel that way. After all, for six decades now,

Caltech air-quality researchers have provided information used by policy makers to pass laws and update standards. "The focus of the research in air quality here at Caltech is on providing *the* best scientific basis for policy making," says Paul Wennberg. "It's focused on actually understanding the processes that are influencing atmospheric composition and then trying to better diagnose what the future might be if various decisions are made."

And the future, he says, is becoming clearer. E&S

John Seinfeld is the Louis E. Nohl Professor and professor of chemical engineering. His work is funded by the National Science Foundation (NSF), the Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA).

Richard Flagan is the Irma and Ross McCollum–William H. Corcoran Professor of Chemical Engineering and professor of environmental science and engineering, as well as the executive officer for chemical engineering. His work is funded by the NSF, the DOE, the EPA, the ONR, NOAA, the Davidow Discovery Fund, and the Wallis Foundation.

Paul Wennberg is the R. Stanton Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering. He receives funding from the NSF, NASA, the Camille and Henry Dreyfus Foundation, and the Davidow Discovery Fund.

Mitchio Okumura is a professor of chemical physics. His work is funded by the NSF, NASA, and the Camille and Henry Dreyfus Foundation.

Tapio Schneider is the Frank J. Gilloon Professor of Environmental Science and Engineering and director of the Ronald and Maxine Linde Center for Global Environmental Science.

INNOVATION IN ORBIT

Harold A. Rosen
MS '48, PhD '51 Electrical Engineering

At any given time, tens of dozens of satellites, seemingly motionless in the sky, hover 22,236 miles over Earth's equator. In this position, known as geostationary orbit, the satellites move in sync with the planet itself, allowing them to serve as communications relays. Geostationary satellites are thus the workhorses of the communications industry—and they owe their existence to Caltech alumnus Harold Rosen.

Rosen, who was born in 1926 and graduated from high school at the tender age of 15, showed an early fascination with science and engineering and, as a teen, was an amateur radio operator. Near the close of World War II, the 18-year-old Rosen—by then a senior at Tulane University studying electrical engineering—joined the Navy as an electronics technician. He completed his undergraduate studies when the war ended and in 1947 began graduate research at Caltech under rocket telemetering pioneer Bill Pickering (BS '32, MS '33, PhD '36).

During his graduate years, Rosen took a part-time job at Raytheon Company, where he was tasked with improving antiaircraft guided missiles and radar; he continued full-time at the company after receiving his doctorate in 1951. His Caltech education, he notes, "gave me such a good grounding in the fundamentals" that he felt capable of attacking any technical problem in almost any field.

In 1956, Rosen was hired by Hughes Aircraft Company. After the Soviet Union's launch of the Sputnik satellite in 1957, he became eager to get involved in a space project, and within two years he had a goal in mind: creating the world's first geostationary satellite.

It was a lofty ambition. Although the advantages of the geostationary orbit for continuous communications were already well known (and indeed were proposed by writer Arthur C. Clarke back in 1945), developing a satellite that was both reliable and light enough to reach the required altitude—and that could be carried by the small launch vehicles then available—was a huge challenge.

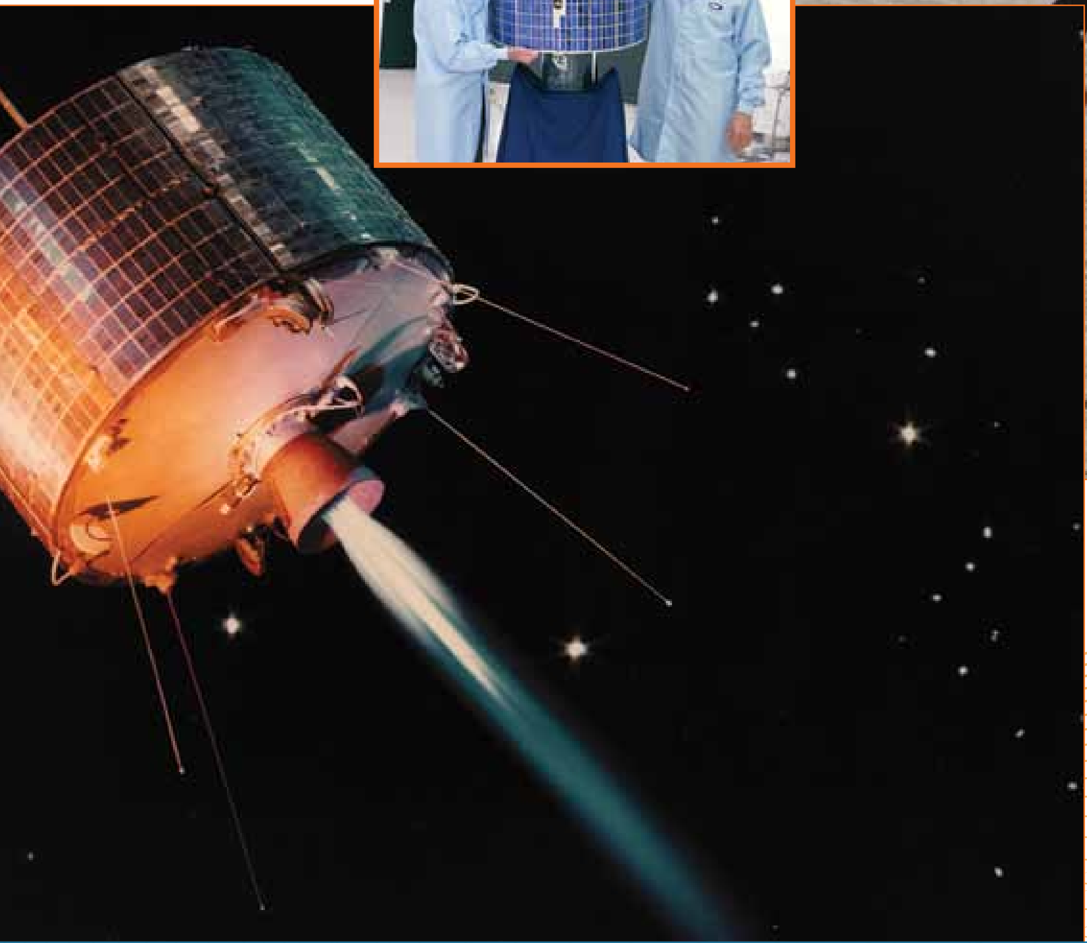
Rosen called on his Caltech education—specifically, a physics class on the dynamics of spinning bodies taught by Nobel laureate Carl Anderson (BS '27, PhD '30)—to come up with a viable design. His idea was to combine a very lightweight communications system with spin-phased impulses that simplified orbit control. Aided by a small team of brilliant engineers he selected, Rosen created a paper design that convinced an initially reluctant management team at Hughes to invest in the development of a prototype. With that prototype in hand, he enlisted Caltech alumnus John Rubel (BS '42) at the U.S. Department of Defense, who was able to convince NASA to fund the Syncom ("synchronous communication satellite") program.

In February 1963, Syncom 1 was launched; it failed soon after its apogee motor kicked in. For Syncom 2, Rosen and his team made several fixes—including swapping out that motor for a Jet Propulsion Laboratory–designed rocket. The new motor worked; in July 1963, the Syncom 2 orbit insertion was successful, and the satellite soon became operational. That August, President John F. Kennedy used Syncom 2 to telephone the Nigerian prime minister via a terminal that was on a ship in Lagos harbor. This first live, two-way call via satellite between heads of government ushered in a new era of satellite-based communications.

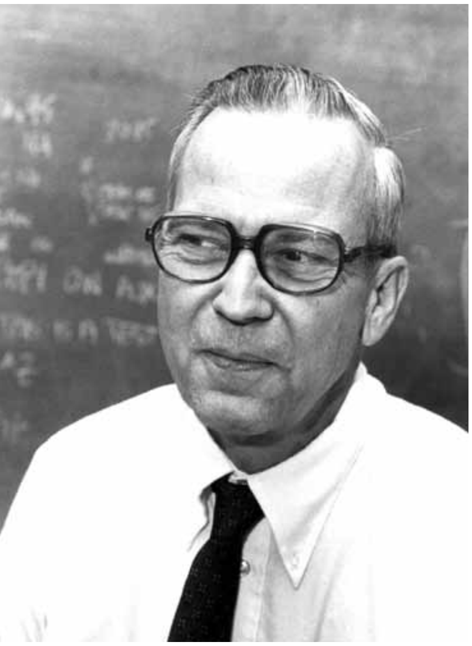
Rosen continued to lead the satellite development program at Hughes and eventually served as a vice president and a member of the company's policy board. Under his technical guidance, Hughes became the largest communications-satellite business in the world. After Rosen's retirement in 1993, he and his brother, Benjamin M. Rosen (BS '54), formed Rosen Motors. The company invented a prototype hybrid-electric power train for automobiles. The power train's flywheel energy-storage system and low-emission gas turbine are now used in stationary power systems. Rosen—who lives in Santa Monica with his wife, Deborah Castleman (MS '86), and would like to eventually secure the record for the fastest 100-meter dash for a centenarian—holds more than 80 patents and has won numerous awards, including the National Academy of Engineering's Draper Prize (1995), the National Medal of Technology (1985), the Communications and Computing Prize from NEC (1985), the Alexander Graham Bell Medal (1982), and the Ericsson International Prize in Communications (1976).

In 2003, he was inducted into the National Inventors Hall of Fame. He is a fellow of the Institute of Electrical and Electronics Engineers and the American Institute of Aeronautics and Astronautics, and a member of the National Academy of Engineering. In 1976, he received Caltech's Distinguished Alumni Award.

Middle: Rosen (right) stands with the late Tom Hudspeth (BS '41), a key member of the team that developed Syncom.



HARDY C. MARTEL
1927–2012



Hardy C. Martel, professor of electrical engineering, emeritus, at Caltech, passed away on March 29 in Pasadena. He was 85.

Entering the field at the dawn of the computer age, Martel was an expert on information theory and electric-circuit theory. "He was one of the first at Caltech to do research on information science and communications technology," says Roy Gould, the Simon Ramo Professor of Engineering, Emeritus, and a lifelong friend and colleague of Martel's. "His strength was in his basic, intuitive grasp of ideas and how things worked."

Martel's intuition went beyond engineering and technology, Gould says, as he was equally adept at working with people—a skill that served him well for the many administrative posts he held at Caltech.

Born in 1927 at Huntington Hospital in Pasadena to Romeo Raoul Martel and Mildred Parkhurst Pray, Martel spent nearly his whole life in the area—most of it at Caltech. His father was a professor of structural engineering at Caltech and an expert on designing structures to withstand earthquakes.

After earning his BS at Caltech in 1949, Hardy Martel went to the Massachusetts Institute of Technology and received an MS in 1950. He then returned to Pasadena for a brief stop at the Jet Propulsion Laboratory, where he helped design the electronics for the guidance systems behind the army's Corporal short-range missile. He returned to Caltech in 1953 as an instructor, becoming an assistant professor in 1955; at the same time, he worked toward a PhD, which he received in 1956. He became an associate professor in 1958, and except for a year working at Bell Labs from 1959 to 1960, he remained at Caltech in the Division of Engineering and Applied Science for the rest of his career; he became a full professor in 1982.

> "He was one of the first at Caltech to do research on information science and communications technology. His strength was in his basic, intuitive grasp of ideas and how things worked."

In addition to being a valued mentor to his students, Martel served in a variety of administrative roles. From 1969 to 1983, he was the executive assistant to the president. He served as secretary of the faculty for many years, as well as secretary to the Board of Trustees (from 1973 to 1983) and executive officer for electrical engineering (from 1981 to 1986). He became a professor emeritus in 1990.

In 1986, Martel started a walnut grove in Paso Robles, California. But his heart was always with the Institute. "He loved Caltech," says daughter Wendy Martel-Vilkin. "It was his life." E&S

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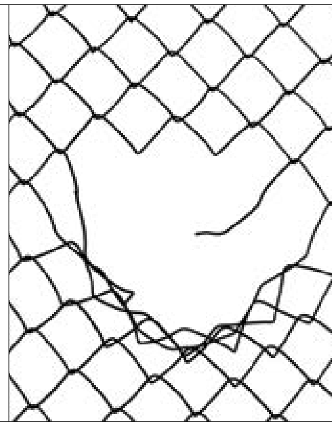

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