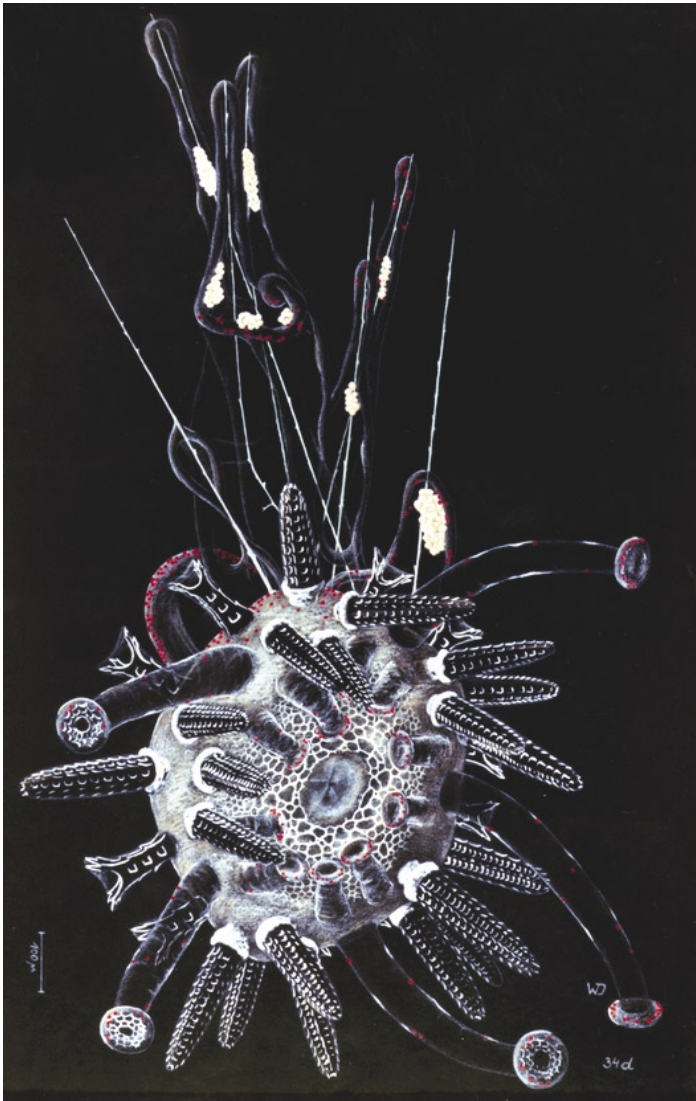


BUILDING A SEA URCHIN, ONE CELL AT A TIME



This nightmarish creature that one might attribute to Hieronymus Bosch is actually a metamorphosing sea-urchin larva about two millimeters in size. The embryonic skeleton of thin rods in the larva's arms remain, while adult skeletal elements—spines, plates, and tube foot disks—have already appeared.

“Cats beget cats and frogs beget frogs, so how you develop depends on what genome you’ve inherited,” says Eric Davidson, the Chandler Professor of Cell Biology at Caltech. Now, for the first time ever, Davidson’s lab has mapped in its entirety the complex network of genes responsible for creating a specific cell—a skeletal cell, in this case, not in a cat or a frog but in a sea urchin.

Genes, of course, are the assembly instructions for creating an organism, and in 2006, the Baylor College of Medicine Human Genome Sequencing Center, along with Caltech’s Davidson and Senior Research Associate in Biology Andy Cameron, plus researchers from more than 70 other institutions, published the entire 814-million-letter instruction book for the California purple sea urchin (*Strongylocentrotus purpuratus*). This genome, as it’s called, is about one-fourth the size of the human genome and contains some 23,300 genes.

That was the easy part. The challenge now is to tease out the relationships between these genes—how they turn one another on and off at specific times in the embryo’s development to create the panoply of adult cell types.

Davidson’s team focused on a cell line that takes in minerals from seawater to build skeletal rods. The gene regu-

latory network that drives this process can be thought of as a blueprint, but unlike a regular blueprint, which describes how static pieces of a structure fit together, the gene regulatory network is a dynamically changing plan, with the relationships between genes at one stage providing the basis for the next stage. The work, coauthored by postdoc Qiang Tu and Paola Oliveri, now of University College London, appeared in the April 22 issue of the *Proceedings of the National Academy of Sciences*.

Says Davidson, “We’ve reached the point where everything you see in a microscope for this cell lineage can be interpreted in terms of what we know about this control program. The network concerns only one day in the life cycle of an animal that lives for 50 or a hundred years, and only one cell lineage of the embryo, but it is a step forward to be able to relate the biology to the regulatory DNA sequence in this way.”

In a second paper in the same issue, Davidson and postdoc Feng Gao report that this regulatory network evolved from another skeletal-cell-forming network present in adult urchins. Sea urchins are the only echinoderms—which also include starfish, brittle stars, sea cucumbers, sand dollars, and other creatures—to have an embryonic skeleton made

LEAN, GREEN CALTECH

from this cell lineage as well as an adult one. By analyzing the gene regulatory network, Gao and Davidson were able to show that the embryonic skeleton arose because a substantial portion of the adult skeleton's regulatory apparatus had been hijacked. This happened when the control systems for several genes at the top of the adult hierarchy got mutated in such a way as to come under the embryonic cell lineage's control, at which point the entire downstream adult network became active in the embryonic lineage. The fossil record shows that this change happened some 250 million years ago. "Gene regulatory network redeployment is one way of introducing novelties into an animal's body plan during evolution," says Gao.

Davidson's lab is pressing on to decipher the other gene regulatory networks, hoping to eventually crack the code for the whole embryo. "The evolution of animals is due to changes in the structure of these gene regulatory networks, so this work provides us with an opportunity to study evolution in a new and decisive way," he says.

□—KS/DS

By the time your carpool arrives at Caltech, you've read two papers in the *AICHE Journal*, downed a cup of coffee, and discussed the subtleties of the Lakers game. When the car pulls into its prime, designated space, you head for the office by way of the Red Door Café. Because you brought your Caltech mug, your rich, organic coffee costs only 81 cents. You blow the savings on a muffin, though, slipping the unbleached napkin it came with into a solar trash compactor on your way out. Your hands are still full as you step into your office, but the renewable-energy-fueled lights sense your presence and switch on, brightening the daylight that streams in through thermally efficient windows.

Sound like a rosy portrait of a more sustainable future? Actually, this kind of morning is already possible, even common, at Caltech. With help from private benefactors and partnerships, the Institute is working hard to slash pollution and waste, minimize future costs, and help environmental technologies gain a foothold.

Caltech has firm ground to build on. Its recycling program, nearly 50 years old, diverted 1,248 tons of waste from landfills in 2006; it was named the city of Pasadena's Recycler of the Year in 2007. Caltech produces almost 80 percent of its own electricity

—a natural-gas-fired turbine puts out 10 megawatts, and the turbine's waste heat makes steam that spins another two megawatts out of a second turbine and also heats labs and offices. A 2003 upgrade of this cogeneration system doubled its power output while lowering the emission of smog-forming nitrogen oxides and carbon monoxide by 17.4 percent.

Even so, college campuses—especially research-oriented ones—use a lot of electricity, water, and other resources. Caltech, as a research leader in clean energy and climate change, has a particular obligation to walk the walk, and members of an ad hoc sustainability committee established in 2007 by Vice President for Business and Finance Dean Currie are examining every aspect of campus life. As committee member Carol Carmichael—a faculty associate in engineering and applied science, and wife of President Jean-Lou Chameau—commented in the *California Tech*, "We want to ensure that the resources entrusted to us are used for teaching and discovery, and not for maintaining expensive, potentially unsustainable practices or forms of infrastructure."

Think committees don't do much? Members of this one have changed Caltech's purchasing, cleaning, and landscaping practices; established Summer Undergraduate Re-

search Fellowships (SURFs) to study Caltech's environmental impacts; created incentives to carpool, bike, walk, and take public transit to Caltech; and helped catalyze "green" building and the ongoing installation of Pasadena's largest solar-power facility.

It's hard to miss the changes. Biodegradable paper- and corn-based cups, cutlery, and to-go containers have replaced petroleum-based standbys at campus eateries, which now mete out unbleached napkins in single-napkin dispensers. Solar-powered trash compactors have appeared on the Olive Walk and on the Chandler patio. Not much larger than trash cans, each holds 150 gallons—even if the trash truck makes 80 percent fewer visits, they still won't be filled to overflowing. Motion-detecting lighting, compact-fluorescent bulbs, dual-flush toilets, waterless urinals, and Energy Star appliances save electricity and water across campus, thanks to Associate Vice President for Facilities Jim Cowell, the committee chair, and Senior Director of Institute Housing Tim Chang, also a member. Further, the housing office has enrolled all off-campus units for which it pays the bills in the Pasadena Water and Power (PWP) residential "All Green" program, 100 percent of whose electricity comes from wind farms. Director of Buildings and Grounds Delmy Emer-



George Hines (BS '08) checks out the "Big Belly" solar-powered trash compactor outside the Red Door Café.

son, also on the committee, has instituted green cleaning practices on campus, supplying the custodial staff with economical, concentrated, nontoxic cleansers. Emerson's groundskeeping staff is on the same page, reducing water use by landscaping with drought-tolerant plants and refining drip-irrigation systems. As *E&S* was going to press, John Onderdonk began work as the Institute's first sustainability program manager to lead and coordinate these efforts.

This summer, four SURF students will research Caltech conservation, supported in part by benefactors such as Kiyo Tomiyasu (BS '40) and his wife, Eiko. Mentored by sustainability committee member and mechanical engineering professor Melany Hunt, Stassy Petkova will quantify Caltech's greenhouse-gas emissions from 1990 to the present, Daniel Alvarez and Silas Hilliard will study Caltech's energy use and evaluate conservation opportunities, and Tyler Hannasch will focus on ways to reduce electricity consumption in the undergraduate Houses.

What's *not* happening is vital, too. Hundreds of cars stay out of L.A. traffic and campus parking spaces because of programs directed by sustainability committee member Kristina Valenzuela, Caltech's transportation coordinator. The latest statistics show that Caltech has 141 registered

carpools, two vanpools, 276 holders of discounted public-transit passes, 193 registered walkers, and 400 participants in bike-to-work programs. Participants enjoy incentives including monthly raffles, rainy-day parking permits, and guaranteed rides home in case of illness or emergency.

But the two biggest changes on campus are the least noticeable. The first—stringent environmentally friendly building standards—might just look like good design. The second—a massive new solar facility—will be above eye level on Caltech roofs.

All new construction and renovations will adhere to the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) guidelines. The three buildings under way—the Annenberg Center for Information Science and Technology, Schlinger Laboratory for Chemistry and Chemical Engineering, and Cahill Center for Astronomy and Astrophysics—will earn gold-level LEED certification. Each building will use 30 percent less water than comparable buildings. The Cahill and Annenberg Centers will use 24–28 percent less energy, while the Schlinger Lab will conserve 17–21 percent. But don't expect to see pallid scientists in gray laboratories—daylight will illuminate 75 percent of rooms in the Cahill and Annenberg Centers and

90 percent of the Schlinger Lab. The buildings won't have those dizzying new-paint, new-carpet, and new-plywood smells either: each project uses low-emission materials, keeping volatile organic compounds such as formaldehyde out of circulation. According to a state government task force, the average California green-construction premium of \$4 per square foot yields a \$67 return over 20 years, maximizing the long-term impact of the gifts provided by Warren (BS '44, MS '46, PhD '49) and Katie Schlinger, the Annenberg Foundation, Charles and Anikó Dér Cahill, Fred (BS '62) and Joyce Hameetman, Stephen Bechtel Jr., and others.

Caltech is also investing in solar energy, leasing the rooftops of three parking garages and four buildings to solar-power companies in order to generate 1.2 megawatts of electricity. The solar plants will offset 7 percent of Caltech's peak power use, and it's the dirtiest and most expensive power—part of the 20-odd percent currently purchased from PWP, half of which comes from burning coal. (It doesn't hurt that PWP raised its rates 20 percent in the first half of 2008.) The first solar plant, under construction atop Holliston Parking Garage, will be the largest in Pasadena. When all seven solar rooftops are up and running, according to

Cowell, "we'll have one of the largest university solar facilities in the country."

Private companies will design, install, finance, and maintain the new power plants, selling all of the power back to Caltech at rates that start at just over 10 cents per kilowatt-hour and that will rise less than 4 percent per year for 15 years. Cowell expects PWP rates, which now top 14 cents per kilowatt-hour, to continue to rise by 5 to 10 percent per year. Cowell's also pleased about the relatively short contracts. "For 15 years, they give us lower, more stable rates and greenhouse-gas reductions," says Cowell, "and then, if we want them to, they take it all away. My feeling is that we're going to invent better panels in 15 years and want to put up our own technology. Or maybe we'll want to do something else. The world is going to be a different place, and I don't have a crystal ball."

It hardly takes a crystal ball to see a future in which people call for campuses to use less power and water and generate less pollution and trash. The simple, low-cost steps Caltech is taking now will set the stage for greater innovation. As Bill Irwin, senior director of facilities management, puts it: "We take a lot of pride in what we have accomplished to date, but we are even more excited about what the future holds." □—AW

JPL GETS A SECOND LIFE

I'm perched on the edge of Mars's Victoria crater, squinting to make out the sediment stratification in the walls across the way. Actually, it's my avatar—my virtual persona—dodging a Martian dust devil as I amble through the alternate reality created by Caltech's Jet Propulsion Laboratory (JPL) in the online world called Second Life. Since JPL's mission is to explore worlds outside the one we know, it's only fitting that it should be breaking ground here. Second Life is an Internet portal to . . . anywhere. In this virtual world, users pick a character to walk or fly

through spaces designed by other users. JPL's piece of real estate is called Explorer Island. Like the ceiling of the Great Hall at Hogwarts, Explorer Island's sky mirrors JPL's real-time weather; the deer that wander JPL's grounds in real life graze in front of the simulated visitor center. Except on Explorer Island, they can fly.

At the entrance to Explorer Island, you're greeted with a pop-up memo listing upcoming NASA events. These workshops, exhibitions, and launches from the real world are open to audience participation on the island. In the "virtual world auditorium,"

you can even participate in NASA meetings through your avatar. Of course, says Charles White, senior member of JPL's technical staff and creator of Explorer Island, "social norms of real life apply." You can contribute your input to the meetings, but scientists reserve the right to mute or even eject anyone who misbehaves.

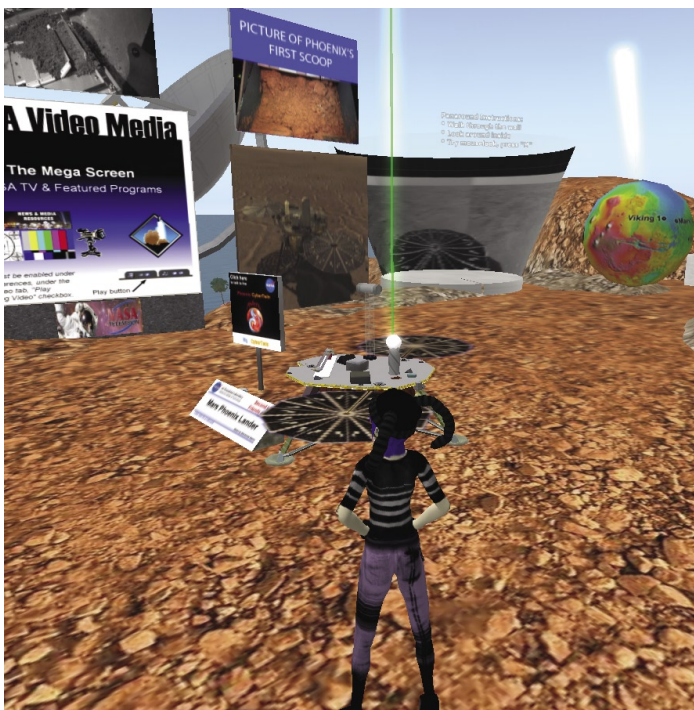
Every Tuesday at 1:00 p.m. in the adjacent NASA neighborhood, called CoLab—the Collaborative Space Exploration Laboratory—NASA researchers mingle with the public. These meetings were originally designed to gather scientists from different parts of the world into the same virtual meeting room, but now any visitor is invited to sit in. The discussions can range from designing spacecraft to creating software for the virtual world or anything in between, as long as the members avoid topics that fall under the ITAR—International Traffic in Arms Regulations—umbrella.

At JPL's site in Second Life, you can walk around displays from Victoria crater or the Phoenix landing site, or sit in on a real NASA organizational meeting. Just watch out for those dust devils!

But the coolest thing for most people is exploring places that JPL missions have visited. The magic of JPL's presence in what White calls a "persistent synthetic environment" is the use of real data. (White, aka "Jet Burns" on Second Life, welcomes each new visitor with a pop-up card full of information. For example, those dust devils ". . . can be three times larger than a full tornado on Earth. In Second Life, you and two other friends can ride them around Mars Mountain.")

White likes to tell of an avatar who said he cried for 10 minutes when he realized he was standing at the edge of Victoria crater. This is the story that brought me to the crater, which is no artist's interpretation, but the real deal—or as real as you can get without actually going to Mars. It's built from photos taken by the rover Opportunity, which crawled into it last September to explore the layered sedimentary rocks that are thought to have been deposited long ago, when water flowed. You can also trudge over rugged red terrain to various exhibits, but watch out for those dust devils and the giant airbag that sweep by every so often. If you're quick, you can catch a ride on the airbag, whose route will change once you hop aboard.

As you descend from the Mars mock-up, you climb a ramp carpeted in the latest



views of Titan's methane lakes. From there you can ascend the scaffolding of Explorer Island's launching pad, highlighted with glowing red spotlights. The Mars Phoenix lander was carried aloft by a Delta II rocket on August 4, 2007, in the first simulcast launch on Second Life, says White. Around 40 avatars attended, filling the program's capacity. The Dawn spacecraft, which will visit the asteroid Vesta and the former-asteroid-now-dwarf-planet Ceres, followed on September 27. The pad now has room for 100 avatars, and it filled to capacity on January 31, when Explorer I lifted off on the 50th anniversary of the real-life event. An audio tape of the 1958 launch accompanied the rocket's ascent, giving visitors the realest taste they're likely to get of America's entry into the Space Age.

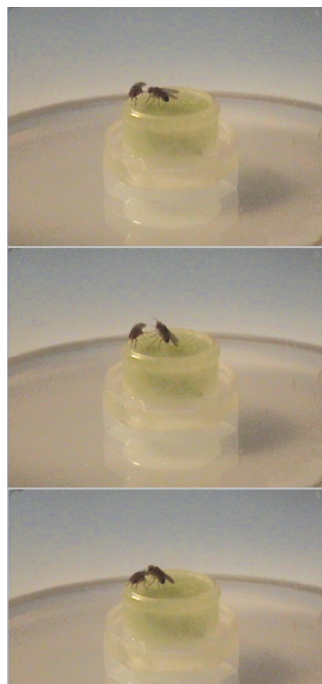
Visitors can still follow bright yellow signs to the Phoenix landing, which was celebrated on May 25 in Second Life as it was in real life. In the large display area, you can investigate a mockup of the lander to your heart's content, check out real images of Phoenix on the surface of Mars and its first scoop of Martian soil, and even pick up a free Phoenix T-shirt for your avatar.

For the time being, Explorer Island is still in the research

phase. White anticipates that interactions like the ones facilitated in this virtual world—where anyone can talk to a NASA scientist and scientists can meet “outside the lab”—are as inevitable as e-mail. “Virtual worlds will just get better and better and more powerful. We need to explore this,” he says. “The world is virtual, but the communication and the experiences are real. People talk about it as if they were there.”

Caltech Professor of Astronomy George Djorgovski agrees. He was recently featured at Second Life's SciArt Media Learning Center, where he regaled an audience of around 50 avatars during “A Special Online Event: The Richard Feynman 90th Birthday Party / Astronomy and Physics Virtual Conference,” otherwise known as “Dick's Digital Nonagentennial Commemorative Colloquium.” After his lecture, Djorgovski received an e-mail from one of the attendees, who wrote, “You've had a big influence on my son. We listened to your talk together, and the day after, he insisted that I buy him a physics book (he's seven). Since then he's been asking me quiz questions on black body radiation, entropy, force, and quarks!” Says Djorgovski, “I'd say it was worth it, if I got a seven-year-old interested in physics!” □—EN

FRATERNIZING FLIES HAVE FEWER FIGHTS

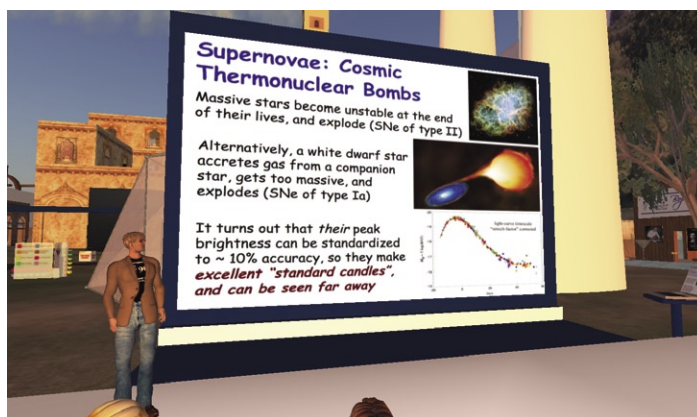


Above: A pair of sumo-wrestling fruit flies. The lunge, in which one fly rears up on its hind legs and charges the other, is the insect's most common fighting move.

If you have cable TV, chances are during bouts of channel surfing you've experienced snippets of something known as the Ultimate Fighting Championship. Literally a no-holds barred contest, two opponents enter the ring—the Octagon, to the initiated—and anything goes until one achieves “submission” over the other. What began as an ethically murky real-life Thunderdome has spawned legions of fans, best-selling books, reality shows, and devoted bloggers.

It would seem the draw of the Octagon has even reached as far as the lab where Caltech scientists led by David Anderson, the Sperry Professor of Biology and a Howard Hughes Medical Institute investigator, use a miniature version (the Octette?) to study aggression in fruit flies. Their recent paper in the *Proceedings of the National Academy of Sciences* suggests that two distinct inputs—genetic and environmental—converge at a particular gene to shape the decision to fight. The work was done by grad student Liming Wang, the first author of the paper, with Anderson in collaboration with postdoc Heiko Dankert and Professor of Electrical Engineering Pietro Perona.

In the study, male fruit flies were housed either in isola-



Left: “Curious George” Djorgovski gives a cosmology lecture at a Second Life bash honoring the late Richard Feynman.

tion or in groups of 10. After three days, pairs of flies from each group were placed in a plexiglass arena. The flies raised in isolation fought roughly half of the time, while the socialized flies essentially never fought. The isolated flies, Anderson says, would begin frantically running around and chasing each other when paired up. In stark contrast, the group-housed flies “just sat placidly eating, like cows grazing in a meadow . . . as if they couldn’t care less about their neighbors.”

The scientists repeated the experiment, this time after moving half of the initially isolated flies to a group setting for another three days while keeping the other half in isolation. The still-solitary flies were even more likely to fight, engaging their rivals 80 percent of the time, while their once-aggressive counterparts now rarely fought. This showed that a fly’s level of aggression was both reversible and situational. In other words, the likelihood that a fly would fight depended on its most recent social experience, regardless of its prior circumstances.

Anderson’s group then analyzed the genetic profiles of both sets of flies and identified genes that behaved differently in the isolated and the social-

ized flies. Comparing this list to one of genes that had been shown by Herman Dierick and Ralph Greenspan of the Neurosciences Institute in San Diego to be associated with aggressiveness, Anderson’s group found one gene on both lists—the unimaginatively named *Cyp6a20*.

This overlap was surprising, given the different methods used by the two labs to generate aggressive flies. The San Diego group bred flies for aggressiveness over dozens of two-week generations, resulting in a stable, hyperaggressive fly lineage. Anderson’s lab focused on social experience, a stimulus measured in days. “We have a common genetic target that acts on different time scales,” Anderson says.

A balance of inherited and environmental inputs makes sense from an evolutionary standpoint. Genes promoting aggression would have obvious benefits in territorial defense and reproductive success; but a mechanism for tempering this innate aggressiveness, for providing situation-specific control of the decision to engage a rival, would also convey an advantage. Sometimes you want to be a lover, not a fighter—the guy who brawls at the slightest drink-sloshing gets bounced from the bar before he can collect very many

phone numbers.

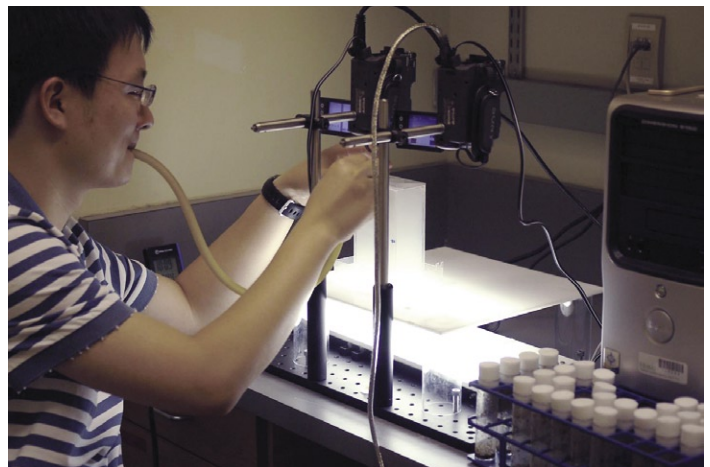
Cyp6a20’s precise function in regulating aggressiveness remains a mystery, but Anderson has an intriguing hypothesis. While measuring levels of *Cyp6a20* in flies, the researchers found it preferentially in the antennae, the fly’s organ of smell, suggesting it might act in pheromone sensing. *Cyp6a20* belongs to a large family of genes that also includes one responsible for converting testosterone to estrogen in vertebrates. The balance between these two hormones has been shown to

influence fighting behavior in birds, fish, and mice, and it’s possible that an analogous system is at work in flies.

If pheromones do help control fly aggressiveness, then Anderson believes “the important question is ‘What changes in the brain of the flies that so alters their behavior?’” Socialized flies could be curbing their responses to an aggression-promoting signal, or they could be responding to an aggression-suppressing cue. These two pathways might produce very different patterns of gene activity in

Wang uses a fly aspirator—a piece of tubing with a plastic tip—to transfer the flies from their vials into the arena, the eerily glowing container.

Simply point the tip at a fly, inhale gently (a plug prevents you from swallowing the fly), move the tip to where the fly should be, and puff!



individual nerve cells.

So in the end, what do the exploits of a few fruit-fly gladiators mean to the rest of us? The fact that genetics and environment intersect at the seat of a complex behavior like aggressiveness, and that this can occur on the scale of a single gene, gives us a new understanding of just how exquisitely regulated our responses can be. As is so often the case when science delves into the “how” of something, we see that the initial question was overly simple. It’s not nature versus nurture, but how much nature versus how much nurture or, perhaps, when nature versus when nurture. Unmasking the constantly shifting balance of power between the two is far more riveting than anything the Octagon can offer on pay-per-view. □—SG



The light fixture in Robinson’s vestibule is an armillary sphere—an ancient astronomical tool—decorated with the signs of the zodiac. Note the compact fluorescent bulb.

FROM THE BIRTH OF GALAXIES TO THE FATE OF THE PLANET

“The bandwagon of saving the planet from environmental pollution and from suffocation is well occupied now. Indeed, everyone is on it. Being on it is rather like being against sin, and, as in the case of sin, the universal practice is to point the finger at other people. . . .” Al Gore, 2007? Nope. It’s Caltech president Harold Brown in a March 1970 article in these very pages that also pointed out the potential of greenhouse gases to cause substantial climate change. Brown closed thus: “Unless Caltech can contribute something unique, we do not want to add another element to the near infinity of activities that have been generated by the universal enthusiasm about the protection of the environment. What we are thinking about is . . . an Environmental Laboratory. A reasonable size to aim for would be 25 to 30 professionals, plus part-time activity by interested Caltech faculty and students.”

Caltech’s environmental scientists must be pinching themselves—this 40-year dream is slated to come true in August 2010. Trustee Ronald Linde (MS ’62, PhD ’64) and his wife, Maxine, have established an \$18 million endowment to create the Ronald and Maxine Linde Center for Global Environmental Science, which will focus on natural and human-caused variations in Earth’s climate and be housed in the

former Robinson Laboratory of Astrophysics. When its current residents move to the new Cahill Center for Astronomy and Astrophysics in 2009, Robinson’s heavy, wooden doors will close for some 18 months as the building transforms into the Linde + Robinson Laboratory for Global Environmental Science.

Already renowned for deciphering the mystery of smog in the ’50s, Caltech established one of the nation’s first environmental-health engineering programs in 1960. The first professor was Jack McKee, who had joined the faculty as a sanitary engineer in 1949. He was followed by civil engineers Norman Brooks (PhD ’54) and Fredric Raichlen, biologist-turned-environmental-scientist Wheeler North (BS ’44, MS ’50), and chemical engineer Sheldon Friedlander, a pioneer in aerosol studies.

In 1969, the Institute added an option in environmental engineering science that granted master’s and doctoral degrees. Next came the Environmental Quality Laboratory, organized in 1971, which was not a lab per se, but a “think tank” that produced several major policy studies on California’s environmental problems. Its facilities were split between a house (since demolished) and a few offices in Dabney Hall of the Humanities. Twenty years later, Bank of America

made possible the Environmental Analysis Center, an open-access, user-operated instrumental facility that that will relocate to the Linde + Robinson Laboratory.

So, how many engineers does it take to solve an environmental problem? Trick question. Even small problems slip into several disciplines, and big problems like climate change necessitate the kind of collaboration that Caltech is famous for. The Environmental Science and Engineering Program now includes biologists, chemists, earth scientists, engineers, and physicists.

These people are scattered through seven buildings—imagine what they’ll be able to achieve when they’re finally working in one. For example, John Seinfeld, who studies the physics of air pollution and explores atmospheric modeling, works halfway across campus from Tapio Schneider, who also researches global circulation of the atmosphere. Chemical physicist Mitchio Okumura studies stratospheric chemistry up Wilson Avenue from planetary scientist Yuk Yung, recognized for his work in stratospheric ozone depletion.

MacArthur Fellow Paul Wennberg, the Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering, will direct the Linde Center. “Caltech is really good at providing the essential ingredients—great



More zodiacal signs can be seen in the library's light fixtures and on Heinsbergen's stenciled ceiling.

facilities, great students, and great professional staff. That's what attracts the best and brightest scientists, people who can pose the big questions and solve big problems."

Wennberg hopes to round out the team with at least four more professorships: a glaciologist, who would study climate-change-related ice melt and its effects on sea level; a physical oceanographer, who would investigate temperature change in the abyssal ocean (thermal expansion of the Pacific could make Palm Springs a future Newport Beach); a biogeochemical carbon specialist to analyze how biology controls carbon; and a researcher to look into how clouds and moisture change when the climate changes. Data from JPL, a world leader in space-based observation of Earth, will complement the program's field- and laboratory-based research.

Bob Walp (BS '51, MS '53), a lead donor to the new Associates Graduate Fellowship in Global Environmental Science, agrees Caltech has a vital role to play. "There's such chaos and ignorance in this area. That's terrible when such incredible stakes are involved. Caltech's wonderful interdisciplinary environment gives it an advantage. I don't think it needs immense task groups and large amounts of money to make progress. It really just takes a few imaginative people. Caltech has been active in environmental

matters at least since I first got here right after World War II, when the smog really hit Los Angeles. Arie Haagen-Smit, the organic chemist, made a big splash discovering the constituents of smog and developing technology to reduce it. That's just one person—and the air's cleaner."

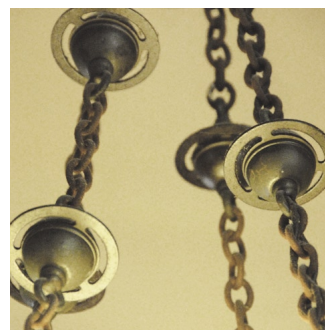
The Linde + Robinson Laboratory will set precedents in the sustainable renovation of research facilities in historic buildings. The elegant entrance, cozy library, and grand staircase will regain their splendor, showcasing elaborate metal- and woodwork, Spanish-influenced bookcases, and a beamed, stenciled ceiling attributed to noted muralist Anthony Heinsbergen, whose other commissions include the Los Angeles City Hall and the Hollywood Roosevelt and Beverly-Wilshire Hotels. Fresh air and sunlight will find their way to the depths of the sub-sub-basement, thanks to the repurposing of a solar-telescope shaft that punches through all five floors of the building, and basement dwellers will enjoy "garden-level" outside views as well. The project will emphasize recycled, nontoxic materials and win a gold—if not platinum—certification from the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Green Building Rating System, and energy-efficient technology will curb the climate

center's own potential climate impact.

The Linde Center will draw talented young scholars, and Caltech will need to support them. To this end, Foster and Coco Stanback have endowed a postdoctoral fellowship, a graduate fellowship, and a "discovery fund." The Caltech Associates have established the Associates Graduate Fellowship in Global Environmental Science to pay one first-year graduate student's tuition and stipend annually.

Graduates of the new program will seed the field with scientist-engineers used to multi-dimensional thinking. As Provost Ed Stolper notes, "Few programs have taken this step of bridging environmental science and conventional environmental engineering—yet it is an approach we believe will be critical to training future leaders."

□—AW



And ringed Saturns grace the lamp chains in the hallways.

It's a good thing that Lucy Jones didn't want to scare us, as she kept assuring the capacity crowd for the press conference in Caltech's Beckman Auditorium on June 4—if she did, the audience would probably have been reduced to blubbering imbecility. Jones, a Caltech visiting associate in geophysics and the chief scientist of the United States Geological Survey's Multi-Hazards Project, was describing the scenario created for what will be the largest earthquake drill ever held in the United States.

"ShakeOut," as it's called, will cut loose at 10:00 a.m. sharp on Thursday, November 13, and features a magnitude-7.8 quake on the San Andreas fault that begins under the shores of the Salton Sea at Bombay Beach, and in 90 terrifying seconds ruptures 180 miles of fault to well west of Lancaster. The ground will move sideways 44 feet in places, and the sedimentary layers of the L.A. basin will quiver like angry Jell-O for 55 seconds—an eternity compared to the magnitude-6.7 Northridge quake's seven seconds. It will take up to three minutes for all of the shaking to die out in some places.

The freeways that cross the fault will be reduced to rubble, and our other lifelines—railways, power lines, and aqueducts—will fare no better. "We'll have 13 million victims," Jones said, "and we'll need help from the Bay Area and Arizona at a time when I-10 and I-15 have been cut."

"This is nearly as big as the event that just hit China," said the USGS's Ken Hudnut, a Caltech visiting associate in geophysics, who, like many others involved in ShakeOut,

wears a red silicone wristband for the Chinese earthquake victims. Hudnut and Brad Aagaard (MS '95, PhD '00) created a highly detailed specification of the earthquake source. Hudnut then oversaw the quake's computer modeling, in which the San Andreas fault was divided up into some 18,000 "sub-faults," each about 500 meters square, along which the slip was forced to propagate, mimicking the rupture of the real thing. (Hudnut also plans to model some of the scenario's larger aftershocks, one of which is a 7.2 on the Sierra Madre fault, aimed right at Pasadena.) Robert Graves (MS '88, PhD '91) of URS Corporation turned this data set into a detailed simulation on the University of Southern California's high-performance computer cluster, calculating the shaking experienced across the Southland at points spaced on a two-kilometer grid. The ShakeOut simulation project was coordinated by the Southern California Earthquake Center (SCEC), and several other SCEC institutions participated.

The ShakeOut scenario, all 308 pages, was constructed by over 300 experts from the USGS, Caltech, SCEC, UCLA, and elsewhere who used Graves's results to create a plausible picture of likely damage to buildings, roads, pipelines, and the like, which in turn were used to project casualties and economic losses. For example, Swaminathan Krishnan (PhD '03), assistant professor of civil engineering and geophysics, and postdoc Matthew Muto modeled the response of multiple 20-story steel-frame buildings at each grid point, paying special attention to the dozen or so locations that have clusters of tall buildings.

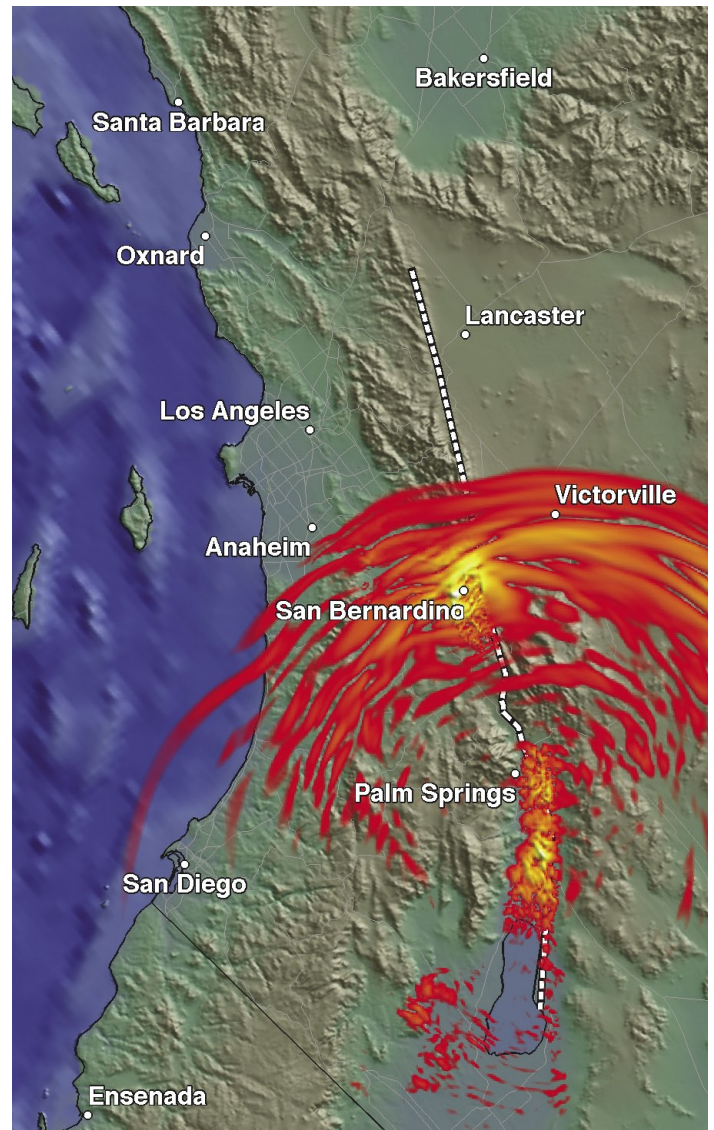
"It's not the worst case, but it's a real good estimate of what we can expect," said Federal Emergency manage-

ment Agency geophysicist Michael Mahoney. Since our building codes are stricter than China's, only five 11- to 20-story steel-frame buildings collapse completely, and just one percent (45,000) of the region's lesser structures are total losses, with one in 25 wood-framed houses and apartment buildings suffering significant damage. With no Santa Ana winds to fan the 1,600 blazes that are started by car crashes, downed power lines, and the like, a mere 133,000 single-family houses are destroyed. "Find an open space of refuge—a park, or a school, perhaps—in your neighborhood," said Michael Freeman, chief of the Los Angeles County Fire Department. "Where would you go if several city blocks are burning?"

The point to all this, of course, is for local, state, and federal agencies to plan their responses. "How do you deal with an event that will literally break the system?" said SCEC director Thomas Jordan (BS '69, MS '70, PhD '73). Thousands of cops, firefighters, and paramedics will be deployed in the statewide "Golden Guardian" exercise, and logistics will be a big focus. "You'll have to think about how you'll feed your first responders three days later," as Jones pointed out—no easy task, even though the ports and the airfields are largely intact, when all the roads are impassable. Getting electricity, water, and other basic services restored will take days to weeks, and some of the hardest-hit areas will be doing without for months. And then there'll be the 1,800 dead and 50,000 injured to deal with. . . .

But this isn't just for the pros—millions of ordinary Californians, in their schools, businesses, places of worship, or just at home, will take part in the drill, not only by "Dropping, Cover-

ing, and Holding On, as the slogan goes, but by creating or updating their own disaster plans. (See <http://www.shakeout.org/>.) There's no time like the present to get prepared—as Jones says, "A large earthquake is definitely in our future." □—DS



Simulation by Robert Graves. Rendering by Geoff Ely, UCSD/San Diego Supercomputer Center.

Ground motions in the ShakeOut scenario 60 seconds after the rupture begins. Yellow regions are experiencing sideways motions of one meter per second or more.

PHOENIX HAS LANDED

On May 25, the Phoenix spacecraft landed safely in the northern polar region of Mars. The lander is now exploring the possibility that liquid water once existed on the red planet.

In 2002, the Mars Odyssey orbiter revealed evidence of water ice hidden beneath the surface of northern Mars. Phoenix's mission, then, is to dig below that surface and analyze soil and ice samples to study the planet's water history. Although Phoenix isn't designed to look for signs of life, it will analyze evidence about whether the icy soil has ever been a hospitable environment for life. Liquid water, which might have existed as late as 100,000 years ago, could have given rise to microbial life; and some bacterial spores, which could remain in a dormant state for millions of years, might be lurking in the soil.

Three weeks into the mission, scientists said they'd hit pay dirt—or rather, ice. Digging into a trench 5 centimeters deep and 30 centimeters wide, Phoenix uncovered chunks of white stuff on June 15. At the time, researchers thought it could be either ice or some sort of salt. But when the white chunks disappeared four days later, the scientists knew they had to be ice. Only ice, which sublimates from solid to gaseous form, could have vanished so abruptly. In an adjacent trench, Phoenix's robotic scoop hit a hard layer at the same depth as those ice chunks, suggesting the presence of more water ice.

Led by the University of Arizona in partnership with JPL and Lockheed Martin, who built the craft, Phoenix rose from the technological ashes of previous missions. The craft uses instruments adapted from the Mars Polar Lander, which crashed in 1999, and the Mars Surveyor lander, whose mission was cancelled just a year before its scheduled launch in 2001. Phoenix was the first spacecraft since the Viking missions in the 1970s to successfully employ rockets to land, as opposed to using the airbag system designed for Mars Pathfinder and used by Spirit and Opportunity. □—MW



Phoenix's parachute slows its descent. This image, taken by the Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment (HiRISE) camera, was the first of a spacecraft landing on Mars.

The HiRISE camera took this snapshot of the landing site after touchdown. The lander, with its solar panels open, appears as a bluish dot at the top. The black smudge on the right is the heat shield and its impact mark, and the lower part of the image shows the parachute, attached to the bottom of the capsule shell.



Below: Called Dodo-Goldilocks, this trench shows chunks of white stuff, which scientists say is ice. Although ice on the Martian surface is not a new discovery (the polar ice caps have water ice, for instance), to see pieces up close—a major part of Phoenix's mission—is cause for excitement.



The spacecraft's solar panels and robotic arm are seen in this image of Mars's western horizon, which Phoenix took shortly after landing.

