California Institute of Technology

E&S ENGINEERING AND SCIENCE

Volume LX, Number 2, 1997

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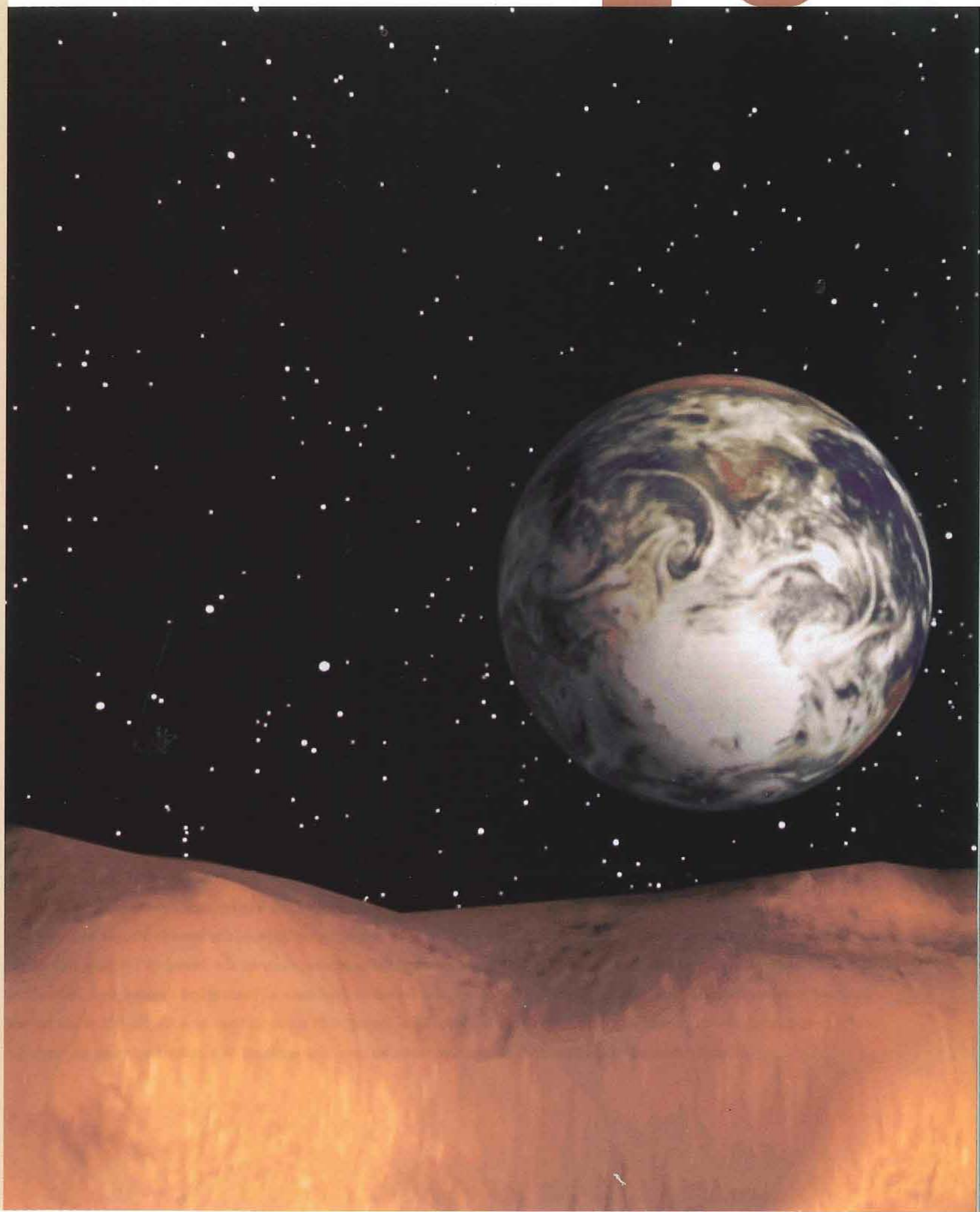

Caltech President-Elect David Baltimore greets members of the faculty (Associate Professor of Chemical Engineering Julia Kornfield, right, and Norman Brooks, the Irvine Professor of Environmental and Civil Engineering, Emeritus, left) after the announcement of his appointment on May 13. Behind them are, from left, Peter Dervan, the Bren Professor of Chemistry and chair of the Division of Chemistry and Chemical Engineering; Gordon Moore, chair of the Board of Trustees and of the trustees' presidential selection committee; and Kip Thorne, the Feynman Professor of Theoretical Physics and chair of the faculty presidential search committee. Baltimore and his wife, Alice Huang, will move to Pasadena in the fall, when he will officially take office. Baltimore's impressive research career is outlined in a story beginning on page 32.

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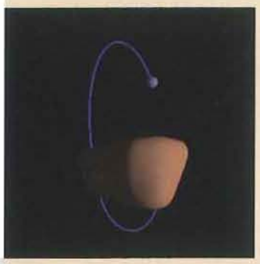

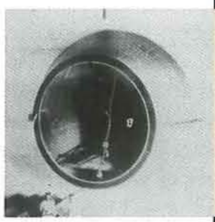

On the cover: In 2004, an asteroid named Toutatis will whiz by Earth at a distance of four lunar orbits. If you were vacationing on Toutatis then, this is what you'd see. Earthbound radar astronomers are taking close looks at a number of Earth-approaching asteroids, as you'll see on page 12.

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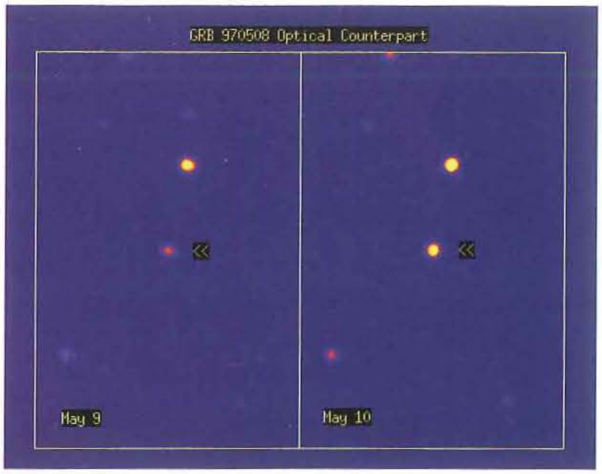


Images of the gamma-ray burst field obtained at the 200-inch Hale Telescope at Palomar Observatory on May 9 (left) and 10 (right) show the visible-light brightness of the optical counterpart (arrow) still rising. The gamma-ray burst was first detected May 8.

Gamma-Ray Bursts Demystified

"When I finished analyzing the spectrum and saw features, I knew we had finally caught it. It was a stunning moment of revelation."

In May a team of Caltech astronomers solved one of astronomy's most intriguing mysteries, pinpointing for a gamma-ray burst an optical counterpart several billion light-years away from the Milky Way. The results demonstrate for the first time that at least some of the enigmatic gamma-ray bursts that have puzzled astronomers for decades occur at very great distances and not, as some have thought, inside our own galaxy.

The bursts of high-energy radiation were first discovered by military satellites almost 30 years ago, but so far their origin has remained a mystery. New information came in recent years from NASA's Compton Gamma-Ray Observatory satellite, which has so far detected several thousand bursts (see *E&S*, Winter 1992). Nonetheless, the fundamental question of where the bursts came from remained unanswered.

Competing theories on gamma-ray bursts have generally fallen into two categories: one that suggests that the bursts to originate from some as-yet unknown population of objects within our own Milky Way galaxy; and another that proposes that the bursts originate in distant galaxies, several billion light-years away. If the latter is true (as was indirectly supported by the Compton Observatory's earlier observations), then the bursts are among the most violent and brilliant events in the universe.

Gamma-ray bursts occur a couple of times a day, says Shri Kulkarni, professor of astronomy and planetary science and one of the team members. These brilliant flashes seem to appear from random directions in space and typically last a few seconds. "After hunting clues to these bursts for so many years, we now know that the bursts are in fact incredibly energetic events," said Kulkarni.

Progress in understanding the nature of the bursts was stymied by the fact that until recently the bursts were detected as very high-energy gamma rays. It is difficult to focus gamma rays, and thus the positional accuracy of the bursts was quite crude, leaving astronomers with thousands of faint stars and galaxies as potential "hosts." An important recent development was the deployment of BeppoSAX, a joint Italian/Dutch satellite launched in late 1996 by the Italian space agency. This satellite, for the first time, provided a rapid and accurate position in the sky for strong gamma-ray bursts. This enabled astronomers to search for possible visible and radio counterparts, using telescopes on the ground. The first such counterpart was detected at the beginning of May, but faded away before its nature could be established.

The satellite detected another burst on May 8, and Caltech astronomers were able to bring telescopes at Palomar Observatory to bear within a few hours. The Caltech team noticed a star-like object that was changing brightness in an unusual fashion at the position of the burst. (Dr. Howard Bond of the Space Telescope Science Institute initially reported the object based on his measurements at Kitt Peak National Observatory.)

The crucial piece to the puzzle was finally found by the Caltech team on May 11 using one of the two W. M.

Keck 10-meter telescopes, the world's largest, on Mauna Kea, Hawaii. The starlike object showed features known to originate in intergalactic clouds in its spectrum. By measuring the wavelengths of these features, the Caltech astronomers were able to measure the distance to a gamma-ray burst for the first time. Their measurements place the burst at a distance of several billion light-years, over one-half the size of the observable universe.

Mark Metzger, assistant professor of astronomy, said he was thrilled by the result. "When I finished analyzing the spectrum and saw features, I knew we had finally caught it. It was a stunning moment of revelation. Such events happen only a few times in the life of a scientist."

Recent observations from the telescopes at Palomar show that this starlike object is fading away. Because such rapid fading had been seen with the burst in March, the Caltech astronomers had to make an extra effort to identify this counterpart quickly so that the Keck observations could be carried out when the object was bright.

The discovery is a major step toward helping scientists understand the nature of the burst's origin. We now know that for a few seconds the burst was more than a million times brighter than an entire galaxy. No other phenomena are known that produce this much energy in such a short time. Thus, while the observations have settled the question of whether the bursts come from cosmological distances, their physical mechanism remains shrouded in mystery.

In addition to Kulkarni and Metzger, the Caltech team consists of Associate Professor of Astronomy George Djorgovski; Assistant Professor of Astronomy Charles Steidel (PhD '90); postdoctoral scholars Steven Odewahn and Debra Shepherd; and graduate students Kurt Adelberger, Roy Gal, and Michael Pahre. The team also includes Dale Frail of the National Radio Astronomy Observatory in Socorro, New Mexico.

"Gamma-ray bursts are one of the great mysteries of science," said Djorgovski. "It is wonderful to contribute to its unraveling." □

626

Longtime residents complain that the San Gabriel Valley doesn't have an identity of its own. Not any more—on June 14, 1997, the area code for the San Gabriel Valley, and with it Caltech, changed to 626. The old 818 area code will still work through February 21, 1998, however. And the telephone company in its infinite wisdom has decided that Burbank, Glendale, and La Cañada Flintridge belong to the San Fernando Valley, which retains the 818 area code. Thus the Jet Propulsion Laboratory's area code remains 818, because although JPL's mailing address is in Pasadena, the vast majority of the facility lies in La Cañada Flintridge.

In other telecommunications news, Caltech's Office of Public Events has changed its toll-free number from (800) 423-8849 to (888) 2-CALTECH.

Fly By

When Ari Hoffman, a sophomore at Tamalpais High School in Mill Valley, California, entered his *Drosophila* project in the Marin County science fair, he never dreamed he would run afoul of animal rights. Hoffman, whose study involved the effects of radiation on the fruit flies' reproduction patterns (number of offspring and percentage of mutations), won first prize in the science fair, only to see it withdrawn because of alleged "cruelty to animals." About 35 of his 200 flies had died before reaching the end of their normal 10-day life span.

Hoffman's prize was eventually reinstated, but not before a story in the *San Francisco Examiner* attracted the notice of Nobel laureate Ed Lewis (PhD '42), Caltech's Thomas Hunt Morgan Professor of Biology, Emeritus. Lewis, probably the most noted living fly geneticist, whose work on fruit flies won him the 1995 Nobel Prize, sent Hoffman a check "as a token award for your accomplishments." Lewis had also begun working with *Drosophila* when he was in high school back in 1934, the beginning of a long and fruitful career studying genetics with this tiny organism. That was before the days of science fairs, Lewis noted in his letter to the student.

Ed Lewis shows Ari Hoffman the view from his lab.

Lewis also invited Hoffman to visit Caltech when he and his father came to Southern California for yet another science fair. On May 20 the two stopped by for lunch at the Athenaeum and a look through Lewis's microscopes at *Drosophila* chromosomes. "Cool," Hoffman said. Lewis also gave him a few samples of his famous mutant, four-winged fly, the creature that had enabled Lewis to show how genes control the body's arrangement. The flies were dead, of course, but had served science well. □—*JD*

Sonoluminescence, Camera, Action!

It wasn't nominated for an Oscar (and no one is saying it should have been), but last fall's movie Chain Reaction *had hidden links to Caltech. Former Lloyd House president Ken Suslick (BS '74), now the William H. & Janet Lycan Professor of Chemistry at the University of Illinois at Urbana-Champaign, became a big noise in the study of ultrasound—ultra-high-frequency sound waves—in the early 1980s (see* E&S, *Spring 1994). Here he recounts how his research led Hollywood to come calling in central Illinois. (This article is reprinted courtesy of* Inside Illinois, *the faculty/staff newspaper of the University of Illinois at Urbana-Champaign.)*

Minor technical errors—such as violations of the laws of thermodynamics—are obviously no problem for Hollywood.

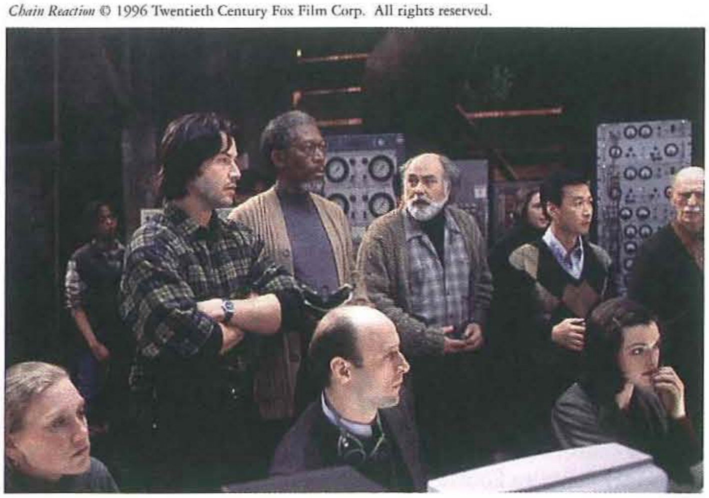
Some of you may have seen a movie last fall called *Chain Reaction*. If so, you have my condolences. Nonetheless, it isn't too often that a chemist finds himself involved with Hollywood, much less gets money for his school off a bad movie.

One pleasant fall day in 1994, I found on my chair—the only safe place to leave a slip of paper in my office—a phone message from someone claiming to be a Hollywood director. "Yeah, right!" I remember thinking as I dialed the number. It turned out that the caller, Gene Serdena, was the set director of a Twentieth Century Fox movie tentatively titled *Dead Drop*, then in preproduction.

The movie was to be about a Nobel-laureate professor and his graduate student, who discover the use of sonoluminescence—the incandescent glow generated when liquids are irradiated with ultrasound—to catalytically produce unlimited quantities of hydrogen (the ultimate clean fuel) from water. (Minor technical errors—such as violations of the laws of thermodynamics—are obviously no problem for Hollywood.) The professor is killed when the bad guys try to steal the discovery, and the intrepid graduate student runs through chase scene after chase scene to expose the evildoers. This is no surprise, since the director is Andrew (*The Fugitive*) Davis. Serdena told me that the grad student would be played by Keanu Reeves, the love interest by Nicole Kidman, and the prof probably by Alan Arkin (or maybe—I kid you not—Marlon Brando). By the time the movie actually got made, Kidman had been traded for a starlet and Brando had been downsized to Morgan Freeman.

Gene called me because of my work on sonoluminescence and other chemical effects of high-intensity ultrasound. He wanted to visit our labs to see what a chemistry lab actually looks like. So Gene and his assistant drove in from Chicago for a visit. With video and still cameras, they shot everything that didn't move. It was fun showing him around and trying to explain why things were set up the way they were. They even gave disposable cameras to my graduate students and myself to see how we live. Cinema verité, at least for the set design!

A week later, Gene called again. Now he wanted to rent equipment from the lab for the set. I explained to him that we do actually use this stuff and that it's very expensive equipment. He sounded disappointed, and then it hit me—he doesn't want equipment that works, only that looks like it works. And I knew about this cavernous storage area in the basement of Roger Adams Lab that was full of old equipment—ancient Infracord spectrophotometers, several dozen old black-and-white monitors, prewar lathes (not sure which war), and so on—all stuff too good to throw away at the time it was hauled down there, but of no use now. I suggested that maybe they'd like to see the "scientific equipment" in our storage area. His assistant returned to Champaign and, with flashlights in hand, we went spelunking into the depths of RAL. She photographed everything (again)



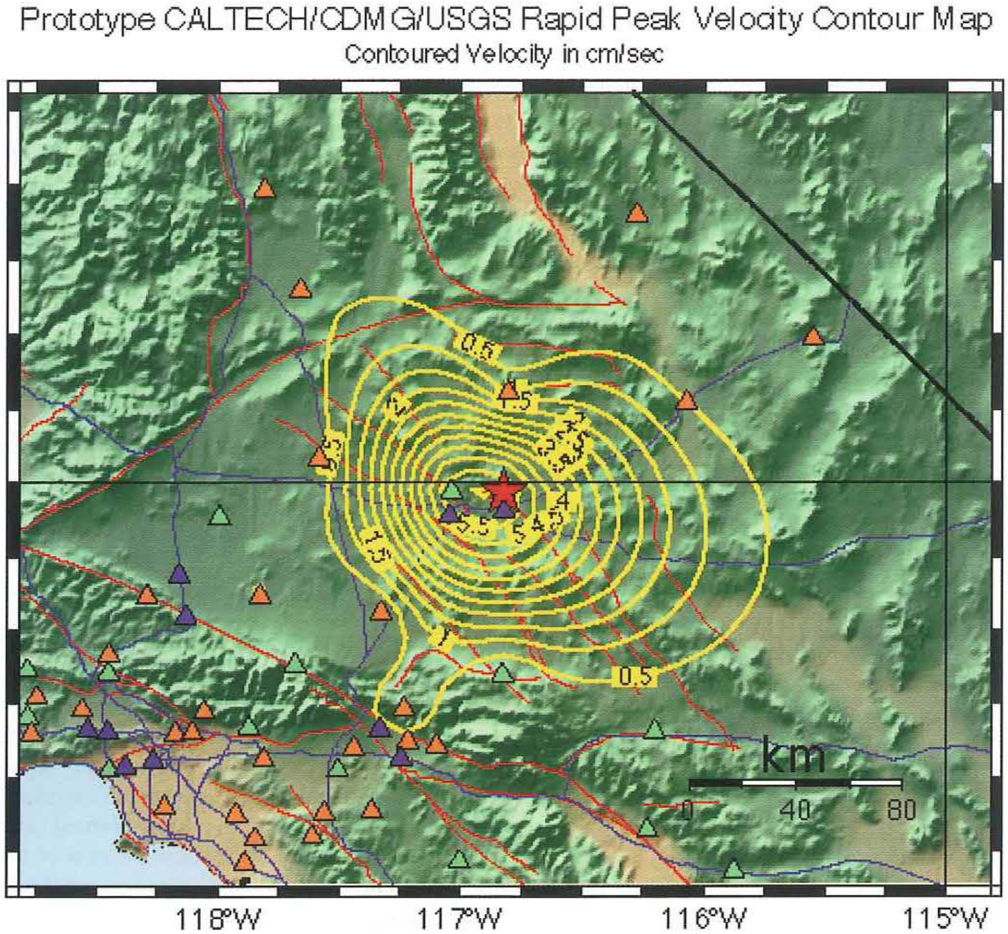
It's a nail-biting moment for Keanu Reeves (left), Morgan Freeman (to his right), and other "scientists" on a set that probably came from the collection of pre-owned lab equipment in Suslick's basement storage. ("Who uses dials anymore?" says Suslick. "Not even the Russians.")

and went away.

When Gene called next, about 48 hours later, I could practically hear him salivating over the phone. This room full of useless equipment turned out to be just the sort of place a set director dreams about (apparently set directors have very weird dreams). But how do we sell this detritus of dead equipment to them? We found that the university cannot sell equipment—no matter how useless—without rampant rivers of red tape. We could, however, declare old stuff surplus once it was of no further use, and simply take it off the books. Whether the junk then went into a dumpster or into a truck made no difference.

So, with help from our business-office manager, I arranged for a donation of $10,000 from Twentieth Century Fox to the school. I didn't even ask a finder's fee. Fox then sent down a crew of four humongous guys and a moving van to match, and they spent a full day hauling away junk that we'd been wondering how to get rid of for years!

Two years later the movie came out, now called *Chain Reaction*. On opening day, we shut down our lab, and I took the whole crew out to the first matinee. I bought the tickets, but my students had to get their own popcorn. Afterward, we agreed that the best part of the film was the labs, which were only slightly hokey. In fact, that was just about the only good thing in the entire movie. Even Siskel and Ebert gave it thumbs down. Fortunately, the UI's School of Chemical Sciences was not listed in the credits, so our anonymity remains preserved for posterity. Until now... □



On March 18, a magnitude 5.4 aftershock of the Landers earthquake rattled much of Southern California. What was really earthshaking, however, was the debut this provided for TriNet, a new seismic network operated jointly by Caltech, the U.S. Geological Survey, and the California Department of Conservation's Division of Mines and Geology. Seismologists were able to determine the quake's magnitude within five minutes—a tremendous improvement over the time it once took to confirm data—and in another five (practically before the TV crews could arrive!) they had created this contour map (above) of peak ground velocities. The red star marks the epicenter, the red lines are faults, the blue lines are freeways, and the yellow contours are in centimeters per second. The triangles are seismographic stations—blue for the Division of Mines and Geology, orange for Caltech/USGS digital stations, and green for analog stations. The maps show at a glance what areas might and might not have suffered damage, in a way that merely quoting magnitudes and epicenters cannot. The maps also go up on the World Wide Web (http://www-socal.wr.usgs.gov/pga.html) the moment they're made.

Oops!

The portrait of turbulence that *Engineering & Science* ran on the cover of Issue No. 3 for 1996 was unattributed, due to an editorial error. Our apologies to postdoc David Laidlaw, who generated the image and was kind enough to provide a copy for us.

DNA Repair Kit

Caltech chemists have found a way to repair DNA molecules that have been damaged by ultraviolet radiation. Professor of Chemistry Jacqueline K. Barton, postdoc Peter J. Dandliker, and grad student R. Erik Holmlin reported in the March 7 issue of *Science* that the new procedure reverses thymine dimers, a well-known type of DNA abnormality caused by exposure to ultraviolet light. By designing a synthetic molecule containing rhodium, the researchers have succeeded in repairing the damage and returning the DNA to its normal state. The research is also significant in that the rhodium complex can be attached to the end of the DNA strand and repair the damaged site even when it is much farther up the helix.

"What I think is exciting is that we can use the DNA to carry out chemistry at a distance," says Barton. "What we're really doing is transferring information along the helix."

A healthy DNA molecule appears something like a twisted ladder. The two "rails" of the ladder, the DNA backbone, are connected with "rungs," the DNA bases adenine, thymine, cytosine and guanine, which are paired together in units called base pairs to form the helical stack. Thymine dimers occur when two neighboring thymines on the same strand become linked together. The dimer, once formed, leads to mutations because of mispairings when new DNA is made. If the thymine dimers are not repaired, mutations and cancer can result.

The new method repairs the thymine dimers at the very first stage, before mutations can develop. The rhodium complex is exposed to normal visible light, which triggers an electron transfer reaction to repair the thymine dimer. The rhodium complex can either act locally on a thymine dimer lesion on the DNA strand, or can be tethered to the end of the DNA helix to work at a distance. In the latter case, the electron works its way through the stack of base pairs. The repair efficiency doesn't decrease as the tether point is moved away from the site of damage, the researchers have found. However, the efficiency of the reaction is diminished when the base-pair stack—the pathway for electron transfer—is disrupted.

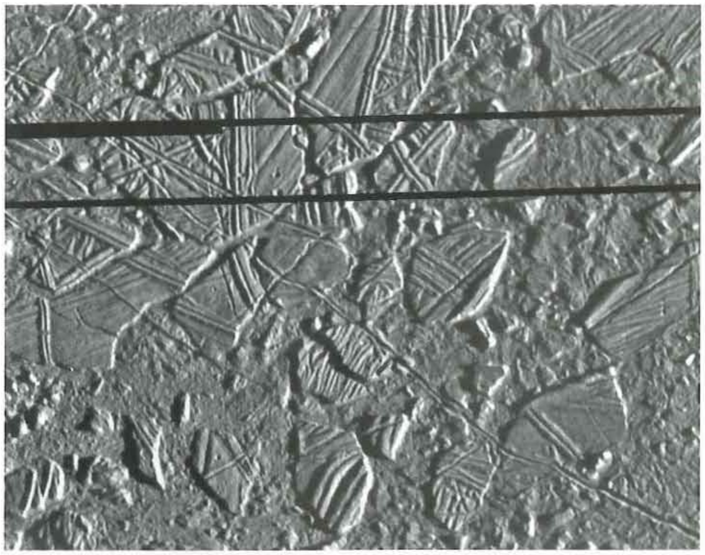
"This argues that the radical, or electron hole, is migrating through the base pairs," Barton says. "Whether electron transfer reactions on DNA also occur in nature is something we need to find out. We have found that this feature of DNA allows one to carry out chemical reactions from a distance." Barton cautions that the discovery does not represent a new form of chemotherapy. However, the research could point to new protocols for dealing with the molecular changes that precede mutations and cancer. "This could give us a framework to consider new strategies," she says.

This research was funded by the National Institutes of Health. Dandliker is a fellow of the Cancer Research Fund of the Damon Runyon-Walter Winchell Foundation, and Holmlin is a National Science Foundation predoctoral fellow. □—*RT*

Waiting to Exhale

In less earthshaking developments at Caltech and the USGS, Ken Hudnut and his colleagues have been monitoring the gradual squishing shut of the Los Angeles basin for the last year and a half now, using a network of Global Positioning System (GPS) receivers. One of these receivers is located atop the Pacoima Dam, where, says Hudnut, "we've seen the center of the arch of the dam deflect downstream, then back up again, and then down again." The movement is about two centimeters (about three-quarters of an inch), and it takes roughly a year per oscillation. "We think this is due to the warming and cooling of the whole structure with seasonal climate changes," Hudnut explains. "It's pretty cool that such a large structure 'breathes,' and that we can measure it. It's not like the dam is about to fail or anything. For all we know, it's been flexing like this ever since it was built in the late 1920s—it's just never been observed before now." If you'd like to see for yourself, there's a World Wide Web page at http://www-socal.wr.usgs.gov/scign/hudnut/dam.html.

But failure is ultimately what it's all about. Ever since Northridge, Caltech's civil engineers have been realizing that ground displacement and velocity contribute more to earthquake damage than does acceleration (see *E&S*, Summer 1995). But old-fashioned seismographs measured acceleration best, so the building codes have been based on that data. Combining digital seismological and GPS data should lead to a much better understanding of what happens to a structure when you shake it, and eventually to more earthquake-resistant buildings, overpasses, and dams. □
—*DS*



If this looks like a close-up of a shattered plate to you, you're not far wrong. The plate, however, is the icy crust of Jupiter's moon Europa as seen by the Galileo spacecraft. The individual fragments are up to 13 kilometers (8 miles) across, and you can see how they have drifted apart from one another, rotating slightly in the process. The scene looks remarkably like aerial views of the spring break-up of oceanic pack ice on Earth, fueling speculation that an ocean of slush or even liquid water lurks just beneath Europa's frozen surface. This high-resolution image (the smallest visible detail is 54 meters, or 59 yards, across) was shot on February 20, 1997, from a distance of 5,340 kilometers (3,320 miles), during Galileo's sixth orbit of Jupiter. For more Galileo images, check out their World Wide Web site at http://www.jpl.nasa.gov/galileo.

Snowball Earth

Those who think the winter of '97 was rough should be relieved that they weren't around 2.2 billion years ago. Scientists have discovered evidence for an ice age back then that was severe enough to partially freeze over the equator. Professor of Geobiology Joseph Kirschvink (BS, MS '75) and grad student Dave Evans have found evidence that glaciers came within a few degrees of the equator's latitude when the planet was about 2.4 billion years old. They base their conclusion on glacial deposits discovered in present-day South Africa, plus magnetic evidence showing where South Africa's crustal plate was located at that time.

Based on that evidence, the Caltech researchers think they have documented the extremely rare "Snowball Earth" phenomenon, in which virtually the entire planet may have been covered in ice and snow. According to Kirschvink, who originally proposed the Snowball Earth theory, there have probably been only two episodes in which glaciation of the planet reached such an extent—one less than a billion years ago during the Neoproterozoic Era, and the one that has now been discovered from the Paleoproterozoic Era 2.2 billion years ago.

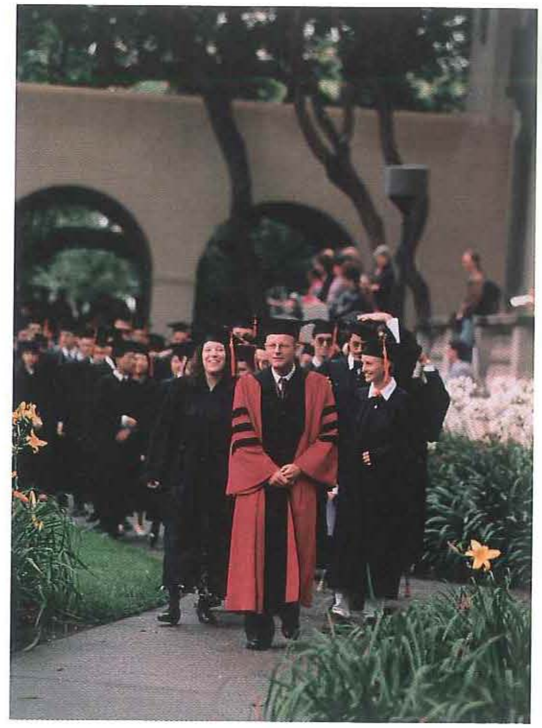
"The young Earth didn't catch a cold very often," says Evans, a graduate student in Kirschvink's lab. "But when it did, it seems to have been pretty severe."

The researchers collected their data by drilling rock specimens in South Africa and carefully recording the magnetic directions of the samples. From this information, the researchers then computed the direction and distance to the ancient north and south poles. The conclusion was that the place in which they were drilling was 11 degrees (plus or minus five degrees) from the equator when Earth was 2.4 billion years old. Plate tectonic motions since that time have caused South Africa to drift all over the planet, to its current position at about 30 degrees south latitude. Additional tests showed that the samples were from glacial deposits, and further, were characteristic of a widespread region.

Kirschvink and Evans say that the preliminary implications are that Earth can somehow manage to pull itself out of a period of severe glaciation. Because ice and snow tend to reflect sunlight much better than land and water, Earth would normally be expected to have a hard time reheating itself in order to leave an ice age. Thus, one would expect a Snowball Earth to remain forever. Yet, the planet obviously recovered both times from the severe glaciation.

"We think it is likely that the intricacies of global climate feedback are not yet completely understood, especially concerning major departures from today's climate," says Evans. "If the Snowball Earth model is correct, then our planet has a remarkable resilience to abrupt shifts in climate. Somehow, the planet recovered from these ice ages, probably as a result of increased carbon dioxide—the main greenhouse gas."

Evans says that an asteroid or comet impact could have caused carbon dioxide to pour into the atmosphere, allowing Earth to trap solar energy and reheat itself. But evidence of an impact during this age, such as a crater, is lacking. Large volcanic outpourings could also have released a lot of carbon dioxide, as well as other factors, such as sedimentary processes and biological factors. At any rate, the evidence for the robustness of the planet and the life that inhabits it is encouraging, the researchers say. Not only did Earth pull itself out of both periods of severe glaciation, but many of the single-celled organisms that existed at the time managed to persevere. □
—RT



David Wales, professor of mathematics and master of student houses, leads the academic procession of candidates for the BS degree in 1997.

Women at Caltech: Not 25 Years, But 53 or 42 or . . .

In response to the notice in the last issue of E&S *on the 25th anniversary of women at Caltech, Hans Liepmann, the Theodore von Kármán Professor of Aeronautics, Emeritus, and former director of GALCIT, pointed out that we had written only about undergraduate women. He thought that the struggle to admit female graduate students also merited mention, and he provided some reminiscences of his own.*

Hans Liepmann

I arrived at Caltech in September 1939 to work as an (unpaid) postdoc in the Guggenheim Aeronautical Laboratories. Due to the outbreak of the war in Europe and various visa problems, my wife arrived a few months later. When she inquired about the possibility of continuing her physics studies, we found that Caltech did not accept female students. I confess that this possibility had not occurred to me at all. I had seen many young women on the campus; I realized that in an institute of technology comparatively few women could be expected, but my middle-European experience did not prepare me for a non-coeducational university!

In the late '40s, I believe, when I was a relatively young member of the voting faculty, we had to vote on the proposed admission of female graduate students. I cannot remember whether this voting by the faculty was supposed to be a poll only or had more decision power. Of the pro and con arguments, I can remember only one, possibly because it was so silly: "If you flunk a girl in class she will cry on your shoulder!" was proclaimed by someone against. This was answered by a loud, but anonymous, voice from the back: "Now, what's wrong with that?"

In any case, after a rather heated debate in the Hall of the Associates of the Athenaeum, the motion was defeated by three votes. When we filed out of the room, Charlie De Prima, a then equally young professor of mathematics, slapped me on the back and said in a rather loud voice: "Don't worry, Hans; three of the old guys are likely to die soon!" This demonstrates the heat of the argument, but the remark was actually not quite fair, since the lineup of votes was by no means according to age.

In 1950, Richard Feynman was considering whether or not to accept a permanent professorship at Caltech. Paco Lagerstrom, who had known Feynman when they were both students at Princeton, and I had either lunch or dinner (I have forgotten which) with Feynman in the Athenaeum. Debating the pros and cons, we proposed that if Feynman should turn down the offer, he should help the cause by giving the failure to admit women as a reason. Fortunately for all of us, he accepted the offer, and so, unfortunately, nothing came of our proposition. But a little later, the faculty vote was reversed anyway.

In 1944 or thereabouts, a young female aeronautical engineer applied to complete a master's degree in aeronautics at Caltech. Her husband worked, I believe, at Lockheed. I don't know exactly how she was permitted to enter, but Gertrude Fila took classes and worked with me on a research project, keeping her one-year-old son in a playpen between two wind tunnels. We even published a paper together. Mrs. Fila's classwork was graded, but she did not get credit toward a degree; however, Clark Millikan had told her that whenever Caltech accepted female graduate students, she would get her MS degree.

When I became director of GALCIT, I discovered correspondence in the files indicating that Mrs. Fila, then teaching at Oklahoma A&M, had asked for her degree and been turned down because the requirements had changed. With a little noise from me, this decision was repealed, and Gertrude Fila, by then a gray-haired professor, marched up with the graduate students and finally got her degree in 1974.

The barriers finally fell, and they fell suddenly. When Jack Roberts, now Institute Professor of Chemistry, Emeritus, was recruited to the faculty from MIT in 1952, he had, according to his oral history in the Caltech Archives, four very, very good grad students who were interested in coming with him to Caltech. One was Dorothy Semenow. Linus Pauling told Roberts that although the faculty and trustees had voted against admitting women, they had never considered a specific case, and he urged her to apply. Pauling put his own considerable clout behind the case, and by June 1953 it was a done deal. Dorothy Semenow received her PhD from Caltech in 1955. Other women followed. The world did not end. □

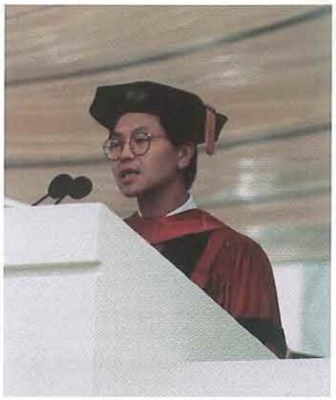
Hope and Glory

Unseasonable rain fell early on the morning of June 13, but by 10 a.m. the skies were clearing and Caltech's 103rd Commencement commenced. Some 202 students received their bachelor of science degrees; 104 master of science degrees, 6 engineer degrees, and 173 PhDs were awarded.

Dr. David Ho, BS '74, director of the Aaron Diamond AIDS Research Center at Rockefeller University, and *Time* magazine's 1996 Man of the Year, gave the commencement address—"Science as a Candle of Hope." Ho touched briefly on his own Caltech experience: "As a young boy growing up in Southern California, this was my dream school. . . . It is the place where I first learned to tackle research with a multidisciplinary approach not limited by arbitrary boundaries that separate biomedical sciences from physics, chemistry, engineering, and mathematics."

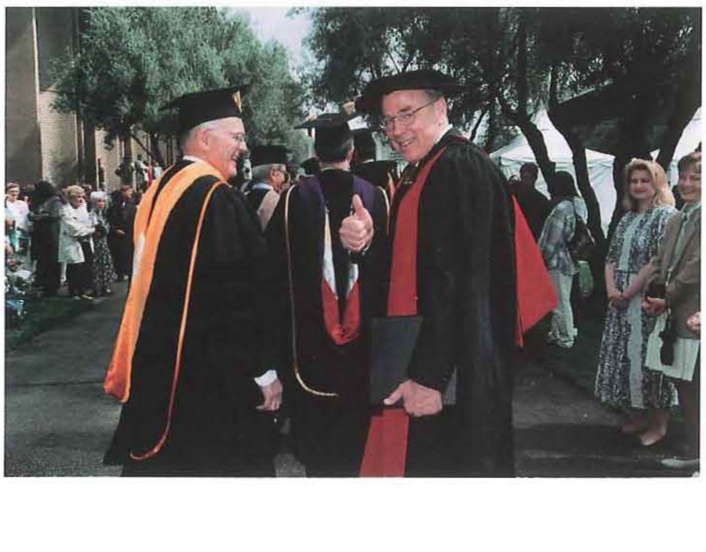
He told the graduating class that they had chosen "a noble profession, one filled with excitement," and illustrated this claim with the story of his own recent discoveries. Ho described how he and his colleagues were working in 1991 "with structural biologists and medicinal chemists to test small chemicals that might intercalate into the catalytic site of the HIV protease, an enzyme essential for the production of infectious progeny virus." He spoke of the overwhelming excitement they felt when they realized that they could inhibit the protease enzyme, thereby blocking viral replication in the test tube.

Three years later, they were able to administer to HIV-infected patients one of the chemicals they had found. Ho described the "joy and amazement as we watched the level of HIV fall ever so dramatically. At first we did not know that we were sitting on top of a fundamental discovery in AIDS research." But then, when they asked the right questions, "it quickly dawned on us that HIV must be turning over rapidly, in a dynamic equilibrium with the host. Using data from our patients and working together with mathematicians, we proved that HIV replication in vivo was rapid and remorseless. In the course of only a few weeks, the old paradigm that HIV was largely a latent virus was completely shattered."



David Ho, BS '74, speaks to the graduating class of 1997.

Later in his talk, Ho, who came with his family to California from Taiwan when he was 12 years old, reflected on the contribution of his heritage to his career—the Asian respect for intellectual achievement and hard work. But, he remarked, "I have been an American for so long that I have nearly forgotten that I am also an immigrant. From time to time, I can still sense the desire that burns in the belly of a new immigrant, the desire to carve out a place in the new world, in the land of opportunities. . . . Throughout its history, America has continually benefited from the drive, labor, and creativity of immigrants, many in the field of science." □



With Gordon Moore (PhD '54), chair of the Board of Trustees, Tom Everhart brings up the rear of his last Commencement academic procession as president of Caltech.

Melting the Mantle

"We have replicated the melting that we think occurs in the deepest mantle of the Earth."

Earth's mantle reaches a maximum temperature of 4,300K, say a group of Caltech researchers.

According to Tom Ahrens (MS '58), the W. M. Keck Foundation Professor of Earth Sciences and Environmental Engineering, and graduate student Kathleen Holland, the results are important for setting very reliable bounds on the temperature of Earth's interior. Scientists need to know very precisely the temperature at various depths in order to better understand large-scale processes, such as plate tectonics and volcanic activity, which involve movement of molten rock from the deep interior of the Earth to the surface.

"This nails down the maximum temperature of the lowermost mantle, a rocky layer extending from a depth of 10 to 30 kilometers to a depth of 2,900 kilometers, where the molten iron core begins," Ahrens says. "We know from seismic data that the mantle is solid, so it has to be at a lower temperature than the melting temperature of the materials that make it up."

In effect, the research establishes the melting temperature of the high-pressure form of the crystal olivine. At normal pressures, olivine is known by the formula $(Mg,Fe)_2SiO_4$, and is a semiprecious translucent green gem. At very high pressures, olivine breaks down into magnesiowüstite and a mineral with the perovskite structure. Together these two minerals are thought to make up the bulk of the materials in the lower mantle.

The researchers achieved these ultra-high pressures in their samples by propagating a shock wave into them, using a high-powered cannon apparatus called a light-gas gun. This gun launches projectiles at speeds of up to 7 kilometers per second. Upon impact with the sample, a strong shock wave causes ultra-high pressures to be achieved for only about one-half a millionth of a second. The researchers have established the melting temperature at a pressure of 1.3 million atmospheres. This is the pressure at the boundary of the solid lower mantle and liquid outer core.

"We have replicated the melting which we think occurs in the deepest mantle of the Earth," says Holland. "This study shows that material in the deep mantle can melt at a much lower temperature than had been previously estimated. It is exciting that we can measure phase transitions at these ultra-high pressures."

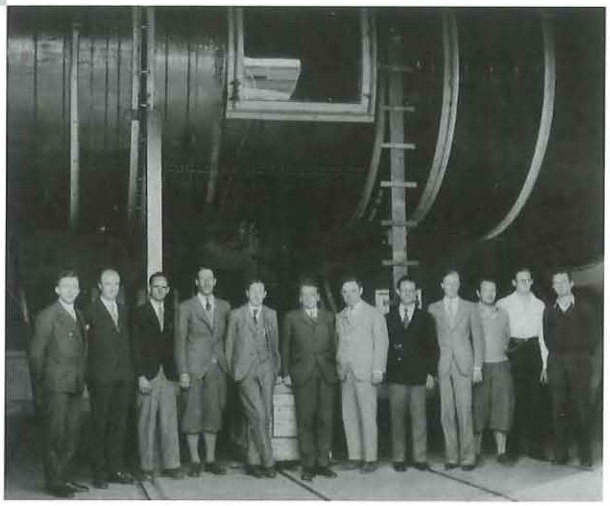
The researchers further note that the temperature of 4,300K would allow partial melting in the lowest 40 kilometers or so of the lower mantle. This agrees well with seismic analysis of wave forms conducted in 1996 by Professor of Geophysics Donald Helmberger and Edward Garnero (PhD '94). Their research suggests that at the very lowest reaches of the mantle there is a partially molten layer, called the Ultra-Low-Velocity Zone.

"We're getting into explaining how such a thin layer of molten rock could exist at great depth," says Ahrens. "This layer may be the origin layer that feeds mantle plumes, the volcanic edifices such as the Hawaiian island chain and Iceland.

"We want to understand how Earth works." □—*RT*

The 10-Foot Wind Tunnel: Over and Out

Above: Flying over campus to bid farewell to the historic wind tunnel were four World War II–era planes: a T-28 trainer, a B-25 Mitchell, a C-46 Commando transport/cargo plane, and a Navy SNJ version of the AT-6 Texan.

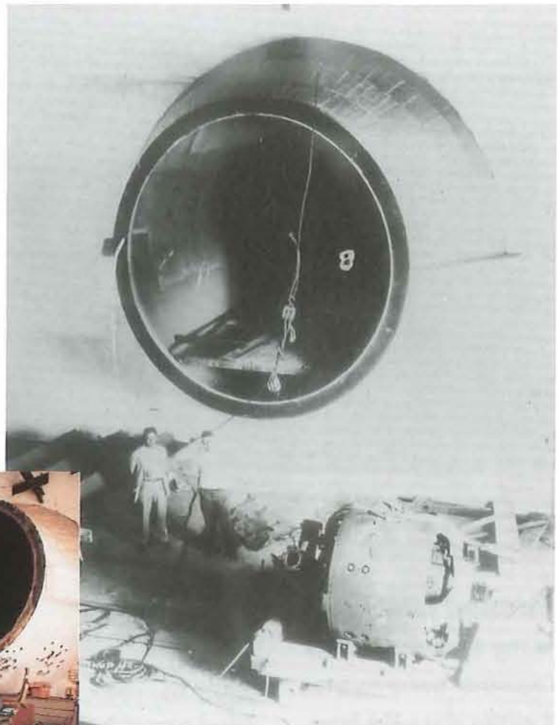


Top right: Guggenheim Aeronautical Laboratory from the south, showing the entrance (detail top left) to the wind tunnel, in 1929. Above: the wind tunnel staff in front of the newly completed test section; from left: W. Tollmien, R. Seiferth, W. Bowen, C. Millikan, H. Bateman, T. von Kármán, A. Klein, F. Wattendorf, E. Sechler, W. Oswald, F. McFadden, and F. Moyers.

GALCIT's 10-foot wind tunnel, the biggest and fastest on the West Coast when it was finished in 1929, was ceremoniously decommissioned April 30, 1997. Early in its 68-year history, the wind tunnel had helped establish Southern California as the aircraft-manufacturing capital of the country; it tested most of the warplanes that helped the Allies win World War II; and many generations of Caltech students learned hands-on aeronautics in its giant test section. But in recent years the 10-foot tunnel had begun to show its age, and the venerable facility needed to make way for a smaller, more cost-efficient model, incorporating new technology.

More than 200 wind-tunnel veterans and aviation fans attended the decommissioning, as four World War II–vintage planes buzzed the campus in salute to their birthplace. During May some tunnel components, including the huge test section, were dismantled and shipped off to rest in various museums across the country; the balances, which measured the aerodynamic forces acting on a model in the tunnel, will be displayed in the Smithsonian Institution in Washington, D.C.; the test section went off to Fantasy of Flight in Polk City, Florida; and various other pieces, as well as wind tunnel models, were parceled out to the Los Angeles County Museum of Air and Space, the Western Museum of Flight, and the Heritage of Eagles Museum. The rest was sold for scrap. The cavernous space occupying four stories inside Guggenheim Aeronautical Laboratory now stands almost empty, save for a few hundred tons of concrete that may be very hard to remove.

The wind tunnel and the building were built simultaneously, beginning in 1926 after Robert A. Millikan persuaded the Daniel Guggenheim Fund for the Promotion of Aeronautics to come up with $300,000 ($180,000 for building and equipment, including the wind tunnel) to build Caltech's aeronautics program from the ground up. (GALCIT is short for Graduate Aeronautical

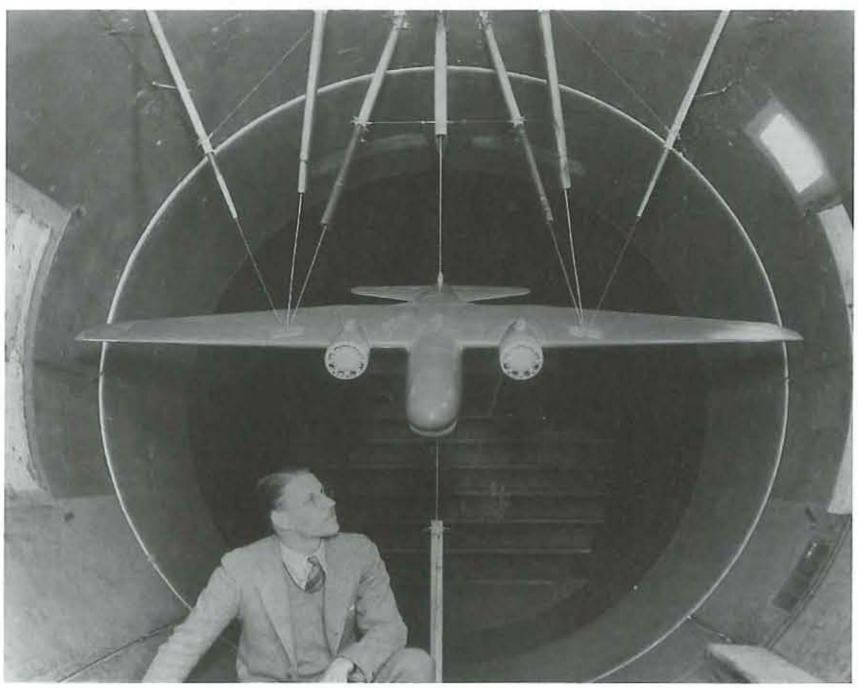


At left is one of the two concrete entrance cones, which neck down the air flow from a 20-foot diameter into the 10-foot test section, as it was installed in 1929. Unfortunately, they were built so solidly that they have created a massive removal problem in 1997. They're still there (far left).

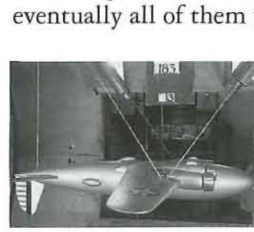
Laboratories of the California Institute of Technology, but originally the G stood for Guggenheim.) Millikan also lured Theodore von Kármán, probably the most distinguished aeronautics professor in the world, from Germany to Southern California to lead the new program. He remained director of GALCIT until 1949, and was followed by Clark Millikan (1949–66), Hans Liepmann (1972–85), and the current director, Hans Hornung. Although von Kármán didn't settle here permanently until 1930, he helped design the wind tunnel while on an exploratory lecturing expedition in 1926.

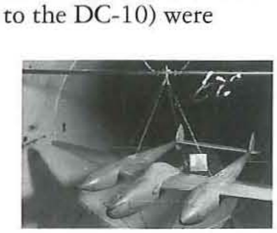
It occupied most of the core of the new building—a space 46 feet tall, 100 feet long, and 25 feet wide. Powered by an electric 750-horsepower World War I submarine motor, its propellers created wind velocities of up to 200 mph. And yes, the propeller blades *have* on very rare occasions been flung loose. Jerry Landry, the current manager of the wind tunnel, remembers such an occasion in 1962 when the hub failed, "allowing various pieces of hub and blades to seek new resting places." The result registered as a small earthquake on the Seismological Lab's instruments.

From the beginning, the wind tunnel was expected to do double duty as a teaching and research facility—including commercial research. Northrop's six-passenger Alpha in December 1930 was the first airplane tested—of more than 1,100 commercial tests. Besides Northrop, numerous other aircraft companies used the tunnel during the thirties, including Boeing, Lockheed, Hughes, and Douglas. The Douglas DC-1, -2, and -3 (and eventually all of them up to the DC-10) were

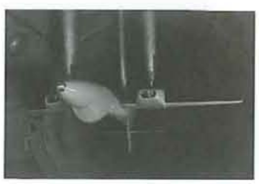


Above: Clark Millikan with a model of the DC-3 in 1935. The planes were suspended upside down for testing in the wind tunnel; the balances that weighed the aerodynamic loads are above. Right: (from left) the first aircraft tested in the tunnel, the Northrop Alpha (1930); an early version of the B-17 (1935); and the P-38 (1937).





Left: The General Motors Stingray coupe was tested in the wind tunnel in 1959 (it came on the market in 1963).



Above: (top) the Spruce Goose (1944), inverted, that is, right side up; (bottom) an early jet aircraft, the Curtiss-Wright XP-87 (1947). The more substantial suspension system replaced the wire rigging (opposite page) in 1941.

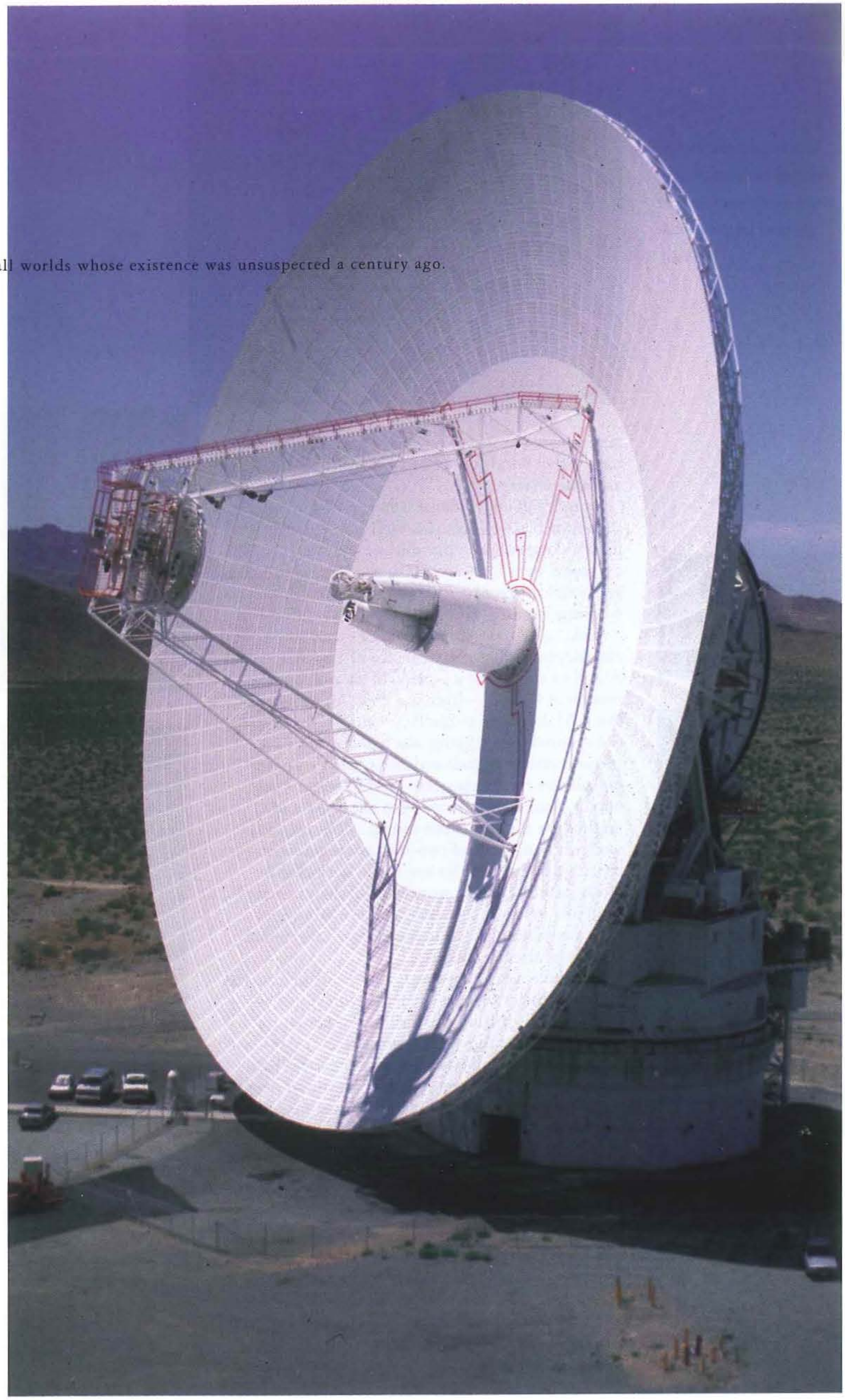
tested here, but it was during World War II that the 10-foot wind tunnel performed its most valuable service.

From 1930 on, students were employed on a part-time basis to man the wind tunnel (and gain practical experience), but during the war, the staff expanded to as many as 60 (in addition to military personnel in aeronautics training), as the tunnel was kept running for three shifts a day, seven days a week, to help develop military aircraft. Most of the warplanes that played such a crucial role in the Allied victory spent a portion of their infancy as models at Caltech—from the P-38 Lightning and the P-51 Mustang to the B-17 and B-29. In 1941 the original wire rigging was replaced by a suspension system of rods and links, which allowed for quicker model changes—and solved the problem of planes flying loose from the wires and crashing at the end of the tunnel. (The original work section, made of two-inch redwood, was also replaced at this time by one made of steel and wood paneling.) The suspension system survived till 1987, when it succumbed to the Whittier Narrows earthquake, putting the 10-foot tunnel out of the aircraft business.

But there was still a steady diet of structures and surface vehicles to keep the wind tunnel busy—antennas, oil-drilling platforms, airport towers, stadiums, street lighting, supertankers, as well as human subjects such as bicyclists, skiers, an Olympic luge rider, and current director Hornung demonstrating the wind speed of Hurricane Hugo for *Nightline*. And of course automobiles—from land-speed record holders (*E&S*, January 1982 and No. 1, 1997) to more common vehicles. General Motors tested its early Corvette here in 1953, and more recently the wind tunnel has hosted the likes of the new EV-1 and its predecessors—the Impact and the solar Sunraycer (*E&S*, Winter 1988). The last test—of a portable helicopter hangar—was conducted in February 1997. Then a bit of history was carted off to the museums. □ —*JD*

Top: Some of the wind tunnel's old timers take a last look inside the test section during the day-long decommissioning ceremonies in April.
Bottom: Hoisted out of Guggenheim by crane, the 1941-vintage test section, diffuser, and a portion of the contraction await transportation to Florida's Fantasy of Flight.

We live amid a swarm of small worlds whose existence was unsuspected a century ago.



Radar Observations of Earth-Approaching Asteroids

by Steven J. Ostro

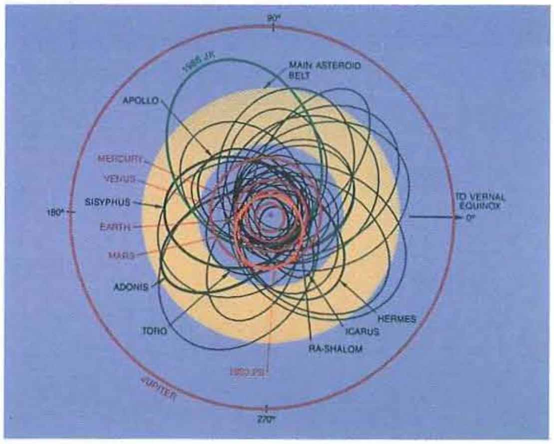
The 70-meter Goldstone antenna is part of the Jet Propulsion Laboratory's Deep Space Network, which also includes sites near Madrid, Spain, and Canberra, Australia. The three locations are approximately 120 degrees apart, so a spacecraft is always within view of one of them. When the Goldstone antenna isn't busy talking to spacecraft, it's also used for radar astronomy. Caltech manages JPL for NASA.

As part of their opposition to the Comprehensive Test Ban treaty, the Chinese have declared that they would like to hold on to their nuclear weapons just in case they have to blow up an approaching asteroid. Are they playing politics? Or are they acting out of a societal memory of a day in the year 1490 when, according to records from the Ming dynasty, stones fell from the sky and killed thousands of people? Are killer asteroids finally getting some respect?

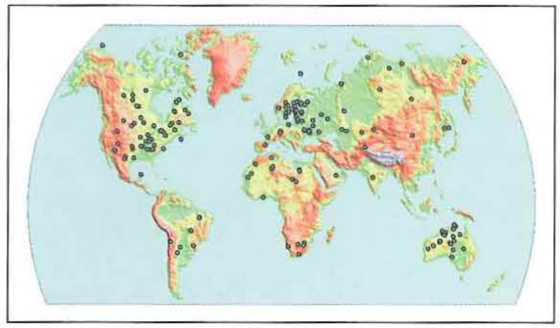
We call these objects Earth-crossing asteroids. The main asteroid belt lies between Mars and Jupiter, but the Earth-crossers travel in orbits that cross that of our own planet and occasionally collide with Earth itself. At that point they become meteors, and, if they don't burn up in the atmosphere on the way down, meteorites. The first Earth-crosser was discovered in 1918 by Max Wolf in Heidelberg, Germany. We now know of a few hundred, most of which have been discovered during the past decade. By looking at the size distribution of craters on the moon, we think we know what the undiscovered population of these bodies looks like. (The cratering record also shows that the impact rate hasn't changed dramatically over the last 3 billion years, which implies that as Earth-crossers hit us and are thus removed from circulation, the pool is replenished at an equal rate, presumably mostly from the main belt.) We believe that there are about 2,000 Earth-crossers at least as large as a kilometer, which turns out to be an important size. Two thousand is a lot—if you drove far from Los Angeles on a perfectly clear, moonless night, you could see about 2,000 stars with your naked eyes. The number of smaller Earth-crossers is much larger—there are some 100,000 waiting to be discovered that are larger than the Rose Bowl, and about 70 or 80 million larger than a typical tract house. We live amid a swarm of small worlds whose existence was unsuspected a century ago, and whose abundances have been realized only during the past few decades.

These are scientifically very precious stones—more so than diamonds!—and taking samples of them, unaltered by a fiery passage through our atmosphere, would tell us a great deal about the evolution of our solar system. In particular, one type of asteroid—the carbonaceous chondrites—formed by condensation 4.5 billion years ago when the solar system did, and they're made out of the same stuff that went on to form the sun, the planets, and us. They're called "carbonaceous" because up to 6 percent of their weight is complex organic compounds, including amino acids and nitrogenous bases, which are the building blocks of proteins, DNA, and RNA. At the other extreme, some asteroids come from planetary bodies that had already condensed, but later melted from the heat of radioactive elements decaying within them. Then, as they cooled, the denser stuff sank and the lighter stuff floated, creating a core-mantle-crust structure just like Earth's. Some time later, they were blown to smithereens in violent collisions with other large asteroids. The fragments from the crust and mantle are now stony asteroids, while the fragments from the core are metallic ones. These objects are actually samples of the insides of small planets, from which we can decipher their histories.

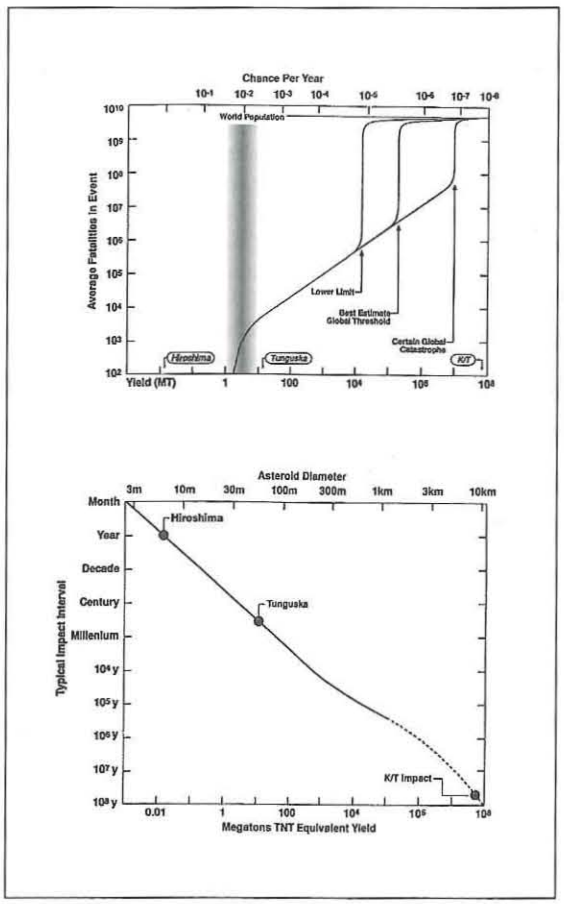
As well as being scientifically valuable, these rocks are potentially a minable resource. The metallic ones are solid hunks of nickel-iron alloy that contain 10 parts per million of platinum and one part per million of gold. And many of them are unbelievably easy to get to. We dream of colonizing the solar system, but the cost of a space mission, regardless of whether there are people on board or just robots, depends on how much orbital velocity change you have to introduce to get from Earth to your destination and back. Since Earth-crossing asteroids come so close, a properly timed launch could essentially just step over to them. For economic reasons alone, these are the objects we're going to colonize first, after the moon.



Left: The orbits of 33 Earth-crossing asteroids. The main asteroid belt is shaded yellow. Right: Every now and then, an Earth-crosser becomes an Earth-hitter. Each of the 156 dots on this map marks an impact crater. Many more, obscured by vegetation and erosion, wait to be discovered. Map courtesy of R. A. F. Grieve, Geological Survey of Canada.



An asteroid hits at about 20 kilometers per second—a velocity well beyond human experience.



The damage an Earth-crosser does when it hits us depends on its energy release, which in turn depends on its size, both of which are plotted logarithmically on the horizontal axes. "Size" is only roughly equivalent to diameter, as many of these objects have irregular (or unknown) shapes. The penetration threshold (shaded) is really more of a transition zone than a sharp threshold. The K/T impact is widely believed to have killed the dinosaurs. After Chapman and Morrison, 1994.

But even if we never go to these objects, eventually it is inevitable—absolutely inevitable—that they will come to us. The surface of the moon is covered with craters made by asteroid and comet hits. The surface of the Earth doesn't have as many craters, even though it has suffered the same violent history, only because ours is an active planet. Plate tectonics, volcanism, weather, erosion, and so forth have erased the record of long-ago collisions. But we're still finding the scars, as the little dots on the above map of the world show.

When an asteroid hits the Earth, the damage it does depends on how big it is, as shown in the diagram at left. An asteroid hits at about 20 kilometers per second—a velocity well beyond human experience—and all its kinetic energy is released upon impact. The amount of kinetic energy depends upon the asteroid's mass, and hence its size. We measure the energy release in megatons, where one megaton (4.2×10^{15} joules) is the energy equivalent of detonating a million tons of TNT all at once. The atomic bomb dropped on Hiroshima was a mere 15 kilotons, a number so tiny that it's way over on the left of the diagram. As we move across the diagram from left to right, at first the objects are too small even to make it through the atmosphere. These meteors do no damage—their energy release just powers a light show. But soon the penetration threshold is crossed; slightly larger ones deposit most of their kinetic energy on or near the planet's surface and devastate larger and larger areas. Should the impact leave a crater, it will be 10–20 times the asteroid's size. Then, at a diameter of about a kilometer, we cross a global threshold. It no longer matters where an object hits—it will kick so much dust up into the upper atmosphere that the sun will be blotted out worldwide for several years, making agriculture impossible and leading to the starvation of roughly a quarter of the people on the planet. This is a civilization-ending asteroid. At much higher energies—10-kilometer

Kilometer-sized, civilization-ending impacts happen on average once every 100,000 years, so the probability that we face one during the next century is roughly one in a thousand.

objects—we cross another threshold where the devastation is so horrendous that most of the life on Earth is eliminated. The most popular mass-extinction event was 65 million years ago, of course, when not just the dinosaurs but some 75 percent of the species on the planet were wiped out, but there are other such events in the paleontological record.

So how often do these collisions happen? The very, very low-energy events—the Hiroshimas—happen maybe once a year. But you hardly ever hear about them, because they leave no trace on the ground and they generally occur over unpopulated areas or the ocean, where their fireworks go unappreciated. Impacts like the Tunguska event, which happened in Siberia in 1908 and released 15 megatons of energy but left no crater, happen once every several centuries. The Tunguska asteroid was about 60 meters across, and it released as much energy as a magnitude 8 earthquake. This is at the low end, in terms of the number of people who could be killed by an asteroid impact. As we approach the global threshold, we suddenly get to the point—because the effects *are* global—where the number of fatalities skyrockets. And, finally, mass-extinction events are very rare—once every 100 million years, on average.

Kilometer-sized, civilization-ending impacts happen on average once every 100,000 years, so the probability that we face one during the next century is roughly one in a thousand. Those odds are extremely low—however, the consequences are extremely horrible. That fact alone suggests that it's worth finding all the kilometer-sized objects and determining their orbits, just in case we're unlucky.

This would be very easy to do. Asteroids are discovered with wide-field cameras that take time-exposures of the sky. The camera pivots to follow the stars, so that they appear as points in the image. But asteroids, which are moving with respect to the stars, show up as streaks. There are several ongoing asteroid searches, but they haven't got the resources to be exhaustive. For less than $5 million a year over a 10-year period, we could find more than 90 percent of the kilometer- and larger-sized asteroids. It seems to us very cost-effective risk reduction—very good insurance—logical in the same way that life insurance, or fire insurance, or car insurance is logical. NASA's annual budget is $14 billion a year, so we're completely perplexed as to why NASA does "not recommend this program...." If you feel that such a program would be sensible, tell your congressperson.

If we did find a threatening object, what would we do? With current technology, if we had enough warning, we could set off a nuclear warhead near the asteroid, nudging its orbit so that it would miss the Earth. However, until we discover such an object, most of us feel that developing a deflection system would be too costly to warrant our actually doing so; also, if we had a standby deflection system and actually started to experiment with orbit modifications, the system might be accidentally used or even intentionally *mis*used to deflect a harmless asteroid into a collision course with Earth—an idea that is very popular with some people who write comic books or design video games. With somewhat more-advanced technology, we could travel out to the asteroid and attach a solar sail or some sort of rocket engine to push it away from us. Everything would depend on how much warning we might have. The odds are that we would have enormous warning—maybe centuries—but not if we don't start looking.

Coincidentally, on May 19, 1996, an asteroid designated 1996JA1, which had been discovered only three days earlier, passed within a hair's breadth of Earth—only slightly outside the orbit of the moon. Less than a week later, on May 25, asteroid 1996JG (discovered on May 8) whizzed by us at eight times the distance to the moon. Both bodies are only a few hundred meters across, so they could not have produced global catastrophes had they hit us. But if they had landed in the ocean (71 percent of Earth's surface is ocean), they might have raised tsunamis that could have wiped out the coastlines of the adjacent continents. Up to 1 percent of the global population would have been killed by such an impact.

Those two asteroids missed us this time, but where are they going to be in the future? Unfortunately, with just optical measurements, it's hard to predict a newly discovered asteroid's orbit for, say, the next century. What matters is the uncertainty. It's one thing to say an asteroid is going to pass one lunar distance from Earth, but quite another to say that the asteroid is going to come within one lunar distance plus or minus 21 lunar distances. That's very uncomfortable. But if we use radar observations, there's very little uncertainty left. Donald Yeomans, Paul Chodas, and

Photo by David Parker, 1997/Science Photo Library

We can get 10-meter resolution, which is about the length of a school bus, and we can measure velocities of one-tenth of a millimeter per second, which is the speed of the tip of the minute hand on a kitchen clock.

The radio dish at Arecibo was carved out of a natural "punch bowl," or sinkhole, in the limestone karst region of northwestern Puerto Rico. The telescope is aimed by moving the antenna feed system, which hangs from rails on a support structure that is itself suspended over the dish from three towers. The telescope can see a cone of sky 40 degrees in diameter and centered on the zenith. The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under a cooperative agreement with the National Science Foundation.

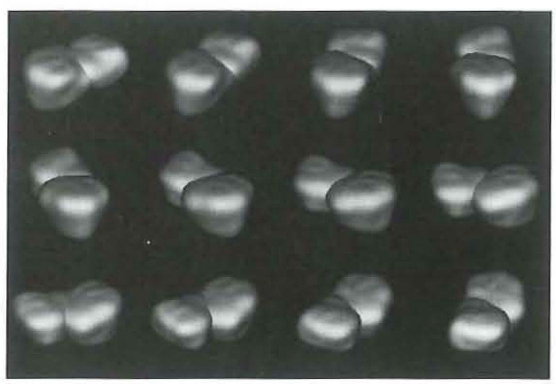
Jon Giorgini of JPL's Solar System Dynamics Group can use our radar data to work up an orbit that's good for 100 years or more. We would immediately know whether we're safe or not.

We study these asteroids with either of two very large antennas. One is the 70-meter Goldstone antenna, about a three-hour drive from Pasadena. Goldstone is part of the Jet Propulsion Laboratory's Deep Space Network, so the antenna is used primarily for talking to spacecraft, but up to 4 percent of its time is devoted to radar astronomy. The other is the largest radio telescope in the world, the 305-meter (1,000-foot) Arecibo telescope in Puerto Rico. The two instruments are complementary. The Arecibo telescope is not fully steerable (Goldstone is), but it's 30 times more sensitive. But it also has been used for radar only 4 percent of the time.

When we bounce a radar pulse off an asteroid, we measure the time it takes the echo to return, which tells us how far away the asteroid is, and the echo's Doppler shift, which tells us how fast the asteroid is moving. (Objects moving toward us compress the echo to higher frequencies; receding objects stretch it out to lower ones.) For an asteroid about 20 lunar distances from Earth, we can get 10-meter resolution, which is about the length of a school bus, and we can measure velocities of one-tenth of a millimeter per second, which is the speed of the tip of the minute hand on a kitchen clock. That's why radar is so powerful in refining orbits.

But wait—there's more! Asteroids appear only as points of light in even the best telescope photo—they're just too darn small. But radar can pick out surface features. A Caltech grad who's now at Washington State University, R. Scott Hudson [BS '85, PhD '91], developed a technique to generate a three-dimensional model of an asteroid from a sequence of radar observations, and from this model we can make images that look like photographs. We tried this for the first time with an asteroid named Castalia, using data we got from Arecibo within two weeks of the asteroid's discovery (by JPL's Eleanor Helin at Caltech's Palomar Observatory) in August 1989. (Castalia was named for a nymph who, while fleeing the amorous attentions of the god Apollo, dived headlong into Mount Parnassus. Instead of making a crater, she left the spring that bears her name.)

Because Castalia was quite close to Earth at the time—a mere 11 lunar distances away—this was also the first-ever set of delay-Doppler data with sufficient echo strength and resolution to reconstruct a shape. (We have since done this with objects at greater distances.) The resolution is pretty poor, but the important finding is that Castalia is a double asteroid—a contact-binary



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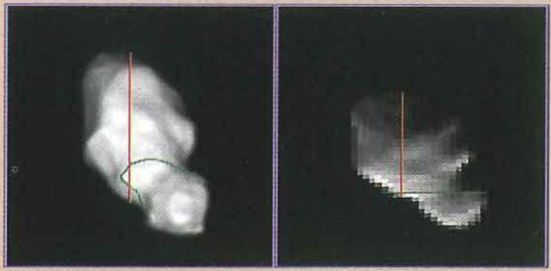
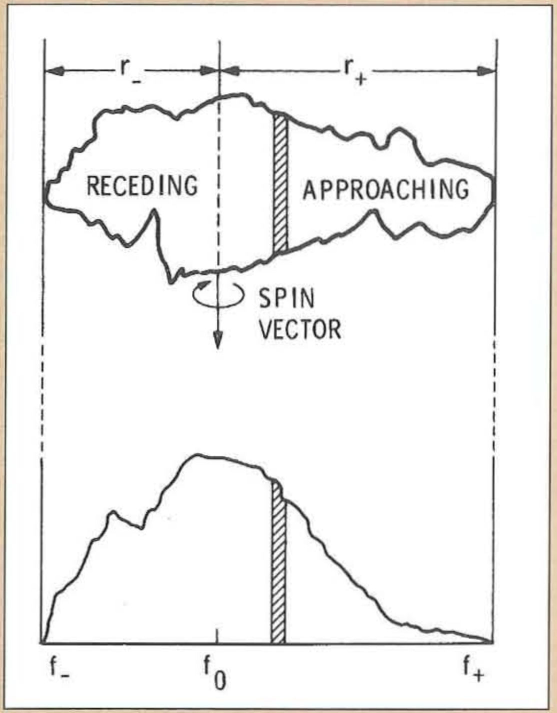
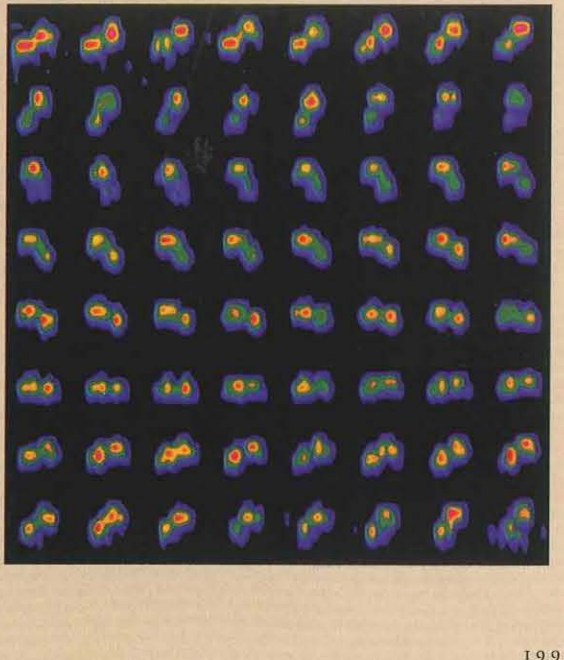
Castalia as modeled by the Hudson inversion looks rather like two biscuits that sat too close together in the oven and fused. The lobes are roughly 0.8 and 0.9 kilometers in diameter; at 100 meters or more deep, the cleft between them could swallow a 27-story building. The dimples on the model might be craters. The asteroid is seen rotating through 220 degrees in 20-degree increments.

"Seeing" Shapes with Radar





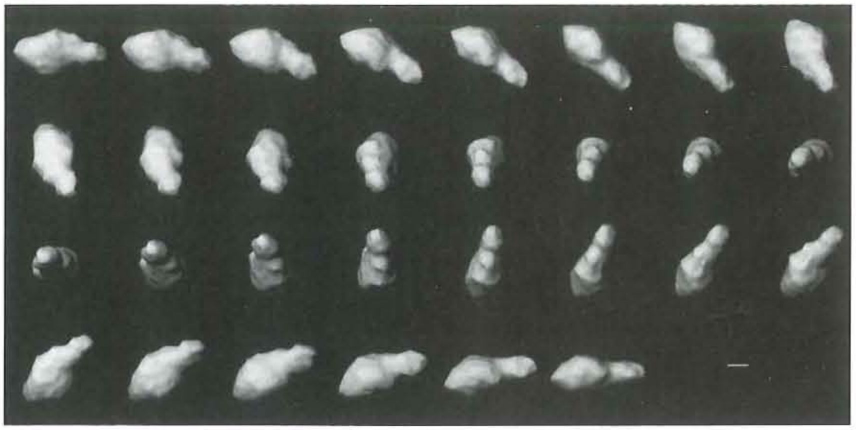


Above: A radar image of an asteroid (right) doesn't look exactly like a 3-D reconstruction of the real thing (left). Radar slices up the asteroid by the length of time it takes a reflected pulse to return—the green line traces out such a slice. Center: The echoes from a slice through a rotating asteroid are shifted to both sides of the center-of-mass frequency (f_0) by the Doppler effect. The signal's strength at any frequency is proportional to the asteroid's area in that slice, as shown by the shaded bar. The red lines in the previous picture are the three-dimensional equivalent of this shaded bar. Bottom: This delay-Doppler "movie" of Castalia consists of 64 images made over 2.5 hours. The images read from left to right, top to bottom. The colors from blue to red represent increasing intensity.

A camera, in essence, holds a sheet of glass perpendicular to the camera's line of sight and maps where every ray of light from the scene you're looking at passes through the glass. Radar imaging works in a fundamentally different way. When an asteroid reflects a radar pulse, the pulse returns to the receiver smeared out over time. The part reflected off the nearest tip of the asteroid makes a shorter round trip than the part bouncing off the farthest tip, and so returns to the receiver first. By chopping up the echo into slices of time as thin as 10^{-7} seconds and measuring the echo's strength in each slice, we can assemble a set of cross sections through the asteroid that tell us something about its shape—the more powerful the echo, the more of the asteroid there is in that slice. However, this doesn't say anything about how that surface area is distributed. But if the asteroid is also rotating, the Doppler effect will shift the echoes from the side of the slice that is turning toward Earth to proportionately higher frequencies, depending on how far away the reflecting point is from the rotational axis's projection in the plane of the slice. (Similarly, the side turning away from Earth will shift the echo to lower frequencies.) Thus, a radar image plots the echo's brightness versus its delay time on the vertical axis and brightness versus frequency on the horizontal axis to generate what's called a delay-Doppler image. In effect, the asteroid has been sliced along two perpendicular planes like a potato being sliced into French fries. And that's one reason why these plots don't look exactly like the asteroid—each point in the image contains the reflection from both ends of each French fry. A point may even contain more than two reflections, if that particular French fry passes through the side walls of a crater, or a cleft on the asteroid's surface! It takes a mathematical analysis, using Scott Hudson's techniques, of a sequence of delay-Doppler images to resolve the ambiguities and reconstruct the asteroid's actual shape. □

asteroid, the first ever seen. Such a thing could form only if the two lobes mated at a very gentle relative velocity, so that they didn't pulverize each other. Perhaps it formed out of the wreckage of a much larger asteroid. If two shards went sailing out along a common trajectory close enough to each other, they might stay gravitationally bound. The two lobes could even be physically touching each other, but in no way "cemented" together. The discovery that contact binaries exist has implications for interpreting the cratering record elsewhere in the solar system, and also for defending ourselves from such objects. If we blew up a nuclear bomb closer to one lobe than the other, we would shatter the nearer lobe but leave the other one completely intact and the asteroid's course unaltered.

Three years after the Castalia observations, in December 1992, we did a three-week-long experiment on another object, called Toutatis. Toutatis, by the way, is one of the most accessible asteroids. Its orbital plane is almost identical to Earth's; it's an excellent candidate to collide with us sometime during the next several million years. In fact, that's how it got its name. Its discoverers, Christian Pollas, Alain Maury, and their colleagues at the Côte d'Azur Observatory, are fans of the Astérix and Obelix comics. Those ancient Gauls swear by the god Toutatis, and the only thing they fear is that someday the sky will fall on their heads. Toutatis won't quite fall on our heads in the year 2004, but it will miss us by a mere four lunar distances, coming close enough to be visible through binoculars. At that point, Earth will be as large in Toutatis's sky as the moon is as seen from the Earth.



Toutatis as seen at six-hour intervals over the week beginning at 10:00 a.m. Pasadena time on December 3, 1992. Although the long axis has essentially returned to its original orientation by the end of the sequence, the asteroid's orientation around that axis is not the same—the lobe that was pointing downward in the first image is now sticking out toward us. The scale bar in the lower right corner is one kilometer long. Data are from Goldstone and Arecibo.

Above left are stills from our three-dimensional model of Toutatis. It's a much higher-resolution model than the one of Castalia, and represents an even stranger world. From some orientations it looks like a single object. From others, it looks like it has two parts. From still others, it looks like it has three. Geologically, we're at a loss to explain this—we know that collisions were involved, but we don't know exactly how. But the strangest aspect of Toutatis is its rotation. It doesn't spin around a single axis, but tumbles in a manner radically unlike anything else in the solar system that we know of. Toutatis rotates around its long axis once every 5.41 days. Meanwhile, this axis is precessing around a direction fixed in space—Toutatis's angular-momentum vector—once every 7.35 days. These are non-commensurate numbers, which means that Toutatis's orientation in space never repeats. There is no truly periodic pattern. How it got into this rotation, we don't know. It had to be a collision, but we don't know what kind of collision. We do know that it would be a spectacular experience to land on Toutatis and watch the sky. Imagine trying to navigate by using the stars—the "Pole Star" would change daily! Earth

Naming an Asteroid

When an (optical!) astronomer discovers an object, the sighting is reported to the Minor Planet Center at Harvard, which gives it a provisional designation (e.g., 1989 AC). Many astronomers may then observe the asteroid, making the measurements needed to refine the orbit. When Brian Marsden of the Minor Planet Center considers the orbit secure, he gives the asteroid a number (e.g., 4179) and then the discoverer(s) can name it (e.g., Toutatis). Marsden considers an orbit secure when the object is seen again, on a subsequent approach to Earth, in the location and at the time predicted by that orbit. In some cases, the object proves to be one that had been seen earlier, but then had been lost before enough observations could be made to pin down its orbit. Marsden then decides which "discovery" counts, i.e., who gets naming rights. In Toutatis's case, 1989 AC proved to be 1934 CT, which had been seen twice by Eugene Delporte in Uccle, Belgium in 1934; the discovery belongs to the 1989 discoverers, whose data permitted the orbit to be traced backward through half a century. □

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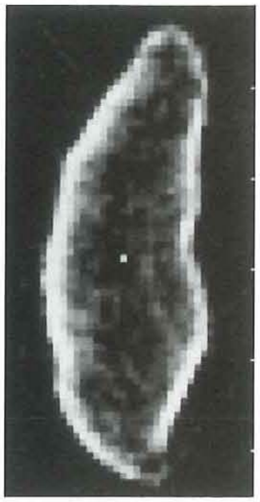
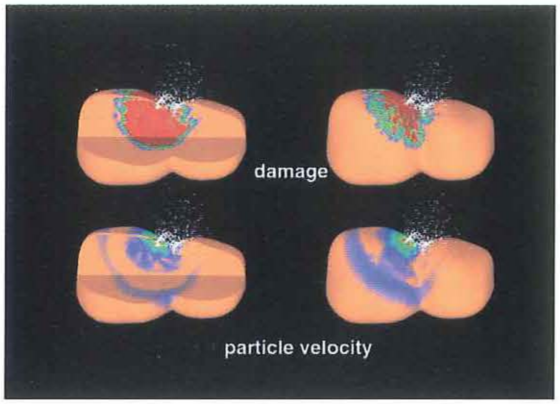


Geographos, as seen from above. The central bright square marks the north pole, and Geographos is spinning clockwise in the plane of the page. The radius of curvature of the knobs on either tip of the asteroid is only a few hundred meters; then beyond the gentle concavity that defines the knob, the trailing edges are nearly linear for a kilometer. The tick marks along the picture's right edge are one kilometer apart. The data were taken at Goldstone in August, 1994.



Above: A 6,000-ton rock hitting Castalia at the comparatively gentle velocity of five kilometers per second has 20 percent more force than the Hiroshima bomb. In this set of exterior and cutaway views at one-tenth of a second after impact, the top row shows damage ranging from minor (blue) to pulverization (red). The red fingers are actually hairline fissures—given infinite computing power, you'd eventually see these fractures opening up and pieces coming apart near the impact zone. The bottom row shows particle velocity (on a logarithmic scale where blue is 0.1, green is 1.0, and red is 20 centimeters per second) as the pressure wave propagates through the interior. Castalia is assumed to be a homogenous, basaltic body. Below: Although the crater itself takes much longer to form, the impact fragmentation is all over in three-tenths of a second. The impact severely damages Castalia, but does not blow it apart or appreciably alter its trajectory.

has a fixed north star—fixed on the time scale of someone reading this, at any rate—because Earth's rotational axis precesses only once every 26,000 years, but Toutatis's rotation and precession rates are comparable to each other.

At left is Geographos, which is about 5.1 kilometers long by 1.8 kilometers wide. It was discovered in 1951 by Albert Wilson [MS '42, PhD '47] and Rudolph Minkowski as part of the Palomar Observatory Sky Survey, which photographed the entire Northern Hemisphere sky over several years. The survey was sponsored by the National Geographic Society, hence the asteroid's name. We don't have a 3-D model of this one yet, but the radar images, processed by Keith Rosema [BS '89] at JPL, are good enough for us to see some unusual features. Geographos is paramecium-shaped—the most elongated body yet discovered. But to my eye the strangest of its features are the knobs on each end. Their leading edges (with respect to Geographos's rotation) are convex and their trailing edges are slightly concave, giving Geographos's ends a sort of pinwheel look. How did these form? And how can they survive, given the constant bombardment they must undergo from other asteroids? Perhaps it has to do with the asteroid's low gravity, long shape, and rapid, five-hour rotation. The centrifugal force at Geographos's tips might be just about equal to its gravitational pull, and the asteroid is almost able to fling the material off. When we finish the 3-D modeling, we can do computational experiments to test hypotheses about how these protuberances formed.

Once we have three-dimensional models, we can use them as targets in physically realistic computer simulations of impacts. Collisions are terribly important, and we need to understand their effects if we are to learn how asteroids evolve. Erik Asphaug of NASA/Ames has run such simulations, based on our model of Castalia's shape and rock properties derived from laboratory experiments. In the frames from an animation by JPL's Eric De Jong and Shigeru Suzuki (above), an eight-meter, 6,000-ton rock (a small asteroid) crashes into Castalia. A spray of particles is ejected, and a shock consisting of a compressional wave followed by a smaller extensional wave (not shown) rips through the body. Exactly what happens depends on both Castalia's physical properties and its collisional history, because every impact affects the asteroid's integrity and the way it responds to impact stress. Even this relatively small cratering event causes widespread internal

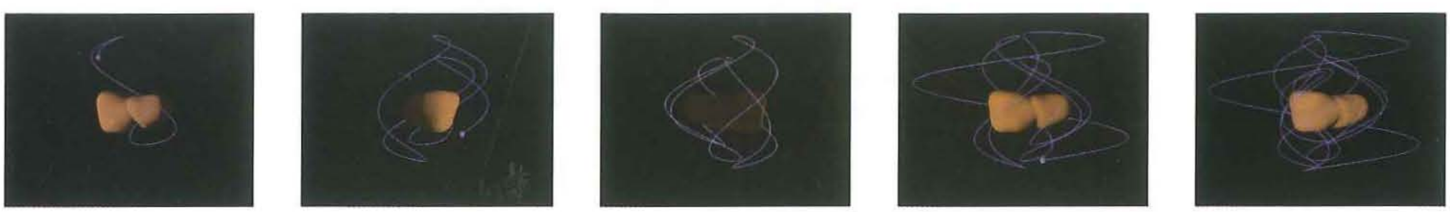
It could bring a whole new dimension to parenting. If your child's been bad, instead of "Go to your room!" you could say, "OK, you go into orbit for a while."

fracturing. Escape velocity on Castalia is about one meter per second, but most of the rock we pulverized in this simulation attained velocities of only a few centimeters per second and so remains gravitationally bound together. It's quite different from what we're used to on Earth, where the self-gravity between, say, the pieces of a broken saucer are negligible.

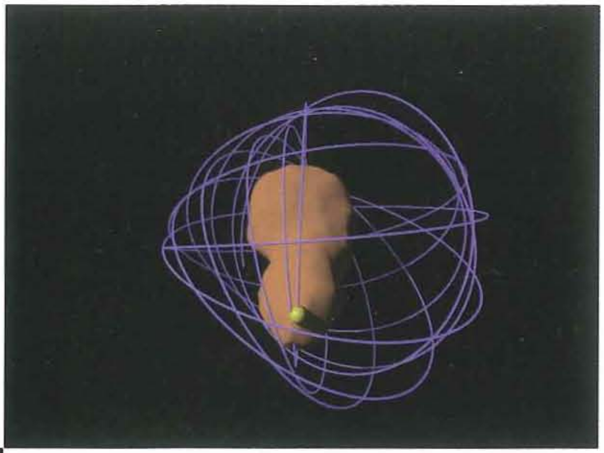
We want to understand the effects of collisions not just to make sense of the physical properties we observe—to connect what we've learned from meteorite samples with what we can learn about asteroidal composition through ground-based telescopes—but also to look ahead to the day when we might have to nuke one of these objects in self-defense. What this and other simulations have taught us is that it might be much easier to turn an asteroid into a flying rubble pile than to alter its trajectory by more than one or two centimeters per second. To make matters worse, loosely consolidated bodies don't propagate stress waves well. A nearby nuclear detonation would basically be "soaked up" by such an asteroid, shattering it into finer pieces instead of pushing it off course. This is a problem, because the overwhelming odds are that any asteroid that could threaten Earth has itself been hit at some time in the past by something larger than eight meters in diameter, and therefore is probably already fragmented.

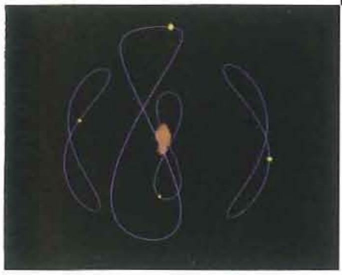
We also want to understand the dynamics of orbits that are very close to small, irregularly shaped, rotating asteroids. Some ejecta will be thrown off too slowly to escape from the asteroid. Daniel Scheeres of JPL has found that the geometry of return orbits—orbits that eventually return to the asteroid's surface, or the equivalent of a ballistic trajectory on Earth—is very peculiar. The top row of illustrations below shows what you would see if you were standing on Castalia and weren't aware that the asteroid was rotating—what we call a Castalia-fixed frame of reference—and you threw up a rock that left a trail. It wanders all over the sky and, depending on where you stood, which way you were facing, and how hard you threw the rock, you'd get a completely different orbit. This is a realm of geometric complexity that we never appreciated before. If you stood off from Castalia and watched it rotate beneath you—a star-fixed reference frame—the orbit would now be almost planar, but the trajectory would still go through a bunch of strange gyrations in space before returning to the asteroid. And finally, of course, if you threw the rock a little too hard, it could whirl around Castalia for several passes before escaping and going into orbit around the sun.

These calculations also apply to human and spacecraft operations in the vicinity of a small asteroid. Imagine what it would be like to play baseball on Castalia—you'd have to have a lot of patience and do a lot of practicing. If you went



A return orbit around Castalia, seen simultaneously in a Castalia-fixed reference frame (above) and a star-fixed reference frame (below). Although the reference frame is fixed in each set of images, the point of view sometimes moves in order to highlight some aspect—the planar nature of the orbit in the star-fixed reference frame, for example. The entire orbit takes 16.9 hours to complete.





Above, right: This return orbit around Toutatis, shown in a star-fixed frame of reference, takes 2.9 days to complete.

Above: This family of four "geosynchronous" orbits—in which a satellite appears to hang at a fixed point in the heavens, as seen from the orbited body's surface—instead trace out figure-eights in the sky over Toutatis. From a star-fixed point of view, the four satellites would be spaced 90 degrees apart in a roughly circular orbit around Toutatis.

out for a walk, and were feeling in good spirits and jumped up, you might go into an orbit that would take you around the asteroid for days! If you were too light on your feet, or unlucky, you might never come back. And parents like to toss their little kids up into the air and say "Wheeee!" They'd have to be really careful about that on Castalia. But it could bring a whole new dimension to parenting. If your child's been bad, instead of "Go to your room!" you could say, "OK, you go into orbit for a while."

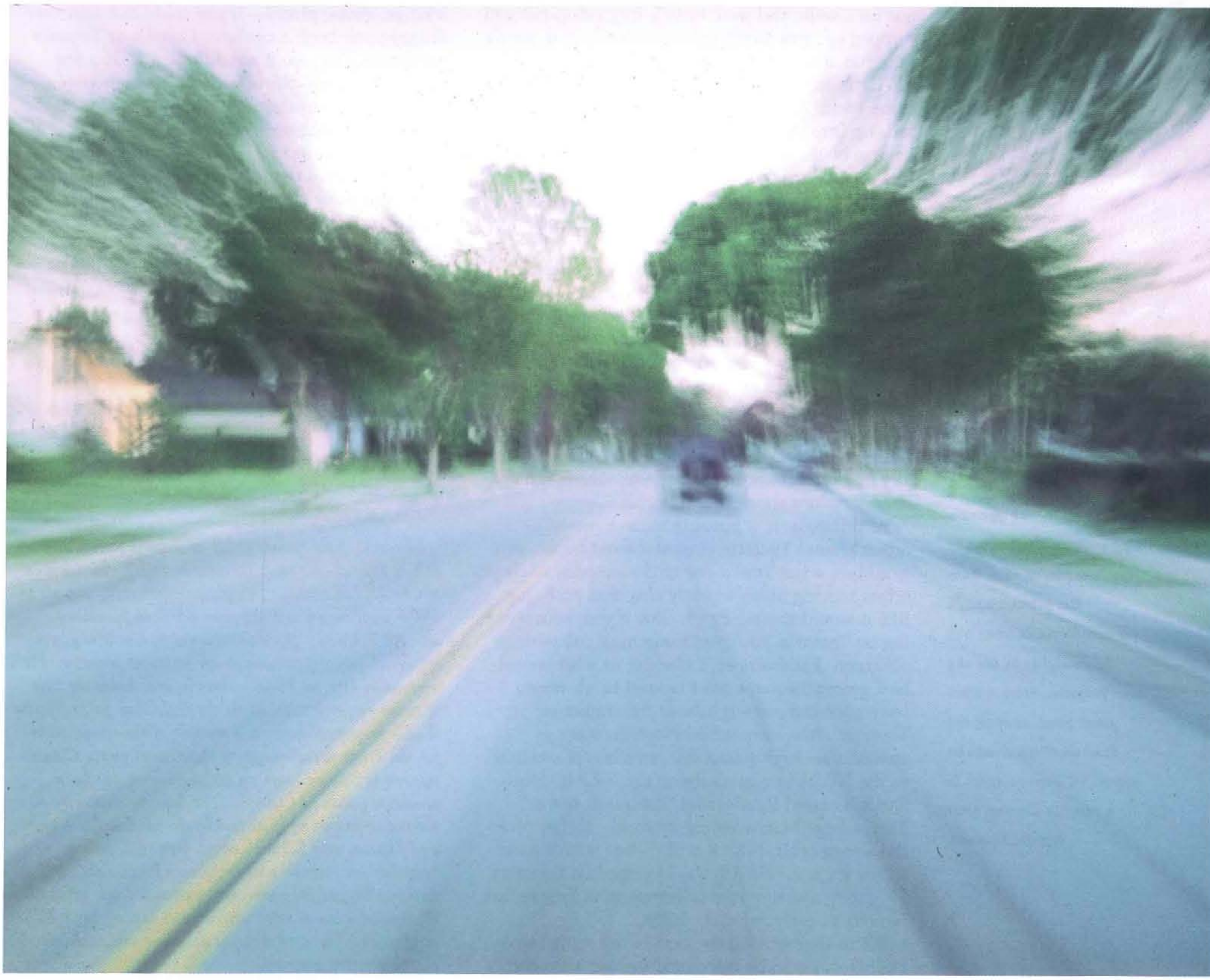
As I mentioned before, Toutatis has a weird, tumbling rotation like a football during a botched pass. Consequently, orbits around Toutatis are very different from orbits around Castalia. On Castalia, in a star-fixed frame, the return orbit I showed you had a strange shape, but at least stayed nearly planar. Not so on Toutatis, where return orbits can form cocoons around it. There are some orbits that circle hundreds of times before eventually making it back to the surface. Above is a star-fixed view of a shorter return orbit.

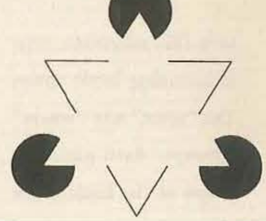
Surprisingly, it is possible to have periodic orbits around Toutatis. In a star-fixed frame, you would see a satellite in one of the simplest of these orbits moving along a nearly elliptical path, just like it would around Earth. But if you were standing on Toutatis, you'd see something completely different. For example, a satellite in what would be a geosynchronous orbit around Earth would trace a giant figure-eight over the surface of Toutatis. And some orbits close to rotating asteroids are highly unstable, which is of concern to the NASA engineers flying the NEAR (Near-Earth Asteroid Rendezvous) spacecraft toward Eros, a large Mars-crossing asteroid. If they pick the wrong orbit, NEAR will collide with Eros or escape from it. NEAR was launched on February 17, 1996, and should rendezvous with Eros in late January or early February 1999.

We're approaching the turn of the millennium. I think it would be wonderful to have an event deserving of that moment in history, such as sending a human being to an Earth-crossing asteroid and really beginning the manned exploration of the solar system. Of course, such an undertaking would be very expensive and isn't likely to happen by that time. Meanwhile, we'll continue exploring with radar. And if we could fund a serious optical search for these objects, we'd start discovering them in huge numbers, and eventually we'd get to the point where almost once a week—certainly once a month—we could have an encounter via radar with a new Earth-crossing asteroid. We could put it on our World Wide Web site (http://echo.jpl.nasa.gov/), so that anybody with a computer could witness the first radar imaging of the object and see the radar movies and eventually the three-dimensional models. With a three-dimensional model, you could make virtual visits to the asteroid, putting yourself into orbit around it and trying to land on it. People love to explore strange, exotic places—if you could call your travel agent and book a cruise to Castalia or Toutatis tomorrow, I'm sure it would sell out. In a few years, with high-definition TV and high-resolution computer models, you could almost vacation there. You could walk around, play a little catch, even hit golf balls into orbit. Our models are the first step toward that experience, and it's going to be how most of us will explore these worlds. Sooner or later the survival of human civilization will depend on how intimately we know these near neighbors of ours, but in the meantime, it would be possible to make a first-time encounter with a fantastic new world part of the regular experience of everybody on the planet who's connected to the Internet. That's my personal millennial vision. □

Steven J. Ostro earned a BS in ceramic science and an AB in liberal arts from Rutgers in 1969. He went on to Cornell for a master's degree in engineering physics in 1974, and earned a PhD from MIT in planetary sciences in 1978. He then returned to Cornell, joining the astronomy department as an assistant professor. He arrived at JPL in 1984, where he now holds the title of senior research scientist, is the Goldstone Solar-System Radar project scientist, is a member of the science team for the Titan radar-mapping experiment on the Cassini mission to Saturn, and, in his spare time, teaches a graduate course at Caltech. The leading authority on the radar properties of asteroids, the satellites of Mars and Jupiter, and Saturn's rings, Ostro has been a "regular" at Arecibo and Goldstone for two decades, and has bagged 80 near-earth and main-belt asteroids. He was also one of seven astronomers to play key roles in three NASA workshops on detecting and intercepting Earth-crossing asteroids.

Our brains have to make hypotheses about what we think is out there in the real world. We hope that these hypotheses are right, because a mistake could be fatal.





How We See

by Richard A. Andersen

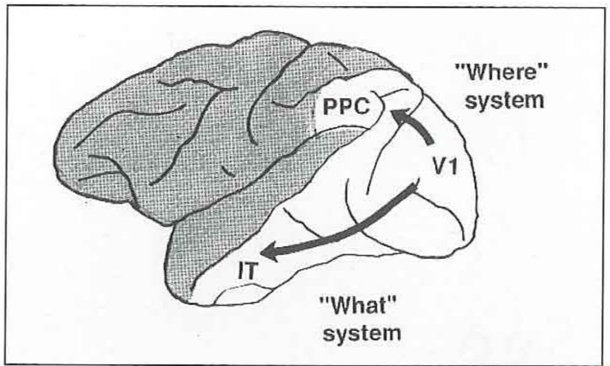
Driving down a street (as here in La Cañada Flintridge, not far from Caltech), generates an optical flow of motion signals. Surrounding objects seem to radiate out from the focus point, expanding toward the edges of the field of vision. Processing of these complex signals occurs in the higher levels of the brain. Photo by David Bradley.

When we look around us, seeing is so effortless that we think we naturally perceive what is actually out there in the world. But, in fact, the brain works very hard at reconstructing its own reality—what we refer to as neural representation. In the well-known Kanizsa triangle shown above, you can see illusory contours that are created by the occlusions, the lines, and the little Pac-Man figures. These "contours," and the perceived variations in brightness lie entirely within your brain and do not exist in the real physical world. Because the brain is often faced with an ambiguous, ill-defined environment, it's very useful to be able to reconstruct such lines. Our brains have to make hypotheses about what we think is out there in the real world. We hope that these hypotheses are right, because a mistake could be fatal. In terms of evolutionary pressure, the brain has evolved over time to create its own reality that meshes with the world in such a way as to enable the organism to survive.

Neurobiologists believe that at least a third of our approximately one hundred thousand genes are exclusively involved in brain function. With that limited number of genes, we can't completely specify all the complex connections and structure in the brain, so during some periods of development, the brain has to look to the outside world for assistance in forming its structures. At a very early age, for example, the brain becomes plastic for vision; during this critical period information from the two eyes, which compete with each other, is used to actually set up the appropriate neural machinery for depth perception.

The understanding that the visual system actually constructs images of reality has led to an exciting revolution not only in neuroscience but also in the field of philosophy. A new school of philosophy called neurophilosophy has reconsidered what the nature of reality and the nature of knowledge are, based on what we now know about how the brain works and about the changes that occur in our neural networks over the course of development.

Visual information required to construct this representation of the world comes in through the eyes and is projected on the retina; then the optic nerve sends this information to the thalamus, which passes it up to the primary visual cortex (called V1), where simple aspects of the visual scene are first analyzed. Then information is projected out to cortical areas around the primary visual cortex, and they process the visual image more elaborately; here is where the more complicated cognitive functions take place. The information travels along two processing streams—one to the upper part of the brain and the other to the lower part. In 1982, two neuropsychologists from the NIMH, Mort Mishkin and Leslie Ungerleider, proposed that the pathway to the upper part of the brain was the "where" pathway, which tells us the location of an object. They labeled the lower route the "what" pathway, because it seems to handle information about the object itself. Patients with



Left: This schematic view of a monkey brain shows the "what" and "where" pathways. Both pathways begin at the back of the brain in the primary visual cortex (V1); the "what" pathway proceeds through the visual cortex in the lower part of the brain to the inferotemporal cortex (IT), and the "where" pathway leads to the posterior parietal cortex (PPC) in the upper part.

injuries, or lesions, to the upper pathway can identify objects and the differences between objects, but can't tell where they are. With lesions to the lower area a person can tell where things are but can't identify them. Lesions in this area can cause an interesting syndrome called prosopagnosia, in which people can't identify faces, including their own. This object-based pathway is also important for the perception of color.

A typical lesion in the upper, or "where," pathway might leave a patient unable to pour a liquid into a glass. He can see the glass and he knows it's a glass, but he can't figure out where the glass is with respect to his body. Another one of the deficits from damage to this pathway is the inability to attend to the area of space opposite to the hemisphere that was damaged.

Monkeys have visual functions similar to ours. They see color the way we do; they see motion and depth; they perceive objects; they make eye movements in the same ways that we do. So they make ideal animal models for studying the human brain, because we can do experiments with monkeys that we obviously can't do with people. We have several rhesus monkeys who participate in experiments for a period of years. Recently we have been successful in placing them in zoos for their retirement. A common technique for studying the visual system introduces very fine (about the diameter of a human hair) wire electrodes into a monkey's cerebral cortex. We park these electrodes near nerve cells. During the experiments the monkeys are awake and performing different tasks that they've been trained to do, such as moving their eyes toward a stimulus, reaching toward a target, or pressing a button for a juice reward. In this way the monkeys "tell" us what they see. As they do their tasks, the electrodes record the activity of the nerve cells. Then we can correlate the activity of specific cells with the behaviors or perceptual experiences the animals have.

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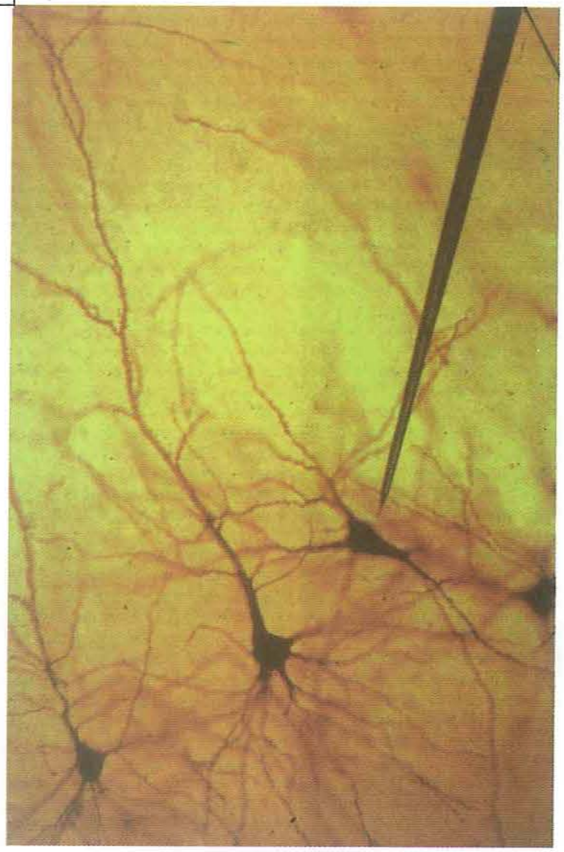
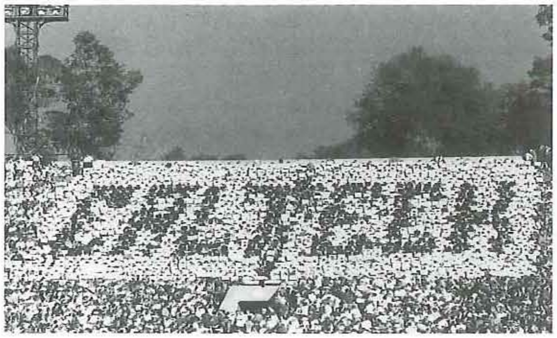


Above: A microelectrode is placed near a neuron to record its electrical activity (photo by Fritz Goro). A recording is shown at right, on the opposite page; the changes in activity are due to the appearance and disappearance of stimuli.



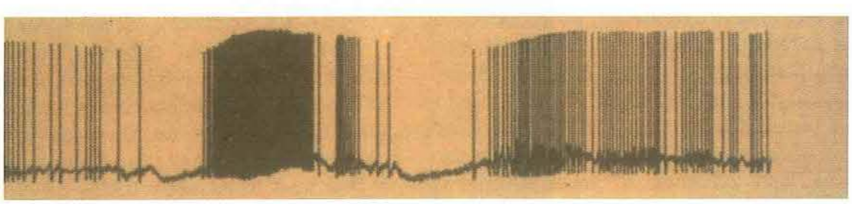
To understand the brain and how it processes visual images, we not only have to know what each single element is saying, but also what the whole ensemble of activity is saying.

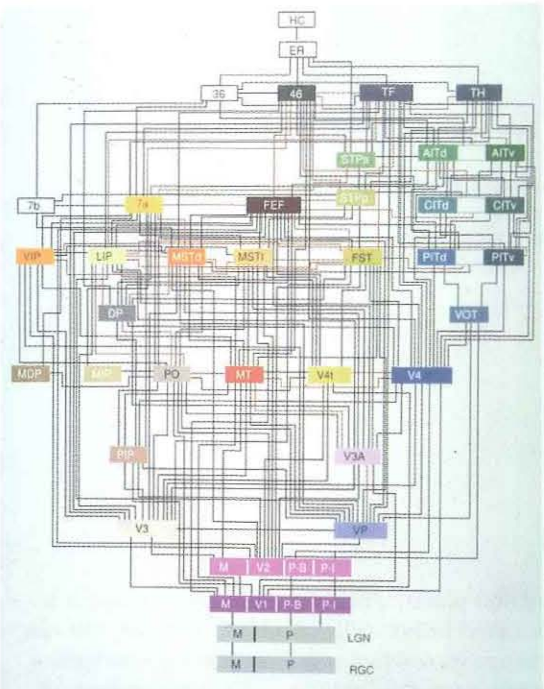
Above: The Rose Bowl prank of 1961 is a good example of population coding, one of the brain's strategies for processing visual information. A single perception is stored across many units, but it only makes sense when all the units are combined.

page shows the type of signal that we record on one of these electrodes. Time is plotted along the x-axis, while the y-axis displays the membrane potential, or electrical activity, coming from one of these nerve cells. When we shine a light or present a stimulus to the animal, a cell that is involved in the perception of that stimulus begins to fire action potentials—pulses that are the communication method for nerve cells. These signals will then be transferred via synapses to other nerve cells to which this nerve cell projects. This synaptic transmission is how messages get sent through the cerebral cortex, and by tapping into this system with our electrodes, we can determine the locations of very specific types of visual processing that the brain uses to reconstruct reality.

The brain uses five basic strategies in its visual processing: population coding, functional localization, parallel processing, hierarchical processing, and association. A single neuron in the brain looks at only a small piece of the world. This fragmentation actually starts in the retina, which has the image of the whole visual field on it, yet a single cell receives its input from only a tiny part of that image. So we have to realize that each time we record a signal from one of these nerve cells, we're seeing only a small part of the entire visual message. This brings us to a concept known as population coding—the idea that a whole perception is stored across many, many units. Our brains are a bit like TV sets; we can think of neurons as corresponding to the pixels on the screen. Of course, a normal TV screen measures about 600 by 400 pixels, while the brain contains about a hundred billion cells. Each one of these cells can change its activity over a certain range to store a small bit of the "picture." A simple example of population coding can be seen in the great Rose Bowl prank of 1961, where each University of Washington fan knew only that he or she was holding up a white or a dark card and, fortunately for the Caltech students who pulled off the prank, no one person could see the whole message. When they all flipped their cards in unison, they inadvertently spelled out CALTECH. To understand the brain and how it processes visual images, we not only have to know what each single element is saying, but also what the whole ensemble of activity is saying together.

A second important feature of how the brain works is known as functional localization. This concept refers to the fact that different parts of the cortex are specialists in particular visual processes. At the turn of the century, a German neuroanatomist, Korbinian Brodmann, divided the human brain into about 50 different areas simply by looking at sections of it under a microscope and noticing the differences in nerve-cell structure or packing density in different cortical regions. With the advent of microelectrode recording techniques, neurophysiologists in the 1970s began dividing the brain up into areas based on different functional activities as well. Often these functional areas corresponded to Brodmann's anatomical ones; for example, V1 was his area 17. But others, like Brodmann's area 19, turned out to contain many different cortical areas delineated by functional differences. It's also important, in dividing up the cortex, to notice that one area might connect to some areas and not to others, so that different cortical areas have specific connectivities between them. About 35 different cortical areas have been identified as being involved with vision in monkeys, and there are probably even more in our own brains.





This schematic diagram illustrates the hierarchy of the cortical areas involved in vision, rising from the primary visual cortex at the bottom up to the highest levels of associative processing at the top. The "where" pathway is on the left and the "what" pathway on the right. (From Felleman and Van Essen, *The Cerebral Cortex*, Vol 1, No. 1, 1991. By permission of Oxford University Press.)

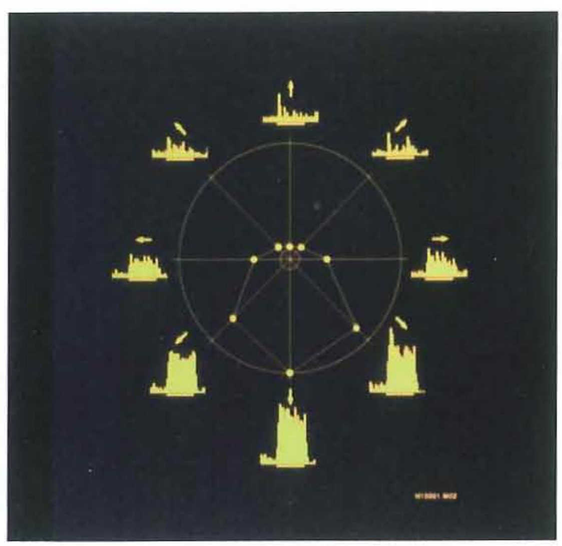
Each one of the boxes in the diagram above (created by Dan Felleman and David Van Essen) corresponds to a cortical area that has a particular function. The primary visual cortex is at the bottom, and information eventually rises to the highest levels of processing in the association cortex, which then connects to the motor cortex to direct movements. The areas on the left correspond to the "where" pathway, and the ones on the right to the "what" pathway.

Of the three remaining strategies, parallel processing divides up information and processes it in parallel along separate lines, and hierarchical processing transfers information from one level to another through more and more complicated analyses as it moves up the system. The final important concept is association—after we've broken up the image and analyzed it along parallel and hierarchical lines, ultimately we have to combine it again into a single perception.

Parallel processing streams break up and analyze different aspects of a scene. For example, when we see a red bouncing ball, we perceive it as one thing —a red bouncing ball. But in our brains some areas are processing the red, others are simultaneously processing the spherical shape, and others are processing its motion. In the last 10 years it's been discovered that visual information is immediately divided in the primary visual cortex (V1) into parallel streams. For example, within V1 are some repeating little patches, recently discovered and imaginatively referred to as "blobs," which contain concentrations of nerve cells that are sensitive to color. These cells preferentially project to a particular area of V2 called the "thin stripe" area. These thin stripes are involved in color processing, and they project in turn into an area called V4, which is also specialized for color. If area V4 sustains damage, the patient will have difficulty perceiving color in the opposite visual field. Another pathway—for motion processing—goes from V1 to the "thick stripe" region of V2, and then on to an area called V5 or MT (for medial temporal area, discovered by John Allman, Caltech's Hixon Professor of Psychobiology and professor of biology) in the visual association cortex. An injury to this pathway produces a very specific motion deficit; a person looking at traffic, for example, could see the cars, but would be unable to see that they are moving.

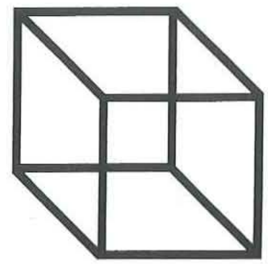
Each of these parallel streams is also organized hierarchically. Take, for example, the pathway for motion that I just mentioned. Cells in V1 extract some very basic information about the direction of motion, which is maintained in area MT and shown in the recording from an MT cell below. When something moves up within the cell's receptive field, this particular cell gives a small response, but it gives a much more vigorous response when something moves downward. This cell is giving information about the direction in which something moves, a very simple and basic sort of function. But, unlike area V1 cells, cells further up the hierarchy in MT also deal with more complex motion clues that are important for perceiving the three-dimensional structure of moving objects.

Work in my own lab has involved the upper reaches of the "where" pathway—the areas that do the higher-level processing of location and motion. Our recent research has tested how monkeys perceive three-dimensional structure from an object's motion. If we were to paint little dots on a hollow, glass cylinder and view it with one eye, the cylinder would look simply like a set of dots until we turn it; then the three-dimensional shape of the glass would immediately pop out. So motion signals can give us impressions of three-dimensional shape. Instead of using a glass with painted

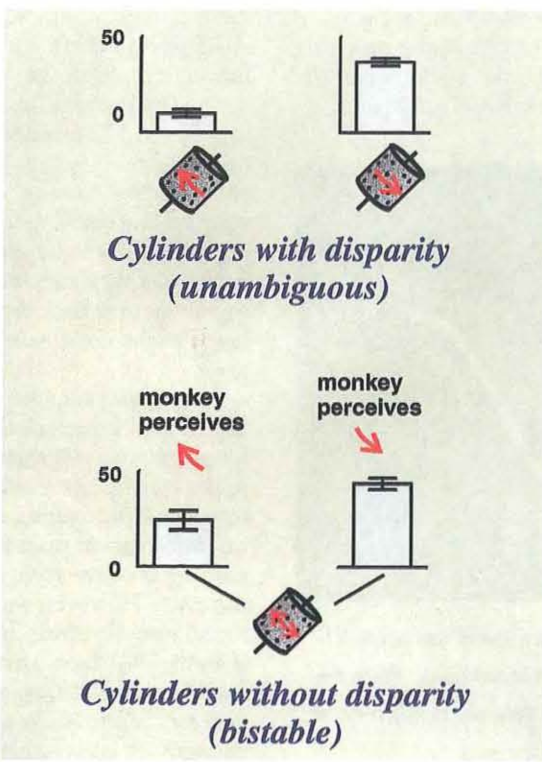


The activity of an MT neuron in response to different directions of motion is shown at right. The cell responded strongly to downward motion and weakly to upward motion. In the plot in the center (the neuron's tuning curve for motion direction), the radius length is proportional to the amount of activity, and the angle to the direction of motion.

dots, however, we use high-speed, computer animation to generate these 3-D structure-from-motion stimuli. When we project such an image onto a flat computer monitor screen, we lose the depth information that we would normally get from looking at the cylinder with two eyes, but, amazingly, due to the motion signals, we can still perceive a revolving hollow cylinder. This computer simulation demonstrates that the brain is able to use motion signals to reconstruct three-dimensional depth. It is most interesting, however, that, since there's no depth information contained in the projected stimulus, the direction in which the cylinder appears to be rotating is ambiguous. Sometimes you may see it rotating clockwise, other times counterclockwise. And it appears to shift directions; we refer to this spontaneous shifting as a bistable percept. An example of another bistable percept is illustrated at right: the well-known Necker cube illusion. Some people will see the upper square as being in front, and others will see the bottom square in front. If you look at it for awhile, you'll see it flip spontaneously. (Sometimes it helps if you concentrate on one point and then on another to see the flipping.)



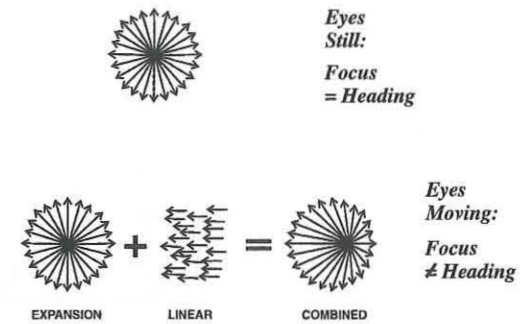
Postdoc David Bradley, grad student Grace Chang, and I trained monkeys to tell us with eye movements which direction they saw the cylinders rotating; we then recorded from their MT neurons. In some trials we added in stereoscopic depth cues in the computer display using an anaglyph technique similar to that used in the old 3-D movies of the 1950s. We found that when the monkey looks at a rotating cylinder with depth cues, the cylinders are unambiguous, and certain cells will prefer certain directions of rotation. For example, when the cylinder is rotating counterclockwise, it will generate a lot of activity in a given cell. But when it's rotating in the opposite direction, the same cell is much less active. Because of the stereoscopic depth cues added to the dots, the cell is sensitive to the three-dimensional structure of the cylinder. In the bistable state, however, in which the cylinder is projected on a two-dimensional surface and there is no depth information, the monkey still tells us the direction he thinks the cylinder is rotating. Sometimes he says it's rotating one way, sometimes the other. When he thinks it's rotating counterclockwise, the nerve cell reliably reports this by the activity it generates corresponding to its perception. This result indicates that we've tapped into the area of the cortex that is analyzing this depth from motion, and we can actually see in the nerve-cell activity what the monkey is *perceiving*. And even though the information on his retina remains the same, the cells respond differently, indicating that the changes in perception—of which way the cylinder is turning—are occurring in this part of the brain.



The diagram at right shows the activity of an MT neuron to rotating cylinders. The upper two bar graphs indicate the amount of activity (in action potentials per second) when unambiguous cylinders containing depth cues rotated counterclockwise (left) and clockwise (right). This MT cell preferred counterclockwise rotation. The lower bar graphs illustrate activity from this same MT neuron, but in both cases wth the same bistable cylinder that lacks depth cues. When the monkey perceived the cylinder rotating in the clockwise direction, the cell was less active (left) than when he perceived the identical stimulus rotating counterclockwise (right).

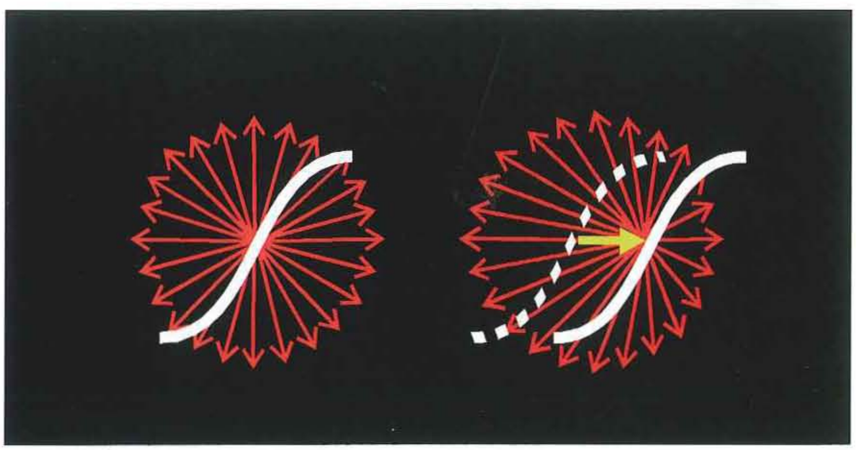
If we continue upward along the motion pathway's hierarchical organization we come to a tiny area called MST (medial superior temporal area), which is about half the size of the nail on your pinkie finger. Humans and monkeys both have an MST; it's specialized for helping us to navigate through the world using motion information. While you're driving along a highway or walking along a street, you generate motion signals. These signals are called optical flow. At the point—or focus—toward which you're headed, there's very little motion, but around this focus point motion appears to radiate out, speeding out toward the edges of the visual field like an expanding circle. We call this spot the focus of expansion; it corresponds to the direction in which you're heading, and it gives you useful information about

The upper stimulus shows that when the eyes are still, the focus of expansion corresponds to the direction of heading. The lower part of the diagram indicates that when the same stimulus is generated by the same self-motion direction, but the eyes are also tracking to the right, generating linear motion to the left, the two motions combine on the retina to form a pseudo-focus displaced in the direction of the eye movement. This pseudo-focus does not correspond to the direction of heading, which is still straight ahead.



where you're going in the world. Cells in MST are tuned to these sorts of expanding stimuli generated by motion and also to the location of the focus. Now, a problem occurs when you're moving through the world in one direction but you begin to track something with your eyes—say a freeway sign—that may be off to the side. Moving your eyes introduces a motion of your visual field in the opposite direction. For example, if you hold a finger in front of you and follow it with your eyes as you move it to the right, you'll notice that everything behind it moves to the left. With a rightward eye movement, you've introduced a leftward motion onto the eye. If you're also moving at the same time, this retinal motion gets combined with the expansion signal, shifting the focus toward the direction in which the eye is moving. If our brains were, in fact, using only this new focus to guide us through the world, when we looked at a sign on the freeway we'd run into it, because that would be the point where the image is now stabilized, with everything else radiating out from it.

But we know we don't do that. To find out what's going on in the brain during this process, we (David Bradley, Marsha Maxwell, and Krishna Shenoy from my lab; Marty Banks, a professor at UC Berkeley; and I) have recorded from nerve cells in MST. The tuning curve of such a cell (which describes the frequency of the electrical signal coming from a cell) for an expanding stimulus is shown at lower left. If the expansion point is straight ahead, this cell is firing at about half activity; if the expansion point is over to the right, the cell is very active, and if it's to the left, the cell's not active at all. If we then have the monkey move its eyes so that it shifts the eye's focus in the direction of the eye movement (the equivalent of looking at the freeway sign), we find that the nerve cells shift their tuning curves to compensate for the eye movement. The cell continues to fire at half activity, indicating that the monkey knows it hasn't changed its heading. What we think is happening is that the areas in the front part of the brain that are sending out signals to move the eyes are also sending signals back into the perceptual areas saying: "The eye is moving; shift your receptive fields to compensate for it so that you still perceive locations in the world as being the same." This mechanism is called efference copy or corollary discharge, and it explains why, when we move our eyes around and shift the images on our eyes, the world still appears stable. We are using information about what we're doing with our eyes to stabilize the visual world. Thus we can see that there is a hierarchy from V1, which measures motion, to MT, which extracts the 3-D structure of surfaces in motion, to MST, which helps us navigate through the world.

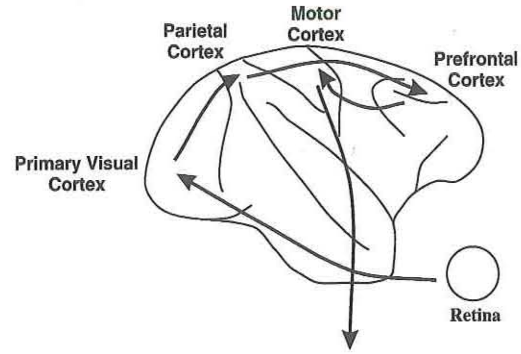


An MST neuron tuning curve superimposed on an expansion pattern shows that the cell responds at half its maximum response when the focus is straight ahead (left). When the eyes are moving to the right, the focus shifts to the right, but so does the tuning curve of the MST neuron (right).

The final processing strategy that I'll discuss is association. The bouncing red ball has now been divided up so that it's processed along three different streams—motion, color, and shape. But since we view the world as a unitary entity, at some point we need to begin bringing this information back together again into one picture. This binding of features back together occurs at the highest levels of the visual cortex, in the visual association areas.

A few years ago, our lab described an area called LIP (lateral interparietal area), which is important for perceiving visual space and is located in the upper "where" processing stream. LIP is also important for making eye movements by gathering information from the visual cortex and sending it to the front part of the brain to move the eyes. However, we not only move our eyes to locate visual stimuli, but also to identify auditory stimuli. We know that our brains can perceive a sound location as easily as a visual location, but auditory information is collected in a very different way. It is assembled from auditory cues

The schematic diagram of the brain at right illustrates the pathway of visual information that leads to visually guided movements. Visual information first passes through the primary visual cortex and proceeds through the posterior parietal cortex to frontal lobe structures. The primary visual cortex is responsible for sensation, and the motor cortex for sending out commands to make movements. Evidence shows that the early neural correlates of plans to make movements appear in this pathway as early as the posterior parietal cortex.



arriving at the two ears, while visual information is imaged on the retinas in the eyes. The brain has to combine these two very different types of signals to come up with a single, unified spatial representation. To this point, we had tested LIP neurons only with visual signals. We were, however, interested in how this high-level processing area might combine or "associate" features of external stimuli to locate them in space. So we developed an auditory localization task.

It turned out that when Brigitte Stricanne, Pietro Mazzoni, and I recorded from nerve cells in the LIP area (which is a part of the posterior parietal cortex), we could also map tuning curves or receptive fields for auditory stimuli. We had the monkey sit in a room with his head facing straight ahead, keeping his head always in the same position. He did, however, have to move his eyes to look at three different locations in the room. We played tones sequentially from speakers in different locations in order to map the cell's preferred location in space. When the animals looked in the three different directions, the preferred auditory location actually shifted in space by the same amount as the shift in gaze direction. In other words, the selectivity of the cell to the sound moves with the eye. This finding shows that the auditory signals have been mapped onto the same coordinate frame as the visual signals, which also move with the eyes. We say that both the auditory and visual signals are in an eye-centered reference frame. Auditory and visual information have been brought together and associated in LIP to form a single common perceptual representation of the world.

But since we view the world as a unitary entity, at some point we need to begin bringing this information back together again into one picture.

In the last couple of years we have begun to investigate how sensory signals lead to decisions and plans for action. Working in such a high-order area as the posterior parietal cortex, with so many fascinating neural activities, we have wondered if *intentions* might be hatched here. Since the posterior parietal cortex lies between sensory areas and motor areas and acts as an interface between them, it seemed a likely candidate for the location of the neural correlates of intention. In experiments published in March in *Nature*, Larry Snyder, Aaron Batista, and I trained our monkeys to do one of two tasks when directed by a signal. On a green signal light they were to reach in the dark for the remembered location of a briefly flashed target; a red signal light told them to make an eye movement (saccade) to the target instead. They had to memorize the target's location over a delay of one to one and a half seconds before they acted. We measured the activity of specific neurons during this delay and discovered that the neurons fired not only to a specific location in the visual field but also according to whether the monkey was planning to look at or reach for the target. Moreover, the cells selective for eye movements were confined to area LIP, the saccade area, and the reach-selective cells were confined to a reach area abutting LIP. This anatomical segregation shows that a motor plan, guided by the visual perception, originates here in the culmination of the "where" pathway, and that the intended response, rather than the visual information, may be the determining factor in organizing how neural computations are made within the area. This may be the place where our thoughts begin to turn into actions, and where our spatial perception is mapped not only by what our senses tell us but also by how we plan to use that information. □

This article was adapted from a talk given by Richard Andersen at Seminar Day in May 1996. Andersen, the James G. Boswell Professor of Neuroscience, came to Caltech in 1993 from MIT, where he had been a member of the faculty since 1987. Before that sojourn on the other coast, he had earned his BS at UC Davis (1973) and his PhD (1979) at UC San Francisco; he was a postdoc at the Johns Hopkins School of Medicine but returned to California as a faculty member at the Salk Institute and UC San Diego. Andersen's research is supported by the National Eye Institute (part of NIH), the Office of Naval Research, the Sloan Foundation, and the Human Frontiers Scientific Program.

Over a 30-year career, his lab has contributed to numerous branches of molecular biology and founded a few. Here are some of the highlights.

David Baltimore: A Short Portrait of a Long Career

by Douglas L. Smith

On May 13, it was announced to the world that Caltech's next president would be biologist and Nobel laureate David Baltimore. Here he chats with two of the people who persuaded him to take the job. From left: Kip Thorne (BS '62), Feynman Professor of Theoretical Physics and chair of the faculty search committee; Baltimore; and Gordon Moore (PhD '54), chair of the Board of Trustees.

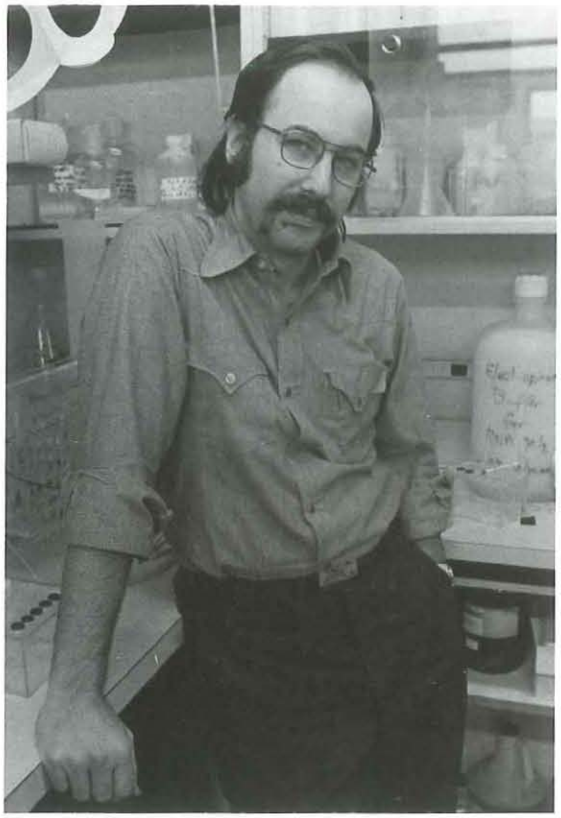
If you've been reading the papers at all, you doubtless know that David Baltimore, Cottrell Professor of Molecular Biology and Immunology at MIT, founding director of the Whitehead Institute, and former president of Rockefeller University, has agreed to become Caltech's fifth president. He should fit in admirably here—he has been a virus man all his life, and viruses are about as small as biological systems come, so Caltech's diminutive size should have a natural appeal. And like Caltech he does small science in a big way—over a 30-year career, his lab has contributed to numerous branches of molecular biology and founded a few. Here are some of the highlights.

Baltimore earned his BA in chemistry from Swarthmore College in 1960, and he finished off his PhD in biology at Rockefeller University in a remarkable three years (he actually got the sheepskin in '64). Postdoctoral positions followed at MIT and the Albert Einstein College of Medicine for a year each, leading to a three-year stint at the Salk Institute in La Jolla, California, where he continued in the burgeoning field of molecular biology, specializing in research on the polio virus. He returned to MIT in 1968 as an associate professor, becoming a full professor in 1972.

Even then, although Baltimore would spend most of the next three decades at That Other Institute of Technology, a Caltech connection had been formed. He had spent the summer after his high-school junior year at the Jackson Laboratory in Bar Harbor, Maine, where Howard Temin was the resident guru. Temin, who died in 1994, had taken his PhD at Caltech in 1960 under Renato Dulbecco, who in turn had come to Caltech in 1949 to work with Max Delbrück. At Caltech, Dulbecco developed (with Marguerite Vogt) the techniques needed to grow animal viruses in culture. He then headed south to the Salk Institute in 1962, where he would become one of Baltimore's mentors. Baltimore, Dulbecco, and Temin would share the 1975 Nobel Prize in physiology or medicine.

Temin and Baltimore independently and simultaneously (the two papers were published back-to-back in the June 27, 1970, issue of *Nature*) discovered an enzyme dubbed "reverse transcriptase" by the unfortunately anonymous *Nature* correspondent who wrote up the finding in that journal's "News and Views" section. (An enzyme is a protein molecule that expedites a specific chemical reaction by providing a pocket into which the reactants can nestle in just the right orientation for the reaction to proceed.) Temin had hypothesized the existence of reverse transcriptase—although not by that name—in 1964, but the idea was considered so far-fetched that most biologists dismissed it out of hand. Reverse transcriptase allows a molecule of ribonucleic acid (RNA) to copy itself into deoxyribonucleic acid (DNA), swimming against the current of information flow.

By the early 1960s, everyone knew that genes, which are the blueprints for making every protein an organism will ever need, are encoded in DNA molecules in the cell's nucleus. The DNA consists of two strands carrying complementary information, like a photograph and its negative, and the two strands mesh together like a zipper. At the appropriate time, the nuclear machinery unzips a portion of the DNA to expose the gene's negative strand and makes positive prints in the form of RNA, a chemically very similar molecule. The messenger RNAs then leave the nucleus and go out into the cytoplasm (the soupy gel that makes up the bulk of the cell) and say to protein-making machines called ribosomes, "Here. Make this." "This" could be a piece of cellular machinery, an intracellular regulator that turns other genes on and off, or even a signal to other cells—for instance, it might tell adjoining cells in a developing embryo that it's time to start dividing and become liver tissue. But information, it seemed, never traveled backward—there was no way to touch up a DNA negative from an RNA print.



Baltimore in the lab in the early days.

This hunch was verified in short order, which got Baltimore thinking further. If a virus could carry around an enzyme to make RNA, why not one to make DNA? The two molecules are very similar, after all. Perhaps Temin was on to something.

People also knew that RNA can be a repository for genetic information in its own right. A host of viruses had been discovered that have no DNA in them, but only RNA—either double-stranded like DNA, or a single positive strand. In either case, the positive RNA strand instructs a ribosome to make a protein, called RNA polymerase, that in turn makes a negative RNA strand—out in the cytoplasm, mind you, not in the nucleus—from the original positive RNA print. The RNA polymerase then makes many prints from the new negative, and the new prints fan out to all the other ribosomes in the cell, co-opting them into making new viruses. Thus, all it takes is one positive RNA print at one ribosome to launch an infection. No DNA is needed, nor is the cell's nucleus involved. In fact, many of these processes will even occur in cytoplasmic extracts from which all the nuclei (and with them, the DNA-handling machinery) have been removed.

But Temin had discovered that the Rous sarcoma virus, a single-positive-strand RNA virus that causes cancer in chickens, can't infect cells whose DNA-handling apparatus has been shut down. This led him to postulate that the viral RNA must somehow be getting translated back into DNA as a prerequisite to converting the cell into a cancer cell.

Meanwhile, back at MIT, Baltimore was trying to apply the techniques he'd developed for studying polio (another single-positive-strand RNA virus) to vesicular stomatitis virus (VSV), a line of research catalyzed by his postdoctoral fellow Alice Huang, an expert on VSV. (Huang joined his lab at the Salk Institute and returned with him to MIT, where they married in 1968. She later became a professor at Harvard Medical School, and is now dean for science at New York University.) Baltimore, Huang, and a graduate student, Martha Stampfer, rapidly discovered that VSV contained a single negative strand of RNA. How, then, could the infection get started?

Simply running the negative RNA strand through the ribosome won't suffice. Any bit of protein you make will come out all wrong, but the odds are the ribosome won't get very far along the negative RNA before running into a so-called stop codon. A stop codon shuts down the ribosome and ejects the completed protein and normally appears at the tail end of the RNA strand. But in a world where black is white and white is black, a stop codon is just as likely to appear in the middle of the RNA. In fact, it's a sure thing. There are no meaningless instructions in the RNA code, so the "negative" versions of stop codons are valid assembly instructions. Obviously, then, the "negative" versions of those assembly instructions are stop codons, and as soon as the ribosome comes across one—and at every step it has roughly a 5 percent chance of doing so—it turns itself off. So at best, you'll get a useless snippet of protein.

Since nobody had ever found RNA polymerase in the cytoplasm of a normal, uninfected cell, Baltimore concluded that the VSV must be bringing not only a negative RNA strand, but also a working RNA polymerase molecule into the cell in order to get the infection started. Once this RNA polymerase had used the negative strand as a template for assembling a positive copy of the virus RNA out of ingredients scavenged from the cytoplasm, the print could run through the ribosome in the usual way.

This hunch was verified in short order, which got Baltimore thinking further. If a virus could carry around an enzyme to make RNA, why not

Above: The Nobel class of '75 in Stockholm. It was a large group, as only the literature and peace prizes were unshared that year. From left: Tjalling Koopmans (economics), Leonid Kantorovich (economics), Aage Bohr (physics), Eugenio Montale (literature), Dulbecco, Vladimir Prelog (chemistry), Ben Mottelson (physics), Temin, John Cornforth (chemistry), Baltimore, and, from the Caltech class of 1939, Leo James Rainwater (physics).

Above, right: Baltimore in a less formal moment, at the MIT press conference that followed the announcement of the Nobel Prize in October.

one to make DNA? The two molecules are very similar, after all. Perhaps Temin was on to something. As Baltimore said in his Nobel acceptance speech, "Luckily, I had no experience in the field and so no axe to grind—I also had tremendous respect for Howard dating back to my high school days when he had been the guru of a summer school I attended at the Jackson Laboratory." And sure enough, Baltimore's lab found that another cancer-causing single-positive-strand RNA virus, called the Rauscher virus, contains a working molecule of what has come to be called reverse transcriptase. Rather than creating more RNA, the reverse transcriptase makes a negative strand of DNA from the positive RNA, followed by positive DNA that binds to the negative DNA in the nor-mal, two-stranded fashion—all in the host cell's cytoplasm. This viral DNA then sneaks into the nucleus and splices itself into the regular DNA, where it gets handled just like the cell's own DNA. It's now known that all cancer-causing RNA viruses get their carcinogenic genes into the host cell this way. (Temin was simultaneously making the same discovery with the Rous sarcoma virus. Dulbecco was awarded the prize for unrelated work that indicated that once a cell has become cancerous, this new state is genetically stable—a finding that dovetailed neatly with Baltimore's and Temin's discovery.) Viruses that insinuate their own genes into the host cell's genes are now known as retroviruses and include in their number HIV, the AIDS virus.

Recalls Baltimore, "After I discovered the reverse transcriptase, I worked for some time on the biochemistry of the enzyme and tried to understand how it actually carried out the process of reverse transcription. That was my first foray into working in cancer-inducing viruses, or cancer at all. I decided that if I was going to go any further, I needed a biological system to work with, and I was introduced by a lucky accident to the Abelson virus, which wasn't at all well known at that time." The Abelson virus induces leukemia in mice. Leukemia is a cancer of the blood, but instead of the cancerous cells congregating in a tumor, they circulate individually. Normal cells divide a fixed number of times—foreordained in their genes—and then quit reproducing and die. Cancer cells, with their altered genes, instead go on dividing forever. Leukemia cells are actually aberrant white blood cells, whose oversupply turns the blood milky and gives the disease its name—leukemia is Latin for "white blood."

Naomi Rosenberg, then a postdoc in the Baltimore lab, developed a method for infecting normal mouse cells with the Abelson virus and then culturing them in vitro, in glass petri dishes. This provided an infinite supply of cells to experiment on, allowing each step of the cancer-inducing process—of which the introduction of a cancer-causing gene, or oncogene, into the cell's DNA is just one facet—to be studied at the molecular level. The process by which a healthy cell turns into one of the undead is a complex molecular ballet, the choreography of which is still being charted worldwide. Up to that point there had been no easy way to study mammalian leukemia in vitro—researchers had to use chicken cells instead. But a bigger payoff awaited—one that would establish a new branch of immunology.

One of the body's chief defenses against infection is protein complexes called antibodies, which constitute about 20 percent of the free protein circulating in our blood. Antibodies ferret out alien substances by means of a pocket that recognizes and binds to an invader—for example, the pocket might fit snugly over a protein that only exists as part of a virus's protective coating. The bound antibody then summons nearby white blood cells to engulf and devour the intruder. Each antibody's pocket is tailor-made to fit one specific shape, but the immune system has to be alert for an infinite number of potential threats. Some of the menacing shapes—viral mutations that might occur in the future, for example—don't even exist, yet the system has to be ready for them when they appear. Antibodies are secreted by white blood cells called B cells, each of which produces an antibody with one specific pocket. Bone-marrow tissue continuously cranks out generic B-cell precursors which, after a few days spent choosing the antibody they'll make for the rest of their lives, become mature B cells. So, given that a B cell's nucleus can't hold an infinite amount of DNA, how could the immune system store the potential to generate what Baltimore estimates to be in the vicinity of 100 billion possible antibody pockets? Well, while Rosenberg was perfecting the culture system, Susumu Tonegawa was discovering that snippets of DNA spontaneously rearranged themselves in nascent B-cell nuclei. (Tonegawa would win the Nobel Prize in 1987.)

As the Baltimore lab analyzed the Abelson cultures, it became apparent that Rosenberg had unwittingly infected (and thus immortalized) B-cell precursors. "When we realized that," recalls Baltimore, "it occurred to me that this might be a way of studying the events of immunodifferentiation." Finding out how a B cell decides what to do when it grows up has since turned into a growth industry. The Baltimore lab's contribution to this field perhaps culminated in the late 1980s and early '90s, when grad students David Schatz and Marjorie Oettinger performed a classic series of experiments that revealed the enzymes that actually carry out the rearrangements.

But finding those enzymes was just the beginning. Each enzyme has to appear at the right time in relation to the others, or the DNA they assemble will be a useless mishmash that won't make a functional antibody. The genes that make the enzymes are controlled by one or more activation sites that lie in stretches of the DNA that are adjacent to the gene proper. Each activation site has its own regulatory protein that recognizes and binds to it. Baltimore's lab was able to locate these sites, which then became the bait that enabled the regulators themselves to be fished out of the cellular soup. These regulators, a class of proteins called transcription factors, collectively coordinate the overall sequence of events—besides turning the genes they regulate on and off, many transcription factors bind to (and thus affect the behavior of) other transcription factors. Tracing the interplay between the transcription factors is yet another field of research the Baltimore lab has spun off.

Finding out how a B cell decides what to do when it grows up has since turned into a growth industry.

One of these transcription factors, published in 1988, is called NFκB. At the time of NFκB's discovery, the Baltimore lab found that it binds to a segment of DNA that helps to synthesize one part of the antibody complex. The researchers therefore assumed that NFκB also played a role in antibody production. Further research, however, indicated that this probably isn't the case. But at around the same time, the Baltimore lab began working on the AIDS virus. It now appears that, regardless of what NFκB's "real" job may prove to be, it also plays a large role in controlling HIV production in a class of white blood cells called T cells. Says Baltimore, "In active T cells, it might contribute 90 percent of HIV production."

In all the excitement of unraveling immunodifferentiation, the Abelson oncogene itself hasn't escaped scrutiny. The gene is related to a normal gene named *abl* after the Abelson viral gene, which was discovered first. (By convention, italics are used for gene names; the protein produced by that gene has the same name, but in Roman letters.) The *abl* gene is somehow involved in DNA repair and in the formation of the cytoskeleton, which is the protein-fiber trusswork within the cytoplasm that holds a cell in shape. (It's presumably the former function, when set awry by a few strategic mutations, that enables the viral version to cause cancer.) What *abl* does, exactly, is still unknown, but it codes for an enormous protein that weighs more than 13,000 carbon atoms. This protein appears to be a sort of Swiss army knife. It consists of several independent units, called domains, at least some of which are involved in intracellular signaling—the means by which cells coordinate such collaborative processes as tissue growth, wound healing, digestive-juice secretion, and embryonic development. The protein's signaling domains are somehow related to its DNA-repair and cytoskeleton-formation functions, but nobody has yet figured out how.

A cell communicates with another cell by secreting molecules that bind to receptor molecules on the target cell's surface. Forwarding that message to the appropriate destination within the cell—intracellular signaling—takes a chain of events that rivals the complexity of Rube Goldberg's finest machines. But instead of a bowling ball knocking over a watering can that fills a bucket that pulls a string that fires a pistol that eventually causes the bread to be toasted, the receptor molecule (for example) cuts free another molecule that seeks out yet another molecule and together they trigger yet another molecule to do something further, and eventually the cell divides or does whatever else the signal told it to do. The Abl protein's signaling domains are components of such intracellular pathways.

The first Abl signaling domain to give up its secrets to the Baltimore lab was a new twist on an old method of governing protein activity within the cell. It's called a tyrosine-specific protein kinase (catchy name!), and it was also discovered independently at the Salk Institute. A protein kinase attaches a phosphate group (a cluster of four oxygen atoms bound to one phosphorus atom) to an amino acid, in this case one called tyrosine. All proteins are made up of long strings of amino acids, which interact with one another through their electric charges, the degree to which they

Collectively, these three domains are involved in coordinating many aspects of cell division, cell differentiation, and cellular activation—just about everything a cell would "want" to do.

attract or repel water, and their stiffness or floppiness, among other things. This web of forces folds the protein up into its preferred shape. Thrusting a phosphate group (which has a negative charge, seeks out water, and is bulky) into the web distorts the balance of forces and affects the protein's shape. And as we've seen over and over again, the protein's shape confers its function—proteins are built around pockets that are designed to do something. In some cases, the phosphate group completes a missing part of the pocket, turning the protein "on." In other cases, the phosphate group obstructs or alters the pocket, turning the protein "off."

Other labs had discovered kinases that attach phosphate groups to the amino acids serine and threonine, but this was the first kinase that sought out tyrosine. The knowledge that tyrosine-rich proteins are amenable to the same control systems as serine- and threonine-rich ones has opened up new intracellular signaling pathways to explore. But the finding has much broader implications. Many classes of enzymatic reactions are controlled by the attachment and removal of phosphate groups—a discovery for which Edmond Fischer and Edwin Krebs won the Nobel Prize in 1992.

Baltimore's lab then went on to discover two more Abl domains that are very similar to the Src (pronounced "sarc") protein, which is also involved in intracellular signaling in as-yet-unknown ways. The *src* gene, as its name suggests, is also related to an oncogene, its cancerous cousin having been discovered in the Rous sarcoma virus we met earlier. (It's easy to imagine how, if the Src protein is part of a signaling cascade that tells the cell that it's time to divide, having a mutated protein stuck in the "on" position can lead to runaway cell division and cancer.)

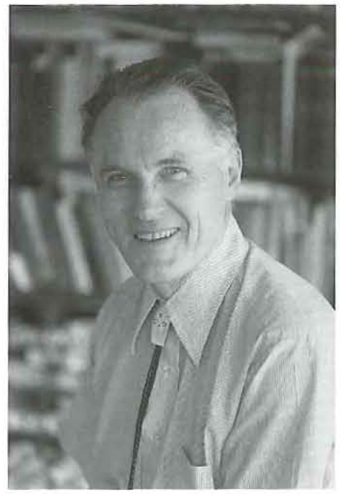
One Src-related domain, discovered in 1986 and called Src-homology region two, or SH2, binds to the tyrosine-phosphate units created by the tyrosine-specific protein kinase the Baltimore lab had previously discovered. (The kinase itself is SH1, but people rarely call it that.) In other words, this binding event is the next step down the signaling pathway initiated by the kinase. "That is a major event in cell signaling," says Baltimore. "We spent a lot of time characterizing the nature of the interaction, but it's been largely taken over by structural biologists."

The other Src-related domain, SH3, was discovered in the early '90s and was the first example of an entirely new class of signaling interactions. SH3 binds to stretches of protein that contain large amounts of the amino acid proline. The notion of using protein-protein interactions as a signaling mechanism had been bruited about for years, but no examples of protein domains designed expressly for that purpose had been found. Again, the discovery of SH3 opened up new avenues of research, as SH3 domains have since been found far and wide.

Collectively, these three domains are involved in coordinating many aspects of cell division, cell differentiation, and cellular activation—just about everything a cell would "want" to do. Says Baltimore, "We're still trying to put these signaling elements together to understand their integration, as well as what pathways they're involved in. It's a long, complicated business." And there are vast tracts of the *abl* gene still to be explored.

With all this going on, it's amazing that Baltimore gets out at all. Yet he helped develop national guidelines for genetic research back in the 1970s, and he has been a prominent figure in the public debate over genetic engineering ever since. His work with retroviruses and reverse transcriptase led to his being invited to help plan the research assault on AIDS in the late '80s. In the early '90s, he was one of the architects of the federal Human Genome Project, which is now working to discover all of the 50,000-plus genes in human DNA. Most recently, in 1996, when the National Institutes of Health created the AIDS Vaccine Research Committee to expedite the search for a vaccine, Baltimore was tapped to lead it—a post he will retain as president of Caltech.

Baltimore sees continuing to be a public figure as part and parcel of charting Caltech's course into the 21st century. At the press conference that announced his selection, he noted that the pace of scientific advance, in fields ranging from cloning to computer science, is allowing us to do things that were impossible only a few years ago. "I look forward to working with the Caltech faculty in advising our society as it adjusts to these changing capabilities. I will also work with the leaders of government, industry, and academia to help prepare society to deal with the profound implications of modern science. The role of national leadership is an important one, and Caltech has a responsibility to play a role in the debates, as they occur, about the development of modern science and engineering." □



Robert B. Leighton
1919 – 1997

Robert B. Leighton, the William L. Valentine Professor of Physics, Emeritus, passed away on the morning of March 9, 1997.

Bob spent his entire scientific career at Caltech, and he established a dominating presence in physics and astronomy research and teaching here. His work over the years spanned solid state physics, cosmic ray physics, the beginnings of modern particle physics, solar physics, the planets, infrared astronomy, and millimeter- and submillimeter-wave astronomy. In the latter four fields, his pioneering work opened up entirely new scientific areas of research that subsequently developed into vigorous scientific communities. In addition, he was a renowned teacher, having edited *The Feynman Lectures in Physics* into their printed form and authored a highly influential text, *Principles of Modern Physics*. For his contemporaries, he set a high standard of teaching quality. In addition, he coauthored, with Robbie Vogt, a set of problems to accompany the Feynman lectures.

In 1948, Leighton's first scientific publication concerned the specific heat of face-centered cubic crystals, but he had already been drawn into Caltech's strong cosmic ray group under Carl Anderson's leadership. He played a key role in 1949 in showing that the mu-meson decay products are two neutrinos and an electron, and he made the first measurement of the energy spectrum of the decay electron (at the time, low statistics experiments suggested that only one neutrino was involved). In 1950, he made the first observation of strange particle decays after the initial discovery of two cases in England in 1947. Over the next seven years, he elucidated many of the properties—for example, mass, lifetime, decay-modes, and energies—of several of the new strange particles, in particular, the lambda, the xi, and what were then called the theta particles (K-mesons).

About 1956, Leighton became interested in the physics of the outer layers of the sun. With characteristic imagination and insight, he devised Doppler-shift and Zeeman-effect solar cameras. They were applied with striking success to the investigation of magnetic and velocity fields on the sun. With the Zeeman camera, Leighton and his students mapped complicated patterns of the sun's magnetic field with excellent resolution. Even more striking were his discoveries of a remarkable five-minute oscillation in local surface velocities and of a "super-granulation pattern" of horizontal convection currents in large cells of moving material. These solar oscillations have subsequently been recognized as internally trapped acoustic waves, which opened up the whole new field of solar seismology, subsequently pursued by Ken Libbrecht.

In the early 1960s, Leighton developed and fabricated a novel, inexpensive infrared telescope. He and Gerry Neugebauer used it to produce the first survey of the sky at 2.2 microns. This survey revealed an unexpectedly large number of relatively cool objects. Some of these have been found to be new stars still surrounded by their dusty prestellar shells, while others are supergiant stars in the last stages of their evolution, embedded in expanding dusty shells of matter ejected by the stars themselves.

During the middle 1960s Leighton was the team leader at JPL for the Imaging Science Investigations on the Mariner 4, 6, and 7 missions to Mars. As team leader and an experienced experimental physicist, Leighton played a key role in forming and guiding the development of JPL's first digital television system for use in deep space. He also contributed to the first efforts at image processing and enhancement techniques made possible by the digital form of the imaging data.

In the 1970s, Leighton's interest shifted to the development of large, inexpensive dish antenna which could be used to pursue millimeter-wave interferometry and submillimeter-wave astronomy. Once again, his remarkable experimental abilities opened a new field of science at Caltech which continues to be vigorously pursued at the Owens Valley Radio Observatory (OVRO) and the Caltech Submillimeter Observatory (CSO) on Mauna Kea using the "Leighton Dishes."

He would always try something new, a different approach to something old, and it paid off in a large number of fundamental discoveries made possible only by his curiosity and skill.

Born in Detroit, September 10, 1919, Dr. Leighton received his BS in 1941, his MS in 1944, and his PhD in 1947, all from Caltech. He continued here as a research fellow (1947-1949), assistant professor (1949-1953), associate professor (1953-1959), professor (1959-1984), the Valentine Professor of Physics (1984-1985), and Valentine Professor, Emeritus (1985-1997). Bob served as chair of the Division of Physics, Mathematics and Astronomy from 1970 to 1975.

All of us who knew and deeply admired Bob Leighton miss him greatly.

Charles Peck
Professor of Physics
Chair, Division of Physics, Mathematics and Astronomy

Memorial donations may be made to the Los Angeles Library Foundation at 630 West 5th Street, Los Angeles, California 90071.

Bob was my personal friend and I worked so closely with him as his student and then as his colleague that it is hard to limit myself to just a few remembrances.

When I first met Bob, he was in the Bridge machine shop working at a lathe. The impression of that first meeting—that here was a true "hands-on" experimentalist—lasted as long as I worked with Bob. Only later did I learn that to do a complicated triple numerical integration for his thesis, Bob had machined the complicated shape out of metal and weighed it. Not only was he a great experimentalist, he was clever.

As I worked with him, I came to appreciate his truly awesome intellectual capabilities. Although an experimentalist, Bob could keep up with essentially any theoretical discussion that had to do with how the world worked; he loved physics. As a graduate student under Bob, I did all the problems in his book. I don't think he was especially impressed; he expected you to do all the problems. That was how he felt you learned.

Bob had about the most inquisitive mind I ever came across. He had to know how everything worked. One rule was that he was always willing to try something new and different. He felt he should never compete with someone, but always do something unique, something that only he could do. It was this principle and his imagination that led him into the many and various things he did so well. He would always try something new, a different approach to something old, and it paid off in a large number of fundamental discoveries made possible only by his curiosity and skill.

The highlight of my association with Bob was the Two Micron Survey of the sky. Bob had the idea of making near-optical-quality mirrors by spinning liquid epoxy, then a new material, and letting it harden while spinning in its natural form, a parabola. He used an air bearing, like one he and Vic Neher had used to demonstrate frictionless motion to the freshmen students, to support the epoxy while it was hardening. We built the telescope in the Bridge machine shops. It was truly Bob's telescope; he had built an "amateur" telescope at home, and now he used every trick he had learned and more to design a 62-inch telescope, a good size for its day. Everything was done on the cheap, emphasizing Bob's cleverness. We needed to "chop" to rapidly sample alternating pieces of the sky, so Bob made the whole telescope shake back and forth at 20 cycles per second. Domes are expensive, so Bob led a group of us—including Jerry Nelson, an undergrad who would later spearhead building the Keck 10-meter telescopes—to Mt. Wilson, and we built the roll-off building to house the tele-scope. Bob had, after all, built his own home all by himself. The astronomy pundits said that at most the survey would detect tens of sources; we ended up detecting thousands. The very first night we turned the telescope to the sky we detected the reddest, most extreme source that we found in the entire three years of surveying. It was typical of Bob's good luck, good luck he worked hard to have. I might add that Bob's 62-inch telescope now is in Washington, DC, in the Air and Space Museum of the Smithsonian Institution.

Bob was a great friend with a fine sense of humor and wonderful to know socially as well as in the lab. In those days the Athenaeum required coats and ties for lunch. Although Bob normally wore a coat and tie every day himself, he was aware of my discomfort and took pity. Thus one hot day Bob took his coat off while eating lunch at the Athenaeum. The horrified maitre d' said, "Dr. Leighton, the rule is that coats are required." Bob calmly replied that he understood the rules. Clearly the maitre d' had done his duty, but Bob stood his ground and from that day on, coats were no longer required for lunch.

As I said, Bob was wonderful to work with. He provided inspiration for people at Caltech ranging from undergrads to senior faculty. Mainly he gave support and encouragement to a large number of young people. He was unstinting in helping people get started. A whole crop of people at Caltech got their beginning with Bob or carried out projects that Bob thought of or thought were good to do. And he was more than generous in giving credit. When the Two Micron Survey was published, Bob insisted that I, not he, be the first author, claiming that I needed the exposure more than he did. For this and many other kindnesses, I'll always be thankful to Bob and hope that we can in some way follow in his footsteps.

Gerry Neugebauer, PhD '60
Robert A. Millikan Professor of Physics

Verner Schomaker
1914 – 1997

Verner Schomaker, possessor of one of the most critical and wide-ranging scientific intellects of our time, died in Pasadena, California, on March 30, 1997, of pancreatic cancer. What follows is a very personal account. Many of those who worked with or were closely exposed to Verner might have written something similar; I am confident that the general flavor would be the same.

Every scientific question seemed to interest Verner, and anyone with a knotty problem was welcome at his always-open door. And his time was always yours—until he, at least, understood in some depth what you were asking, and preferably you did too. The answer did not, of course, always come in one session—even though the sessions could last for many hours, past meal times and past other appointments that you forgot about because you were so engrossed. His memory was prodigious, and when he encountered a problem he 'worried it,' like a dog with a bone. He might not have all the insight he wanted when the question was first raised or even during the next few days or weeks—but he wouldn't forget. You might encounter him some years later, and he'd say, "I've been thinking about what you said, and . . ."

He was at once friendly, open, uncommonly generous, and extremely bright. He was, to those who were privileged to work with him or otherwise benefit from his insights, simply without peer as a one-on-one teacher. In the '40s and '50s, many who worked with him felt complimented when he would say, "How can you be so goddamned stupid?" since we realized that he *expected* us to understand and that, frustrated though he might be with our slowness, he would not give up until we understood, or left. In his later years, he learned patience and mellowed somewhat, and those who couldn't follow an abstruse line of reasoning he was explaining might be asked, "What do I have to do, say it *louder*?" But *never*, and I do mean ***never***, was there any animosity involved in what might seem to some to be harsh remarks. Nor did Verner's own ego ever intrude. He was selfless, far more so than almost anyone imaginable with his level of intellect and accomplishment. He was interested in getting things *right*, not in who got the credit, and was never afraid to admit his errors and his own limitations, although he overestimated them (as he, generously, did the abilities of some of his collaborators).

He is best known for his contributions in electron and X-ray diffraction. He thought that his most important contribution had been in the early days of electron diffraction, for development of techniques for the visual interpretation of the scattering of electrons by gas molecules. None of the structures reported from his productive group had later to be revised, when sector methods gave greater resolution and precision. But he published in many other fields as well—one of his final papers (with Jürg Waser) was on the "Global Thermodynamics of Systems That Include Stressed Solids," and he was saddened that he could not interest any colleague in studying it intently enough to discuss it with him meaningfully. At least one of his papers became a "citation classic" in the Science Citation Index. His total publication list, however, probably didn't reach 200 papers, because he was a perfectionist when writing a paper, and because he was so readily distracted by the intriguing problems presented by those who sought him out. His generous spirit, his penetrating intellect, his breadth of interests and curiosity, and his selflessness led almost everyone within his orbit to use him as a consultant. There is little doubt that if there were a "Science Advisor Acknowledgment Index," he would have ranked at or very near the top. It has been estimated that during the '40s and '50s, at least one third, and perhaps as many as one half, of the papers published by the Gates and Crellin Laboratories (the Caltech Division of Chemistry) concluded with a phrase such as, "We are grateful to Professor Verner Schomaker for helpful discussions," or "The valuable insights provided by our colleague Verner Schomaker helped to make this work possible." And these papers covered the gamut of work in the division, not just in diffraction, but in quantum mechanics, immunochemistry, NMR, spectroscopy, thermodynamics, and inorganic and organic chemistry. In those years, the reference "V. Schomaker, unpublished" was extremely common—in others' papers especially.

A native of Nebraska, where he grew up on a farm, he earned a BS from that state's university in 1934 and an MS in 1935. He then moved to Pasadena, where Pauling quickly recognized his uncommon qualities. After receiving a PhD in 1938, he went up the academic ladder in chemistry at Caltech (taking time out for wartime research from 1942 to 1945). In 1958 he left academic work to join the Union Carbide Research Institute (just north of New York City), where he spent seven years—but when it became apparent that the initial promise of something modeled on the Bell Labs or what was then the Shell Development Laboratory was never going to materialize, he joined the faculty of the Department of Chemistry at the University of Washington in Seattle. He became professor emeritus in 1984. After his retirement, he was also a faculty associate at Caltech, dividing his time about equally between Pasadena and Seattle.

His family has requested that donations in his memory be made to the Verner Schomaker Memorial Fund, California Institute of Technology, Office of Donor Relations, Mail Code 105-40, Pasadena, California 91125. The fund will be used to support student research.

Kenneth Trueblood, PhD '47
Professor of Chemistry, UCLA

He might not have all the insight he wanted when the question was first raised or even during the next few days or weeks—but he wouldn't forget. You might encounter him some years later, and he'd say, "I've been thinking about what you said, and . . ."

I always admired Verner's great brillance and his deep humanity. His analytical and quick mind always went to the nub of a problem that he faced or was presented with, and he often quickly solved these problems. His mathematical ability and his structural insights were very great and his colleagues as well as industry frequently sought his advice, including the great Linus Pauling. He liberally and freely gave of himself. His mechanical abilities were equally great, and premier among the many apparatus he designed, there was a fine electron diffraction machine with a rotating sector. On a more personal note, I well remember a camping trip on which the car broke down way out in the tules. His methodical approach quickly located the problem: a part in the distributor had broken down. Whittling a replacement out of a twig and carefully cutting a gasket from strong paper readily fixed the problem.

Verner was highly critical of ideas presented to him and could be scathing and scornful. His deep-seated honesty would not allow him to pass over any shallow or pretentious assertion lightly, and his criticism could be blunt. Yet he was also extremely helpful to everybody, especially to an underdog. Thus he took under his wing a young fellow recently from Switzerland who had come to study under Linus Pauling and was quite overwhelmed by the brillance of the other students and the quality of the research at the Institute.

They say "they don't make them like that any more," but this is very subjective. It is mainly for us oldsters for whom the world has become more lonely. I miss you, Verner, and the many great and heated discussions we had.

Jürg Waser, PhD '44
Professor of Chemistry (1958–75)

Edward E. Zukoski
1927 – 1997

Ed served as my alterconscience; new work, curriculum innovations, novel concepts—rational and irrational—were usually first unloaded on Ed.

Edward E. Zukoski (MS '51, PhD '54), an authority on the science and technology of combustion, a highly respected member of the Caltech faculty for 40 years, and a bouyant friend to all who knew him, died on May 26, 1997, of complications attending a heart attack several years ago. Ed possessed an exuberance for life and for his work that was so rich it warmed us and brightened our days. When he was in good voice his hearty laugh echoed throughout all of Guggenheim. And with the same emotional energy, he fumed against stupidity and arrogance in science and in public life.

Ed was born June 29, 1927, in Birmingham, Alabama, into a professionally and socially prominent family that was committed to public service and at times espoused liberal causes that might, considering the place and time, seem unusual to us and certainly to Birmingham society. Continuing in the family tradition, Ed attended Harvard College and received the bachelor's degree of engineering science in 1950. That same year he was awarded one of the new Guggenheim Fellowships in Jet Propulsion to attend Caltech, studying aeronautics with emphasis on jet propulsion in the center inaugurated by Professor Tsien Hsue-shen the previous year.

It was Ed's good fortune that experimental combustion facilities at the Jet Propulsion Laboratory were available for his use in pursuing his doctoral research, which attacked an urgent current problem of combustion stability in ramjet engines and gas turbine afterburners. In addition to resolving confusion that had persisted in the field for years, Ed's work laid the foundations of the flame holding mechanism and established him as an objective and meticulous experimentalist. Ed's experimental research, together with the analysis carried out by his fellow research student, Tom Adamson, opened a large field of combustion issues in which the fluid mechanical and chemical aspects of the problem could, to a certain extent, be separated.

Ed continued his experimental combustion research at JPL for three years after completing his doctorate and joined the Caltech faculty as assistant professor of jet propulsion in 1957. During his long career at Caltech, Ed and his students made major innovative contributions in other fields: magnetogasdynamics, aeroacoustics, problems of propellant control under microgravity conditions and, most recently, hydrogen/air mixing in supersonic combustion ramjet propulsion systems. In each of these activities Ed left his characteristic mark of objective and thorough experimental research, eschewing the experimentalist's natural diversion from the physical problem toward elegant instrumentation.

In the summer of 1961, Ed participated in a fire research study directed by Howard Emmons and sponsored by the National Research Council. The problems of unwanted forest fires and building fires appealed to him both as a technological challenge and as an important issue of public service. Over the years Ed became a national leader in fire research and, together with his students and his colleague Toshi Kubota, developed a comprehensive description of convective fire plumes that has become the technological standard. A symposium on the fluid mechanics of fire plumes, organized by his former student Baki Cetegen, was held in his honor in 1996 at the meeting of the United States/Japan National Resources Panel on Fire Research and Safety in Gaithersburg, Maryland.

There are other facets in Ed's life that, I think, highlight some of the essential attributes that make Caltech the unique institution we know. Ed was my third doctoral student; over a period of 45 years we shared a close collegial relationship in our research, our teaching, and the supervision of our research students. Ed served as my alterconscience; new work, curriculum innovations, novel concepts—rational and irrational—were usually first unloaded on Ed.

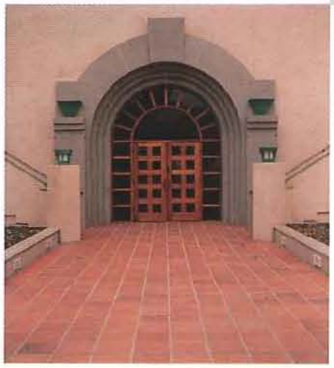
During his doctoral studies until sometime before his marriage to Joan Breckenridge, he was a fixture in the Marble household. He accompanied us on camping trips with our children, worked with us on remodelling our house, and even filled in as baby-sitter. He was a strong swimmer and an avid skin diver. It was not unusual on a late weekend afternoon for Ed to show up at our front door, still damp from his activities, with a sack of abalone (those were the days!) and an expression strongly suggesting that it would be great with him if my wife would prepare some for dinner. His suggestion was never refused. Our children considered him family, frequently more tolerant than their parents. When, on one of our camping trips in Arizona, Ed engineered the capture of a weary tarantula, he became their hero.

In many ways Edward Zukoski contributed, sometimes energetically but often quietly and unobtrusively, to the quality of our lives in both the Guggenheim and the Thomas Laboratories. He will be sorely missed.

Frank E. Marble (Eng '47,PhD '48), Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion, Emeritus

Memorial donations may be sent to Planned Parenthood of Pasadena, 1045 N. Lake Ave., Pasadena, CA 91107; or to the Wilderness Society, c/o Pamela Eaton, 7475 Daykin St., Suite 410, Denver, CO 80221.

Honors and Awards



Caltech's Moore Laboratory (above) and Avery House were jointly selected to receive the Crown City Award for architectural and/or landscape excellence from the Pasadena Beautiful Foundation.

Michael Alvarez, associate professor of political science, has been awarded a 1997 Haynes Foundation Faculty Fellowship for his proposal, "Who Governs Southern California: Will the Rise of Latino Political Power Continue?"

William Deverell, associate professor of history, has been elected to the board of the California Council for the Humanities. The Council both administers a competitive grants program and conducts projects of its own, including several planned for the California Sesquicentennial, beginning in 1998.

Kenneth Farley, associate professor of geochemistry, has been given a five-year fellowship by the David and Lucile Packard Foundation.

Donald Helmberger, professor of geophysics, has been selected by the American Geophysical Union to receive the 1997 Inge Lehmann Medal, which is awarded for outstanding contributions to the understanding of the structure, composition, and dynamics of the Earth's mantle and core.

Sossina Haile, assistant professor of materials science, has been chosen by the Minerals, Metals, and Materials Society to receive the 1997 Robert Lansing Hardy Medal, which recognizes exceptional promise in a young person in the field of metallurgy. Haile studies solid-state ionics, which conduct electricity through ions rather than electrons and are important in fuel cells, which may one day provide a clean, alternative energy source.

Wilfred Iwan (BS '57, MS '58, PhD '61), professor of applied mechanics and director of the Earthquake Engineering Research Laboratory, has been awarded the 1997 Nathan M. Newmark Medal from the American Society of Civil Engineers for his contributions to the dynamic analysis of buildings and other structures.

Jonathan Katz, assistant professor of political science, has been selected for the 1997 *Congressional Quarterly* Press Award for the best paper in the field of legislative politics presented at the 1996 American Political Science Association meeting. The paper, which he cowrote with Gary Cox (BS '78, PhD '83), was entitled "Baker v. Carr and Incumbency in Postwar U.S. House Elections."

Wolfgang Knauss (BS '58, MS '59, PhD '63), professor of aeronautics and applied mechanics, was elected an Honorary Fellow by the International Congress on

On May 8, Arnold Beckman (PhD '28) received the "Treasures of Los Angeles" award from LA mayor Richard Riordan and the Central City Association. Beckman, who was a member of the chemistry faculty until 1940 and was chairman of Caltech's Board of Trustees from 1964 to 1974, has given approximately $270 million for the direct support of research, much of it in universities in Southern California. Here he is congratulated at the award ceremony by Harry Gray, the Beckman Professor of Chemistry and director of the Beckman Institute.

Fracture for "contributions in dynamic fracture."

Gordon Moore (PhD '54), chair of Caltech's Board of Trustees and cofounder of the Intel Corporation, has received the Chairman's Award from San Jose's Tech Museum of Innovation. The Chairman's Award recognizes extraordinary dedication to the museum's educational mission and to the betterment of Silicon Valley through philanthropy and volunteer involvement. Previous recipients are William Hewlett and David Packard.

Sterl Phinney (BS '80), professor of theoretical astrophysics, has been elected a Fellow of the American Physical Society for his contributions to the understanding of black hole dynamics, active galactic nuclei and quasars, binary and millisecond pulsars, and globular cluster dynamics; and for his method of measuring the intergalactic magnetic field.

David Politzer, professor of theoretical physics, has been awarded a Guggenheim Fellowship for 1997, one of only 164 appointed this year in the U. S. and Canada.

Robert Rosenstone, professor of history, has been selected for the 1997–98 Florence Fulbright Chair at the European University Institute in Florence, Italy.

David Rutledge, professor of electrical engineering, has received the Microwave Theory and Techniques Society's 1997 Distinguished Educator Award.

Edward Stolper, the Leonhard Professor of Geology and Chair of the Division of Geological and Planetary Sciences, has been named a Geochemistry Fellow by the European Association for Geochemistry for his outstanding contributions to geochemistry.

Petr Vogel, senior research associate in physics and lecturer in physics, has been elected a Fellow of the American Physical Society for his innovative theoretical work in double-beta decay and neutrino interactions, including his definitive calculations of reactor neutrino spectra.

Ahmed Zewail, the Pauling Professor of Chemical Physics and professor of physics, has been named the 1997 recipient of the Robert A. Welch Award in Chemistry, presented by the Welch Foundation for "outstanding contributions to chemistry for the betterment of humankind." □

Everhart Chair Established

In a twist on the familiar story of the retiring executive who departs with the gift of a commemorative chair, Caltech President Tom Everhart has been given a chair in the full expectation that he will leave it behind. It is the Thomas E. and Doris Everhart Professorship, endowed by the Institute trustees in recognition of the Everharts' decade of service to Caltech. Trustees Chair Gordon Moore (PhD '54) announced the creation of the Everhart Chair at a trustees' dinner held in the Everharts' honor in May. The initial recipient will be in the biological sciences.

Moore also announced that the trustees have established the Doris Everhart Award, which will be presented annually to an undergraduate who has "actively supported and willingly worked for organizations that enrich not only student life but also the campus and/or community as a whole, and who has, in addition, exhibited care and concern for the welfare of students on a personal level."

The Everharts' name will also be associated with undergraduate education through the Thomas E. and Doris Everhart Endowed Scholarship Fund, established by the President's Circle of the Caltech Associates. Thus far, more than $400,000 has been pledged in endowments, ensuring the creation of a Thomas E. and Doris Everhart Scholarship, which will be awarded to an outstanding student. Associates President Milton Mohr made the announcement as a surprise to the Everharts at the President's Circle Garden Party in June.

And the Graduate Student Council has named its lecture series the T. E. Everhart Distinguished Graduate Student Lecture Series. □

Tom and Doris Everhart shook hundreds of hands as they said goodbye to the campus during a gala luncheon on the Court of Man June 5. The entire Caltech community—faculty, students, and staff—turned out to celebrate the past 10 years and to wish the Everharts well in their new home in Santa Barbara.